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16-01 Paths to ADA-Compliance: the Performance and Cost Efficiency of Measurement Technologies that Support ADA-Mandated, Self-Evaluations of Pedestrian Rights of Way

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Paths to ADA-Compliance: the Performance and Cost Efficiency of Measurement Technologies that Support ADA-Mandated, Self-Evaluations of Pedestrian Rights of Way

FINAL REPORT

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Transportation Research Center
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16. Abstract

This study used terrestrial laser scanner and open source processing algorithms to develop an approach to automate the evaluation of transportation infrastructure in public rights of way. We estimated compliance or noncompliance of specific roadway features with the design standards adopted by the US Access Board and required under the Americans with Disabilities Act (ADA) such as minimum sidewalk width, maximum cross slopes and presence/absence of pedestrian connectivity automatically with extracting roadway features from point cloud data (PCD). We then compared the accuracy and cost efficiency of the automated with more conventional evaluative techniques to identify the potential risks, gains and the overall efficacy of these approaches. The collected raw data were processed through a sequential process including simplification, optimization, segmentation, and road feature categorization. Finally, the road elements were detected as the road feature objects. By developing a more thorough assessment process, this research provided communities with the information necessary to strategically plan transportation infrastructure improvements for people with limited mobility.

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1 INTRODUCTION

People with disabilities have rights based on the movement laws that defend their equality with all members of the society. The Americans with Disabilities Act (ADA) advocated for the rights of individuals with disabilities, provided satisfying services for individuals with disabilities to live within the community. The ADA of 1990 is a civil rights statute that prohibits discrimination against people who have disabilities. As a necessary step to providing accessibility under the ADA, local public entities are required to perform inventories of their current facilities. Among other things, the ADA requires access to the roadway paths, like sidewalks and curbs. The information developed through the inventory (or self-evaluation) process must be quantified and presented as a baseline so that progress can be monitored and measured. The ADA Application Guideline (ADAAG) is the one primary set of laws that address dealing with and the technical necessities for the planning, designing, and the construction of facilities which are required for the condition of individuals with disabilities. The primary goal of this study is to provide an automated process solution as one of the fastest and securest ways of checking the accessibility of the existing facilities for ADA. While the incentives for completing an ADA transition plan are many--e.g., they act as valid defenses in ADA-related legal actions and work toward fostering more walkable, attractive, and livable communities, overall--completing an inventory of physical barriers can be a daunting task given a municipal budget and staffing constraints. The explosion of recent technology has modified the manner of automated analysis and condition assessment. In this paper, the authors present a brand-new analysis algorithm to assess the accessibility compliance of the prevailing facilities based on the point cloud data (PCD) analysis technique. A set of data points are needed as a database to begin the analysis. The data is being collected in X, Y, and Z coordinates that are referred to as PCD to represent the surface which preserves flexibility and accuracy within the new and existing transportation facilities.

Stakeholders are responsible for providing accessibility for individuals with disabilities, particularly in using route facilities like sidewalks and curbs. This includes people that are concerned with the transportation and construction projects. Congress analysis in 2000 shows that twenty percent of the Americans have disabilities. As well, the number of individuals with disability will increase as the population ages. Obviously, individuals with disabilities have much concern associated with the use of public facilities, especially sidewalks (1).

A series of demanding compliances are required to evaluate the facilities in various levels. New constructions need to consider ADA, or ADAAG and the Uniform Federal Accessibility Standards (UFAS) (as long as it is applicable) in the design and construction phases (1). For the existing facilities, however, ADA requirements' checklist needs to be observed. ADAAG provides a list of the vital features to be checked in numerous steps --from planning to construction-- in the new and existing transportation and construction projects. However, roadway facilities' conventional way of checking is usually time-consuming and costly; it is impossible to maintain the facilities in a convenient timeframe (2). The foremost important guideline on accessible design is that the UFAS must be observed in all steps of construction (3).

2 BACKGROUND

ADA is one of the first comprehensive civil rights law which supports people with disabilities and protects them from discrimination on the basis of disabilities. The ADA is divided into five titles that relate to different areas of public life such as employment, programs, and activities of state and local government entities (design criteria for the built environment, transportation, communication, medical diagnostic equipment, and information technology), private entities that are considered places of public accommodation. Title I address equal employment opportunity. Title II of the Act address programs, activities, and services of public entities —including public rights of way and public transportation—accessible to those with disabilities (4).

As a necessary step to providing accessibility under the ADA, state and local government entities are required to evaluate their current facilities, according to the accessibility requirements of the Act. These public entities are then required to develop a transition plan, which details how accessibility Act noncompliances within the public right of way will be corrected, scheduled, budgeted for, and monitored for progress and compliance. The process of evaluation for accessibility can help communities solve problems and lead to changes that can help people with disabilities. (5)

In the long term, improving accessibility for people with disabilities may reduce paratransit demand response services. Improving accessibility is especially important given both the high costs of providing demand-response transit service (which can be as much as four times as much per trip as fixed-route bus service (6)) and trends toward a rapidly growing older and limited mobility population. In Michigan, for example, the proportion of the total population that is 65 and older is growing much more rapidly compared to other segments of the population. The US Census Bureau estimates that 19.5 percent of Michigan's population will be 65 and older by the year 2030—an increase of 38.1 percent from 2015—whereas the total population of Michigan is projected to grow by less than one percent over the same period. (7)

It should also be noted here that improving accessibility via ADA compliance brings benefits not only to people with disabilities but the whole community at large. (8) For example, active transportation research has shown that public right-of-way accessibility will bring a more livable community. (9)

The ADA was passed almost unanimously by Congress and signed into law by President George H.W. Bush on July 26, 1990. The Department of Justice settled with the City of Toledo, Ohio that the city agreed to remove the barriers for people with disability. (10) Since that time, the Disability Rights Section (DRS) of the Department's Civil Rights Division reviewed several other local and state governments to develop technical assistance checklists that local agents could immediately use to become full compliant with the requirements of the ADA. (11)

The above project now includes over 222 settlement agreements with localities in all 50 states, including four Michigan communities (Burton [2004], Detroit [2004], Mount Pleasant [2001], and Muskegon [2010]). In most of these cases, the compliance reviews were undertaken on the Department's own initiative under the authority of Title II Section 504 of the Rehabilitation Act of 1973. Therefore, the governments receive financial assistance from the Department and are prohibited by the Act from discriminating by disability. In other cases, reviews were undertaken in response to complaints filed against the localities when communities have inaccessible programs or facilities and lack an up to date transition plan. (12)

The beginning step for preparing an ADA transition plan is conducting an inventory of existing physical barriers that limit accessibility; i.e., the self-evaluation process. Deficiencies that were frequently found in an inventory of pedestrian facilities in public rights-of-way include sidewalks, pedestrian paths, and curb ramps, etc. The information developed through the inventory process must be quantified and presented as a baseline so that the progress can be monitored and measured.

While the incentives for completing an ADA transition plan are many, completion of such a plan and the inventory of existing physical barriers, in particular, can be a daunting task. Lack of budget and lack of staffing combined, make the inventory process extremely challenging to complete. For example, a survey sponsored by the National Cooperative Highway Research Program showed that budgetary constraints on staffing and support of ADA programs are significant factors to complete transition plan related tasks. (13) As a result, many transition plans tend to stall in the inventory phase, either awaiting a full completion of self-evaluation activities or unable to take the data collected and develop priorities for remediation.

2.1 THE IMPACT OF MEASUREMENT EQUIPMENT ON AN ANALYTICAL PROCESS

To explore a more cost-effective method for data collection in the self-evaluation step of the transition plan, efforts are to be made in developing measurement systems that combine sensing technologies with mobile platforms. Lidar is a surveying technology that collects spatial information based on distance traveled by a laser beam. Therefore, it is also called laser scanner. Lidar is widely used in surveying and 3D model creation in many industrial sectors because of its high accuracy (i.e., millimeter level accuracy). In the construction industry, each project includes many different tasks, which could benefit from using new visualization and automation measurement-interfacing techniques. Recent developments in terrestrial LiDAR, GPS, and inertial measurement unit provide the ability to collect 3D point clouds with high frequency and accuracy, which in turn lead to high accountability and a high quality of city model reconstruction and road feature extraction. Identifying accessibility compliance is the principal purpose of our attempts in developing an automatic method of analysis. The collected datasets need to be segmented to check these compliances. Each segment represents an object in the PCD.

PCD is used to generate a 3-dimension surface with particular coordinate information for each segment, which may be used in facility's evaluation process, to analyze the accessibility of the new and existing public facilities for ADA compliance. Different measurement methods have been used to record the surrounding coordinates. One of the most stable and accurate items of measurement equipment that can provide X, Y, and Z coordinates is the laser scanner. Laser scanners are developing dramatically. In 2000, laser scanners could approximately collect around 1000 points per second, and nowadays, it can collect around a million points per second (14). In this research, we use a Leica C10 laser scanner which can read up to 50,000 points per second. Laser scanner collected point cloud data has been employed for surface modeling of as-built objects for an accurate mensuration of the objects (15). Such laser scanner data is also widely used to detect static and moving objects in the fields (16).

2.2 OBJECT DETECTION IN PCD.

Nowadays, road features are becoming more complex, and this leads to more complicated complaints about urban environments. Usually, PCD produces a rich source of data which need to undergo a PCD processing to identify and detect the objects in the target. It is essential to extract objects, such as edges, pedestrians, curbs, and ends, from PCD. Over the past few years, many efforts have been made for object detection from PCD such as detecting buildings, doors, etc. (17). Cluster analysis is one of the primary methods for massive data analysis to detect objects, which is a massive PCD processing that helps recognize different naturally clustered groups or structures. In other words, the clustering can create a set of meaningful subclasses of data, which makes it easier to detect different objects (e.g., Curbs, Ramps) comparing to detection in the whole dataset directly (18). Figure 1 shows that PCD data processing would be essential for high-level sensing tasks such as simultaneous localization and mapping to detect an object (19). For example, Wang et al. (2003) evaluated a mathematical framework that integrated simultaneous localization and mapping to detect an object and help with the detection and tracking of moving objects.

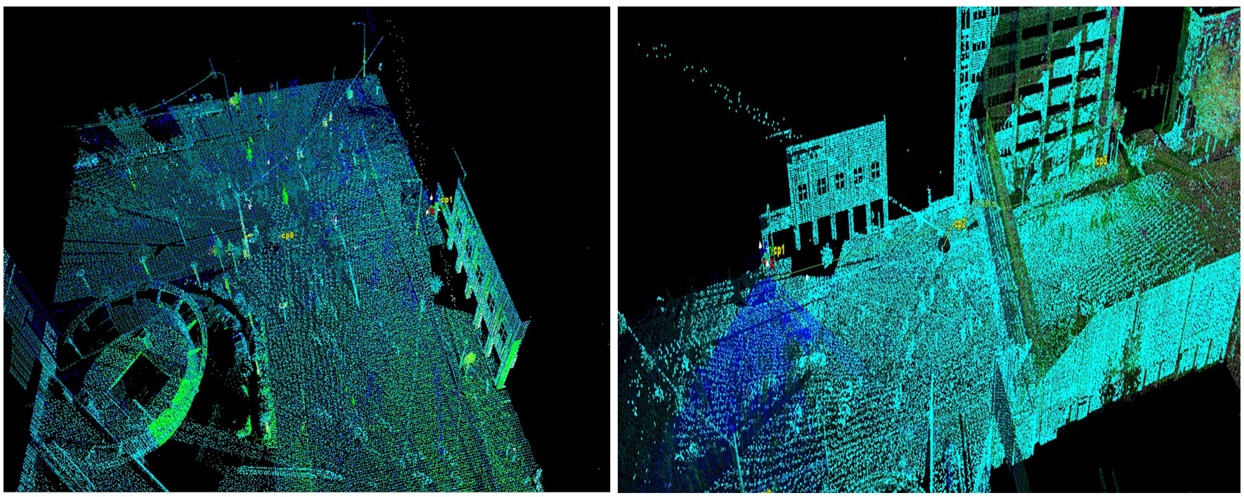


Figure 1: 3D Laser Scanner Point Cloud data

2.3 THE ROLE OF AUTOMATION IN THE ANALYSIS PROCESS

The automation in accessibility assessment will facilitate the realization of compliance through the following steps:

1. Conducting automatic data analysis and reviews as the best practice which leaves more time for interpretations that can facilitate the federal or state agencies' self-evaluation process,
2. Boosting productivity through automated calculation process by algorithms, where the PCD processing would be time-consuming otherwise,

3. In the same way as most automated systems, improving the efficiency and accuracy of ADA evaluation.

The manual evaluation methods faced different problems which need to be considered in this automated method, such as the classification of ground surfaces, intersections, cars, pedestrians, vegetation, poles, sidewalks, and building options (20).

Completely different scopes –like ground surfaces, intersections, cars, pedestrians, vegetation, poles, sidewalks, and building options—need to be thought about in the automated method. Isolating the noise and cutting back the number of errors in the data and unnecessary points to layers is one of the foremost and vital benefits of the automated method. In addition to classifying planes and ground surfaces, it also extracts edges, pedestrians, curbs, and ends. The advantages of automated modeling and identification are significant. In scanning a public environment with many intersections and a thousand miles of sidewalks and curbs of various classifications and styles, the automatic identification and modeling will save the cost and time of many operating hours (20).

2.4 ADA REQUIREMENTS FOR ACCESSIBLE ROUTES

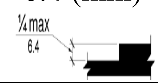
The Americans with Disabilities Act of 1990 includes the civil rights law that requires general protection for individuals with disabilities similar to those given to persons on the basis of race, sex, national origin, and religion below the Civil Rights Act of 1964. Ramps and curb ramps are required along accessible routes in public. These requirements are applicable wherever sidewalks meet. The ADA intends to address, in the long term, all public facilities which provide services for the public. The public facility ought to be made accessible to individuals with disabilities via an endless, unobstructed pedestrian circulation of networks. Therefore, once altered, most streets (except for rural roads associated with highways) need to produce an accessible pathway where possible (21).

An accessible route is a roadway specifically designed to provide access for people with disabilities, including those who need a particular width and require passing areas for their wheelchairs or other mobility devices. The accessible route is needed wherever a circulation of ways is altered or designed. The allocation of public facility for individuals with disability will contribute to cities and turn into various structures as well as some additional engagements. The main ADA checklist for existing facility includes:

1. Route of travel for instance stair, stable, firm and slip-resistant, 36 inches wide, protruding into the circulation paths.
2. Ramps which are included on the slope with the ratio of 1:12 (means for every 12 inches ramp, the height increases one inch). For a 1:12 slope, at least one foot of ramp length is required. Ramps longer than 6 feet should have railings on both sides, railings sturdy. The railings should be mostly between 34 and 38 inches high. Width between railings or curbs must be at least 36 inches.
3. Parking and Drop-Off Areas should include 8 feet wide for the car plus 5-foot access aisle, 8-foot-wide spaces, with minimum foot wide access aisles, and 98 inches of vertical clearance, available for lift-equipped vans).
4. Building Entrances (If there are stairs at the main entrance).

In Table 1, accessibility guidelines for accessible routes are linked to different regulations. The following values confer that it is required to measure different aspects of the paths' accessibility.

Table 1. Accessibility Guidelines for Accessible Routes

Source	Maximum Allowable Running Grade without Handrails	Maximum Allowable Running Cross Slope	Maximum Allowable Vertical Change in Level
ADA Standards for Accessible Design 1 (US DOJ, 2010)	5.0%	2.0 %	6.4 (mm) 

In the following table, guidelines for curb ramps have been shown for ADA and ADAAG. Requirements for curb ramps apply just to the ramps that go through curbs or are designed up to them (Figure 2).

Table 2: Accessibility Guidelines for Curb Ramps (CR)

Source	Maximum Slope of Curb Ramps	Maximum Cross-Slope of Curb Ramps	Maximum Slope of Flared Sides
ADA Standards for Accessible Design (US DOJ, 2010)	8.33 %	2.0 %	10.0 %

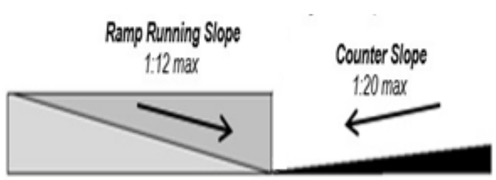


Figure 2: Curb Ramps (CR) Slope's Details

The literature review associated with the accessibility for people with disabilities was taken into consideration, whereas focus was put on assorted variables including topography (ramps, slopes), accessible routes, curbs, alternate routes, boards, signage, facility maintenance, social barriers and access to the public services like bus or taxi. In this report, the authors present a brand-new analysis technique which is based on unorganized PCD measurements. This method can measure existing facility components employing a Leica C10 laser scanner for scanning the study area. The automated algorithm will provide reliable measurement and analysis results for evaluation of ADA compliance of infrastructure facilities. The aim of this study is to evaluate reliable routes for those who need to access them using a federal or state roadway facility with an automatic measuring technique for ADA roadway users.

3 PROPOSED METHOD AND ALGORITHM:

Manually checking of the compliance of roadway's infrastructures with ADA requirements is time-consuming, costly, and error-prone (22). Because laser scanning is known to have better data quality and much higher cost than image sensing, the study will focus on exploring different image sensing-based measurement systems through benchmarking them to laser scanner-based system. As a result, laser scanning will be mainly used to collect ground truth data for comparing with and evaluating different image sensing-based measurement systems. The primary aim of this study is to develop a method and corresponding algorithms which use manipulated standard algorithm to automatically evaluate the compliance of transportation and construction infrastructure/facilities (i.e., ramps, curbs, and alternate routes) with ADA based on analyzing PCD. The identification of the route's accessibility status is an essential function of this analysis which is carried out by analyzing quantitative features (e.g., width, depth, and the slope of curb ramps and sidewalks) of the roadway infrastructure and comparing the results with regulated requirements. A critical step in our research is the infrastructure/facilities component classification (e.g., for the curb ramp and sidewalk). In our study, two significant steps are made: (1) detecting surface normal of planes; and (2) segmenting the point cloud into separate datasets to represent potential objects. The following four steps describe the fully automated segmentation and tracking of transportation infrastructure:

1. Data acquisition and preprocessing: Scanning the environment with the laser scanner. Collected PCD data from the laser scanner is preprocessed by importing it into PCD platforms (e.g., Microsoft Visual Studio, Cloud Compare, and Cyclone). PCD will be thus cleaned up and organized,
2. Data processing: In this step, PCD data is filtered based on points coordinates information, outlier removal (K-nearest point), and normal estimation,
3. Classification: A rich amount of the information (such as Points coordinates and colors) was captured in PCD by the laser scanner. After the preprocessing and processing steps, PCD still has random objects which need to be classified based on their features. In this step, we use plane normal vector information to extract different surfaces such as roads, sidewalks, and ramps,
4. Feature Extraction: PCD is classified based on the plane vectors. Each surface has some unique information which is used to classify objects. After this classification, each object has associated geometric information such as slope, width, and length. We use this information to analyze ADA Requirements such as sidewalk width or ramp slope.

A summary of the proposed methodology is present in Figure 3.

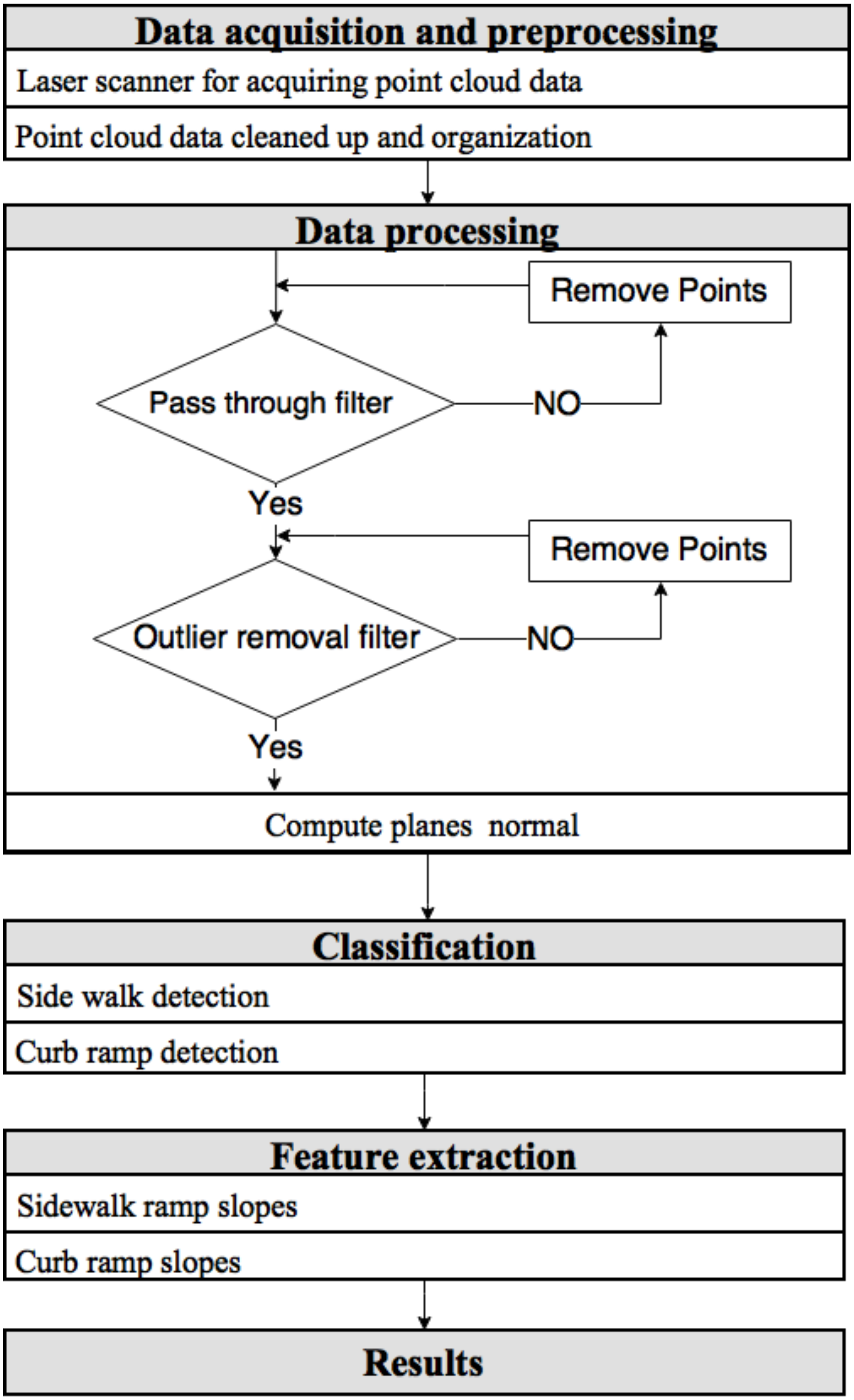


Figure 3: Proposed methodology steps

3.1 DATA ACQUISITION AND PREPROCESSING:

The laser scanner produces a large number of points with their coordinates information. In this study, around 70 million points have been collected. High-quality data is required in order to process the PCD data (23). The authors have developed an automated algorithm in a preprocessing step to produce high-quality information which improves operational processes. Before any PCD processing (Figure 4), noise and errors need to be filtered (Figure 5 and 6) and then, it needs to organize as meaningful patterns.

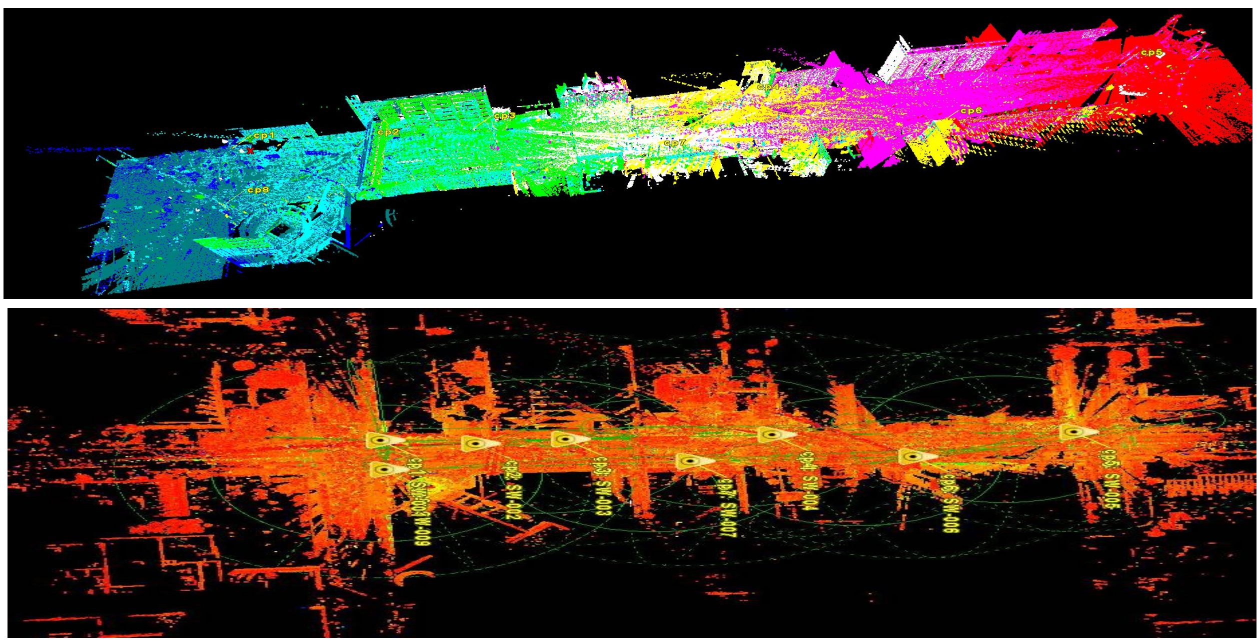


Figure 4: PCD before data processing

In the PCD data, each data point has its X, Y, and Z coordinates together with its color intensity. Figure 5 shows the distribution of points along the X, Y, and Z dimensions and the color intensity by individual points. The plot matrix of the information about the point cloud data distribution is shown in figure 6.

X	Y	Z	Rf	Gf	Bf
-16.97142982	149.055542	-1.83205605	1	0.984314	0.694118
-17.40548134	149.3778076	-1.82924902	1	0.980392	0.537255
-17.02037239	149.3696747	-1.83608496	1	0.980392	0.94902
-31.09266853	153.6121979	-1.78347397	1	0.984314	0.156863
-31.22300339	152.2851105	-1.804775	1	0.984314	0.478431
-31.15230179	152.1466675	-1.80657601	1	0.984314	0.521569
-31.14230347	152.2229767	-1.80526304	1	0.984314	0.501961
-31.10012245	152.179596	-1.80596495	1	0.984314	0.439216
-31.11326408	152.1891937	-1.80572104	1	0.984314	0.513725
-31.11257935	152.2046509	-1.80541599	1	0.984314	0.247059
-31.00472069	152.0660858	-1.80657601	1	0.984314	0.321569
-31.05157852	152.0063629	-1.80816305	1	0.984314	0.290196

Figure 5: PCD X, Y and Z coordinates and color intensity

Figure 6 shows the distributions of points along the dimensions of X, Y, Z and color intensity in four separate figures, respectively. The plot matrix of the point cloud data distribution has been shown in Figure 7.

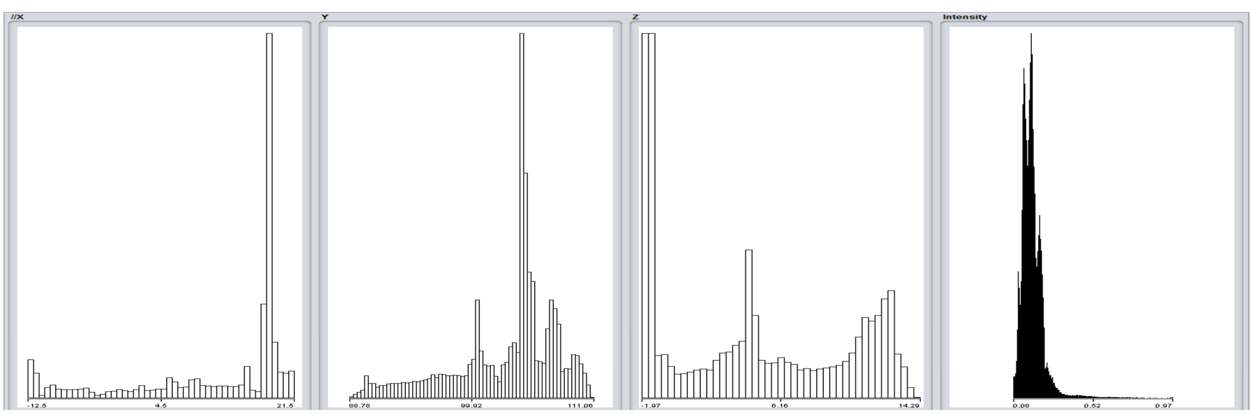


Figure 6: PCD error range frequency

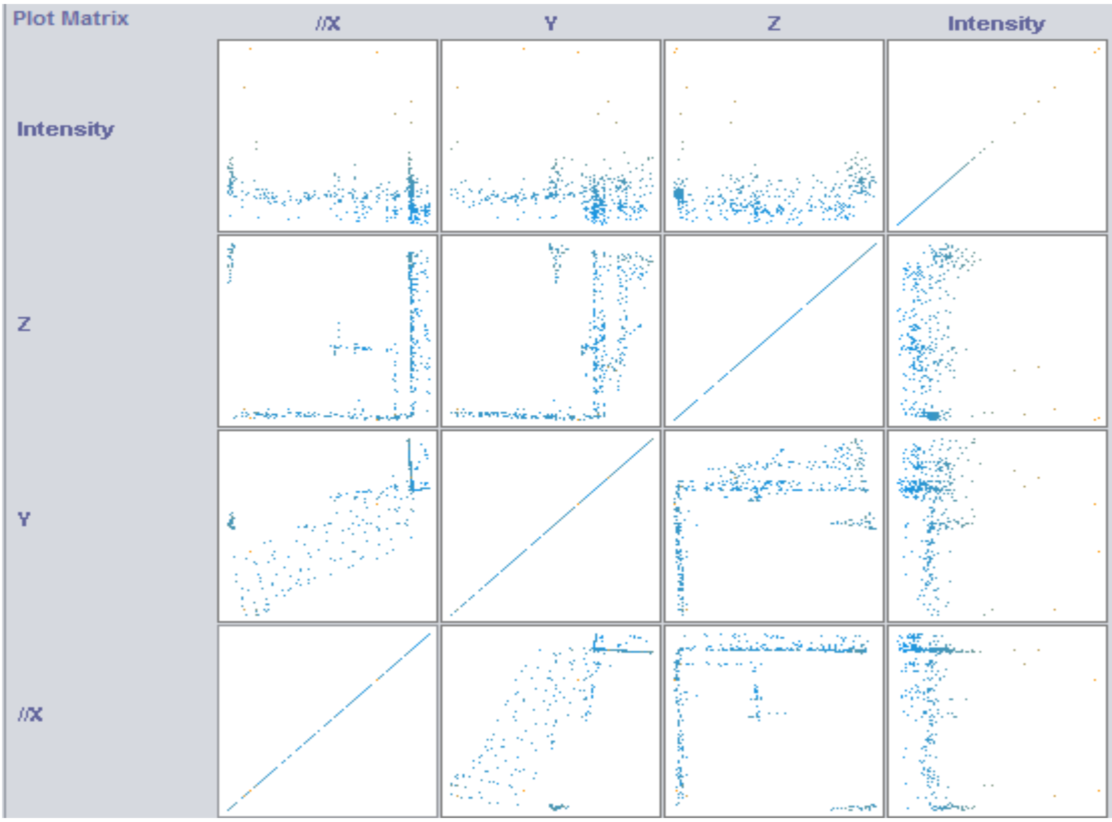


Figure 7: PCD plot matrix of the case study

3.2 DATA PROCESSING:

After preprocessing the PCD, the information is ready for use in the processing and analyzing step. In the processing step, elevation and outlier removal filter was applied to the points to exclude the outlier by Descriptive Statistics method (e.g., mean and standard deviation) and to outrange the points based on their coordination information (Figure 8).

This step processes PCD using normal estimation and data segmentation. In this step, surface normals are calculated using the point cloud data information; segmentation of the PCD provides a compact representation for robust model fitting after surface normals were generated from the normal estimation process. This step has three subtasks: passing through the elevation filter, statistical outlier removal, and normal estimation.

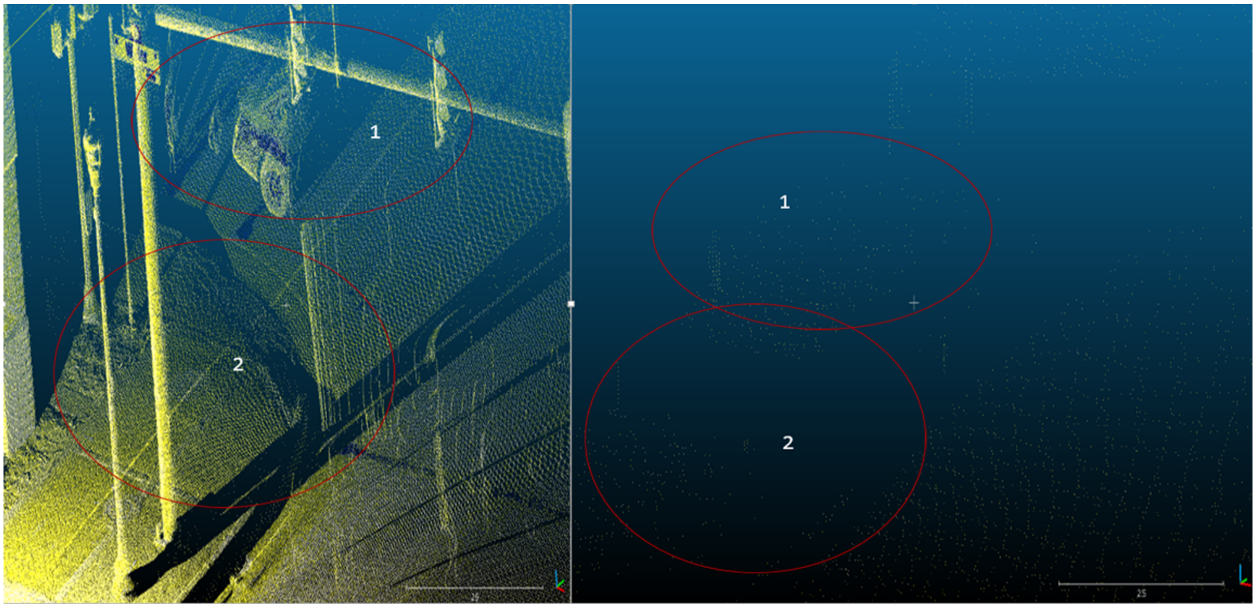


Figure 8: The effect of applied filters on point cloud data

3.3 PASS THROUGH ELEVATION FILTER.

The first step of PCD processing is to use a pass-through elevation filter to filter the points based on their elevation information (Z). The points that were beyond the boundary of the dense PCD environment have been removed. In this case, those points that belonged to building facades, trees, electrical poles, etc. removed. The boundary distance was set to be from ground zero to 6 ft.

3.4 STATISTICAL OUTLIER REMOVAL.

The laser scanner generates point cloud datasets of varying point densities which makes erroneous results if it is directly used to determine surfaces normal because the points belong to different surfaces. This process is generally conducted in descriptive statistics, which can correct these irregularities by a variety of statistical methods such as the mean, median, and standard deviation. The sparse outlier removal is one of the most commonly used methods in normalizing points in PCD. The sparse outlier removal calculates by computing standard deviations (σ), sample distributions (S) and the mean values (μ) of the nearest neighbor distances (N). (14) The distance (D) between points P1(x1, y1, z1) and P2 (x2, y2, z2) is calculated by Eq. (1).

$$D\ (P1, P2) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \qquad \textbf{Equation 1}$$

The data will trim if the calculated distance is out of the Z =μ± α*σ boundary. Aligned with the goal of this research, Equation (2) and Equation (3) were used to normalize PCD in this paper.

$$Z = \mu \pm \alpha * \sigma \qquad \textbf{Equation 2}$$

$$\sigma = S/\sqrt{K} \qquad \textbf{Equation 3}$$

In the proposed algorithm, for providing a right balance between accuracy and efficiency, α = 1 and k = 100 have been set. Experiments with multiple PCD segmentations from the collected PCD confirmed that using μ ± σ thresholds would eliminate noise in our PCD (Figures 9 and 10).

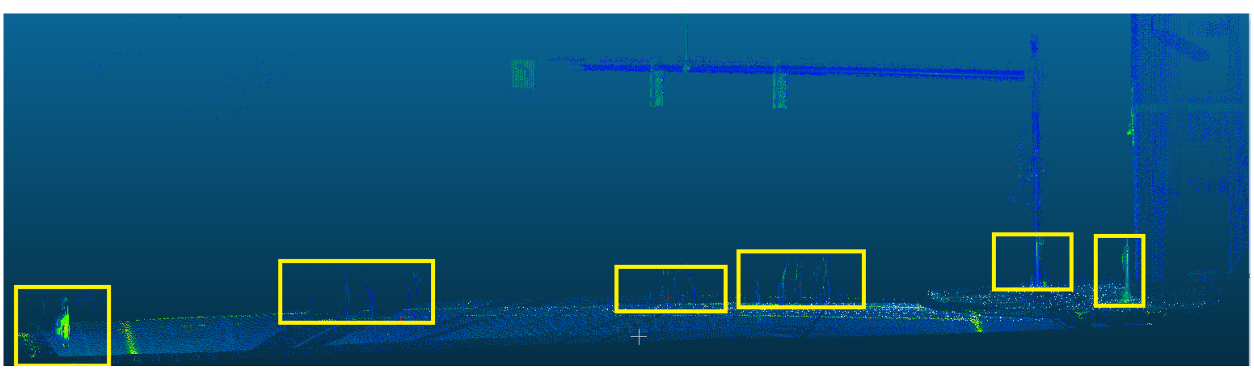


Figure 9: Noises and Errors in PCD

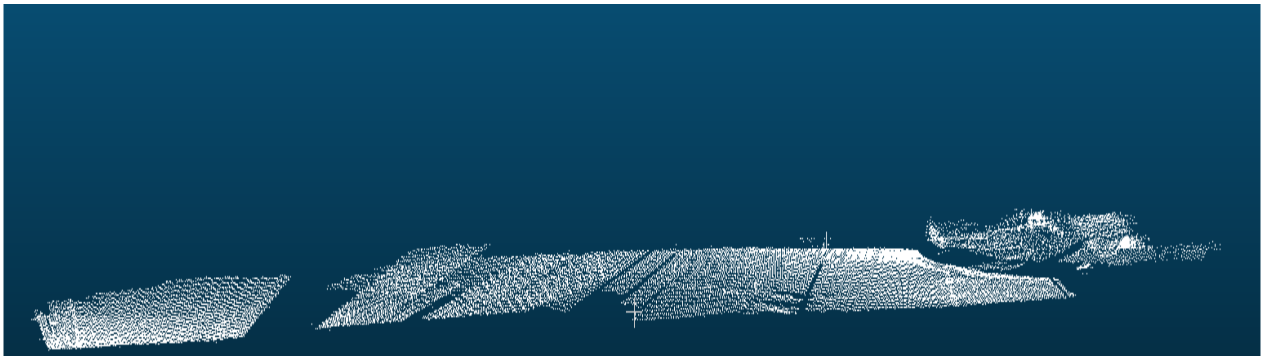


Figure 10: PCD after Pre-Processing

3.5 NORMAL ESTIMATION

After a series of sequential steps such as Pass-through elevation and outlier removal filter, the data were ready to be processed for pattern identification and normalization. These steps prepare the PCD for planes/surface fitting. Planes/surface fitting is a process where estimated surfaces were fitted with points in the PCD with the angular direction of the surface deviating no more than 15 degrees away from the strict vertical vector estimated using neighboring points within 100 nearest points. Uniform PCD data has better estimation results of the normal vectors from the same surface comparing to non-uniform data (25). Figure 11 shows the magnitude and direction of vectors that describe surface normals. The left part shows surface normals fitted to non-uniform points in PCD. The right part shows surface normals fitted to the points using the normal estimation technique described above.

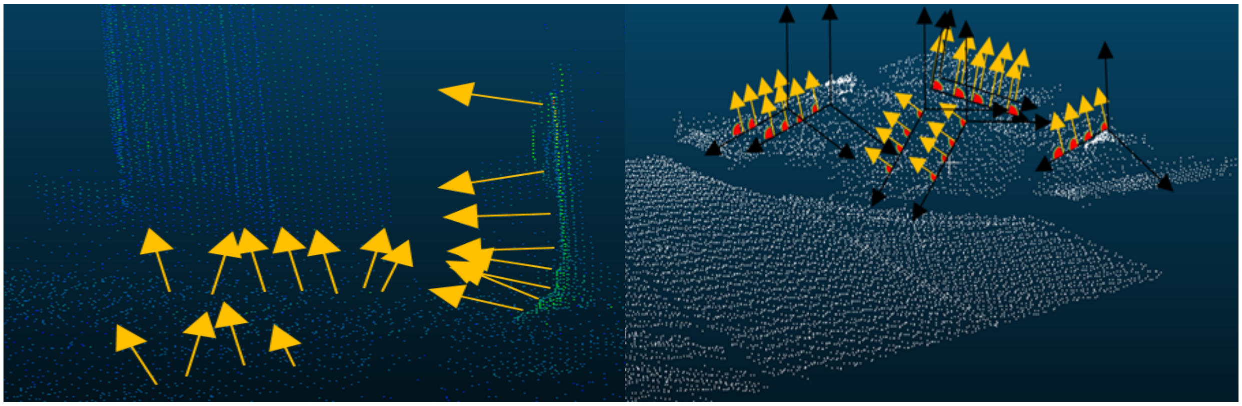


Figure 11: Non-uniform and uniform PCD after normal vector estimation

The ground plane is unrecognizable right after the data pre-processing. Our method to detect the plane is computing the plane equation for the set of data in Euclidean space. The plane equation was used to find normal planes in the planar segmentation process. The hessian's normal form is used to describe planes. The four coefficients of the plane are normal x, normal y, normal z, and d, as shown in Equation (4).

$$ax + by + cz + d = 0 \qquad \text{Equation 4}$$

The equation for a plane with nonzero normal vector n= (a, b, c) through the point x_0= (x_0, y_0, z_0) can be described as the set of points (x, y, z) that satisfy the Equations (4) in our data processing (26).

3.6 CLASSIFICATION

The boundary points in the automated segmentation provide numerous benefits for road facilities evaluation such as the facility's edge detections (27). Boundary points make a higher accuracy in plane normal calculation process in a massive PCD to detect objects which have similar geometric information. For example, Miraliakbari (2015) successfully extracted a curbstone and road surfaces by using jump detection method to detect height differences and height data histograms (28). Using the elevation gradient with the surface normal of the local neighborhood can isolate the curbs from the rest of the objects in a scene (29).

In an attempt to improve efficiency and accuracy on our classification step, we develop an automated curb ramp and sidewalk detection method based on the plane vectors. Each plane has a specific angular direction which produces a unique normal vector. We used the plane normal vector characteristics to extract each object automatically and organize points. The points are organized based on their characteristics in different sets of data for the further calculation process.

Also, there are several techniques that we can use to fit a parametric model into the data, such as Naïve Bayes Classifier Algorithm, K Means Clustering Algorithm, and Support Vector Machines Algorithm. Random sample consensus (RANSAC) is selected to estimate the residual of the objects in a model based on the distance threshold (30) because of the robust approach which is used in this method to estimate the matrix. In the algorithm, we used RANSAC to determine if a point is an inlier or an outlier of an object.

Object segmentation is another step in our automated classification process. In this step, point cloud data are broken down into different objects, based on their characteristics and contextual information on neighboring points. Figure 12 shows the segmentation results of the PCD.

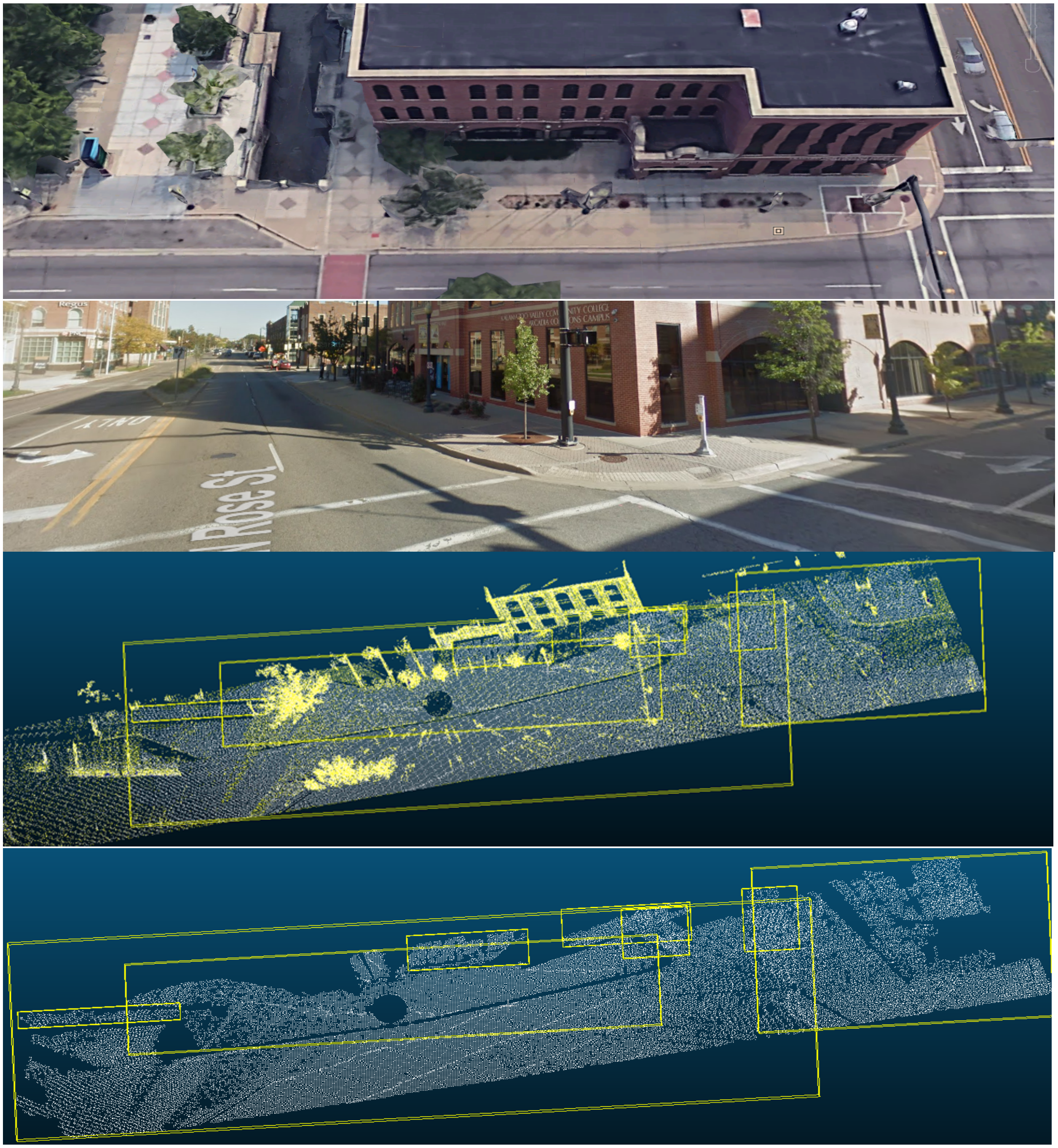


Figure 12: Sidewalk and ramp detection flow in automated PCD (top view, front view, full top PCD view, surface top PCD view)

4 CASE STUDY

People with different disability facing different barriers to access to the public and commercial services. (31) Business district of Kalamazoo, Michigan provides a useful case study for studying disability barriers based on ADA. The case study of this project located on Ross Street between West Michigan Ave. and East Kalamazoo Ave. in downtown Kalamazoo. This area is located in a business district with various public and commercial buildings (e.g., a museum, university campus buildings, public parking facilities, banks, and hotels) which cause high pedestrian traffic. It is a mixed residential and commercial area with a wide variety of resident individuals as road users (Figure 13).

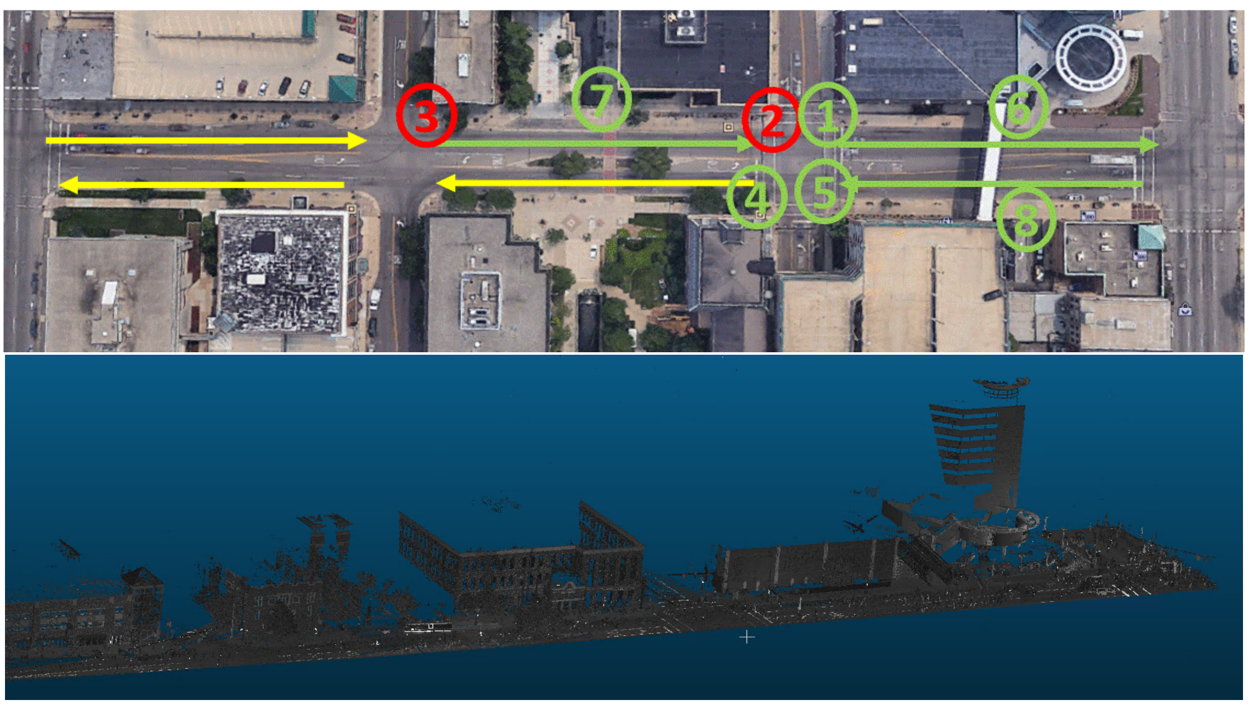


Figure 13: The Bird-eye-view image of the Case Study area and its PCD (Green color passed ADA and red color rejected)

Some constraints that affected data collection through laser scanning are described as follows: The Leica C10 laser scanner used in this study scans 50,000 pts/s, and it takes 2 to 5 minutes to finish each scan (Figure 14).

Figure 14: The Bird-eye-view image of the Case Study area and its PCD

Pedestrians static or moving slowly near the laser scanner are "blocking" the view of the laser scanner. Furthermore, the moving vehicles may block the laser beams while the laser scanner scans areas. Therefore, the vehicles and pedestrians will need to be analyzed and removed from the PCD. (Figure 15)

Figure 15: The Laser Scanner -view image of the Case Study area (Sources of errors)

5 EXPERIMENT

Bascom and Christensen (2017) research shows that seventy percent of people with a disability need to balance their accessibility needs with their life which show how significant is measurement accuracy impacts in their life quality. (32) By accurate detection and analysis of sidewalks and ramps, automatic measurements of different object elements could subsequently be conducted. The experiment was conducted to evaluate the accuracy of the proposed method. The sidewalk and curb ramp features (Figure13) were manually measured by measuring tape to obtain a ground truth for curbs and sidewalks. The following subsections (Tables 3 and 4) compare results of two sets of objects detected features measurement. Table 3 and 4 present the performance of the proposed algorithm for crucial features of the sidewalks and ramps in the case study of compliance checking

Table 3: Results of Comparison of Selected Curb Ramp Slope

Results of CurbRamp Slopes			
Number	**By Manual Measurements**	**By Proposed Method**	**Difference**
1	8.17%	7.99%	0.18%
2	10.42%	10.21%	0.21%
3	10.42%	10.60%	-0.18%
4	7.11%	6.45%	0.66%
5	7.62%	7.64%	-0.02%

Table 4: Results of Comparison of Selected Sidewalk Slope Comparison

Results of Sidewalk Ramp Slope			
Number	**By Manual Measurements**	**By Proposed Method**	**Difference**
6	1.23%	0.95%	0.28%
7	2.00%	1.67%	0.33%
8	1.14%	1.57%	-0.43%

The proposed method and algorithms were tested by experiments with different curb ramp and sidewalk data sets. The measurements derived from the proposed method were close to the ground truth data. Checking with the requirements of ADA regulations must be followed to ensure the accessibility of the public facility to people with limited mobility. (33) As shown in figure 13, green color represents sidewalks and ramps passed ADA regulation, and red color represents curbs did not pass ADA regulations. Table 2 shows the results of curb ramp slope data by comparing physical measurements with the results obtained using the proposed automation method in 5 different ramps in the study area. The mean absolute error of the selected curb ramps data is 0.22%, which shows the accuracy of our proposed method. Three out of 5 selected curb ramps passed ADA requirements for the maximum slope of curb ramps 8.33% based on these results.

Moreover, Table 3 shows the results of selected sidewalk ramp slope data by comparing manual field measurements with the results obtained using the proposed automation method in 3 sidewalk segments in the study area. The mean absolute error of the selected sidewalk ramp slope is 0.13%, which shows the accuracy of our proposed method. This shows all the selected sidewalk ramp slopes passed the ADA requirements of 2.0% maximum allowable running cross slope.

6 ALTERNATIVE TECHNOLOGY

In this research we also used a Segway which was equipped with Light Detection and Ranging (LiDAR) and three cameras as an alternative mobile device to scan and analysis surfaces. LiDAR as a horizontally scanning laser scanner which generates point cloud data to be used for environmental recognition. Following figures shows a frame of data collected from the LiDAR.

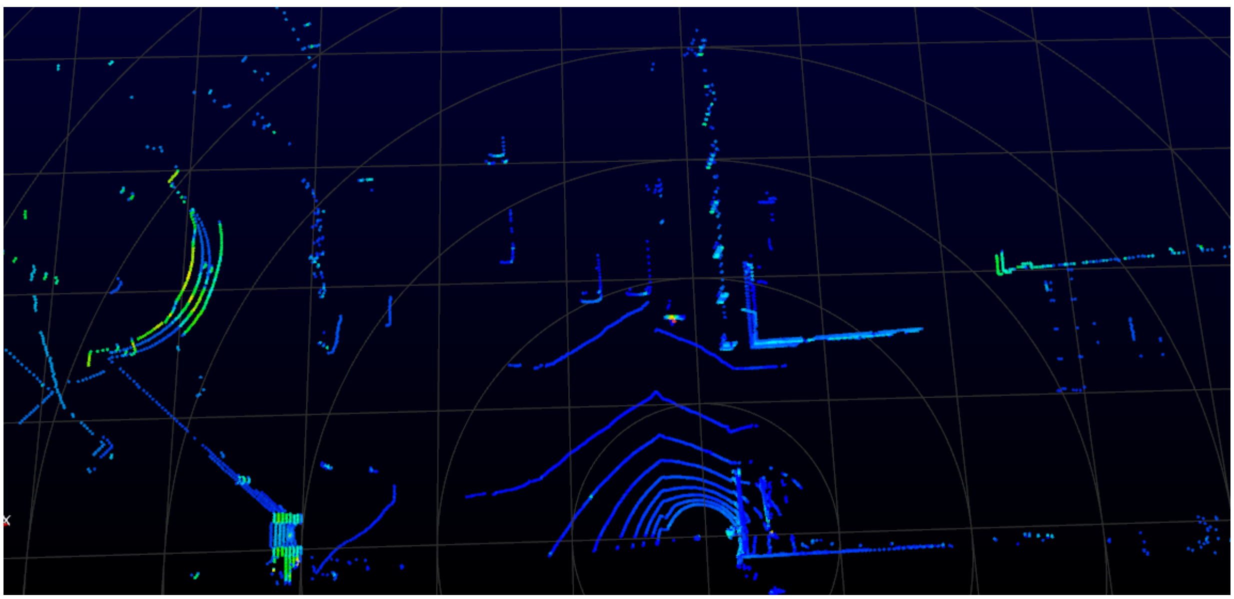


Figure 16 A frame of LiDAR data

6.1 Mobile platform setup

Lidar and cameras are light enough to be carried by a mobile agent system such as the Segway. The LiDAR based detection system sets a high bar for accuracy, portability and versatility, especially when being installed on a small mobile device like Segway. LiDAR devices, such as Velodyne V-16, can produce up to 50,000 points per second, which are enough information for surface detection in PCD environment. LiDAR and laser scanner both produce 3D environment point cloud data. In this study, we used Segway as a mobile platform and LiDAR as a measurement unit and 3 cameras (2 GO-PRO and one Sony) at different angels to capture 270-degree fields of view as shown in figure 17.

Figure 17 Segway Setup

6.2 CONTINUOUS OBJECT LEARNING (COL) METHODOLOGY

The long-term goal of the LiDAR technology is to detect and recognize not only fixed elements, such as sidewalks and ramps, but also moving objects such as vehicles. One important step in this part is checking visibility of using LiDAR frames to detect objects (e.g., curb ramp and sidewalk) in a cloud environment. This process includes following four steps:

(1) Recognize and focus attention on urban area elements such as sidewalks and ramps or cars;

(2) Raw laser scanner data into rich, flexible data set;

(3) Detect sidewalks and road features; and

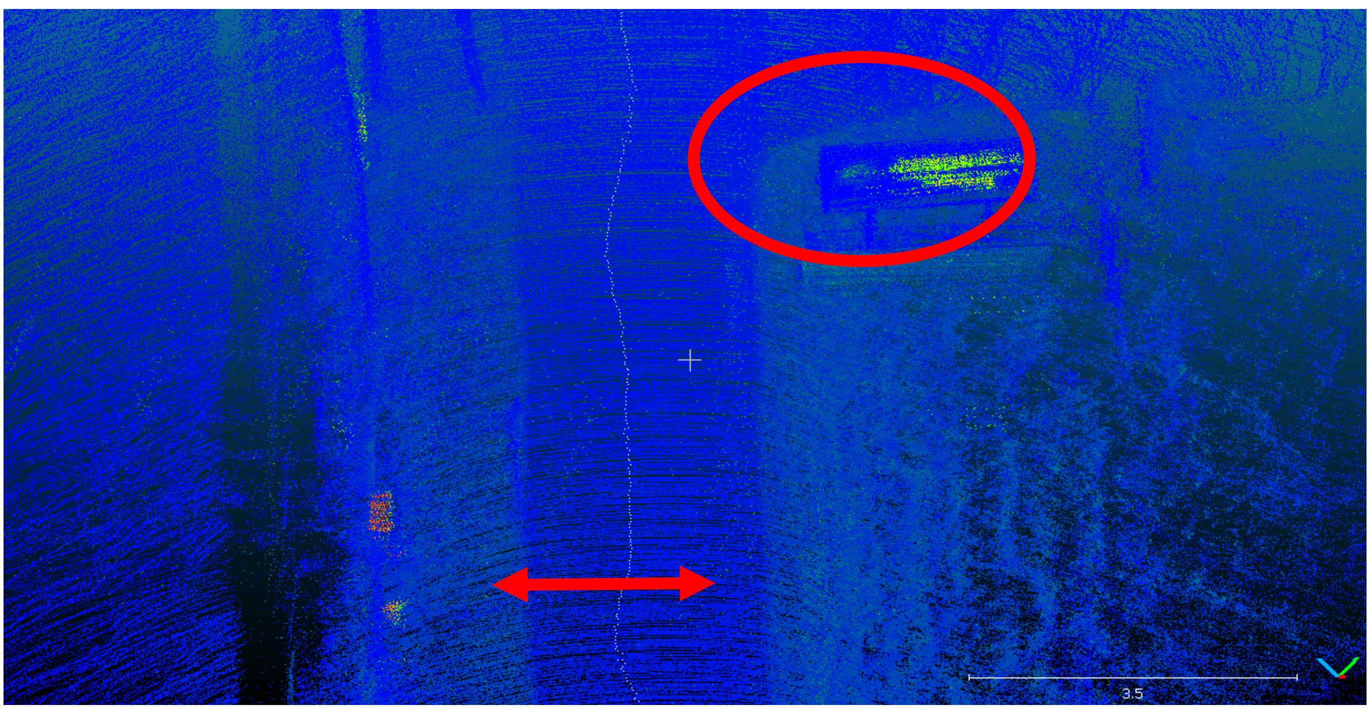
(4) Generalize collected object data into categorized data set over time.

Figure 18 Data collection with mobile platform

6.3 Results using alternative technology

The aim of this part of the research is checking feasibility of using a mobile platform equipped with LiDAR and camera to detect static and dynamic objects. Figure 18 (a) shows a camera fields of view. However, Figure 18 (b) shows the same fields of view but from the LiDAR. As shown in figures, LiDAR can find and detect sidewalks, signs as well as grass. Based on results. The objects are detected based on their characteristics, such as color, elevation as well as distance. Unfortunately, COL in this step could not find a relation at time T to time T+1 automatically. Processing LiDAR data or laser scanner data is a time-consuming task and needs a semi-automated or fully automated process.

(a) Camera fields of view



(b) LiDAR fields of view

Figure 19 Views by camera and LiDAR

7 RESULTS AND CONCLUSION

This study is one of the few in using a comprehensively automated algorithm to assess the compliance of roadway features with ADA. The primary motivation of our research is to prepare a comprehensive evaluation method of public infrastructure facilities (such as curb ramps and sidewalks) with regard to ADA requirements, using PCD collected by laser scanning. ADA maintains design criteria for safe and accessible roadways to people with disabilities. Data acquisition and 3D modeling can facilitate the evaluation process of local facilities about ADA requirements. Point cloud data is a high-quality 3D modeling data collected by laser scanners.

The different methods were investigated in examining accessibility. For example, Alghamdi. et al. (2017) used a simulation technique to check compliance (34) and Ai. et al. (2017) reported an accurate measurement technique of the sidewalk cross slope and grade by using LiDAR and camera data. (2) However, they reported diverse appearance challenging to implement a fully automated curb ramp extraction method, so they used a semi-automatic approach. In our research, an automated assessment methodology for ADA compliance is proposed, utilizing various types of point-based measurement technology using LIDAR. Typical data format from these measurements are in the form of point cloud data (PCD), and this study addresses the steps to identify critical features that constitute ADA compliances from these measurements. Although a variety of sensors are available to measure different maneuvers, only a few of them can provide comprehensive data (32). The collected data needed to be further processed and interpreted. Various techniques were utilized such as normal estimation, surface fitting, segmentation, and road feature categorization. This helps with the automated detection of road elements such as sidewalk and curb ramp, and the automated measurement of their dimensions such as slopes. Experimental testing was conducted to evaluate our proposed method on Ross Street in Kalamazoo, Michigan.

The results show that the mean absolute error of the selected curb ramps data is 0.22% and the sidewalks are 0.13% when comparing with other manual measurements. Our proposed method and algorithms are expected to help local authorities assess their infrastructure facilities and identify accessibility problems with regards to ADA requirements.

Segway, as mobile platform, was used in this research. It produces a valuable source of data. The Mobile platform produce static and dynamic object related information such as X, Y, Z as well as time and distance. These data are used in a process of detecting objects. One of the most important advantages of using mobile platform is the capacity of collecting data from the same object in a 3D environment at time T and T+1. In a mobile platform setup, one object would be scanned few times, which produces more points of the same object than laser scanners at a 360-degree view. However, laser scanners produce massive number of points in one view.

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