Pole Like Object Detection using PCA in Terrestrial LiDAR System

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Abstract. Many vertical objects like trees, poles, and pole like structures play a crucial role in the inspection of road safety and planning for road development. The detection of such objects further proves to be helpful in averting roadside accidents and other problems. Light Detection and Ranging technology can be used in identifying these objects. In this paper, we have proposed to detect pole like structures from the dataset generated using a Light Detection and Ranging system. Our proposed pole like object detection approach first segments data into multiple small clusters. The clusters are further analyzed to compute the covariance to identify the linear relationship among the variables. Then eigenvectors and eigenvalues are computed to identify the directions and strength of the data points of clusters. Finally, the Principal Component Analysis approach is used to detect the pole-like structures. The approach is used to identify the target object which uses a threshold value for the angle of the object greater than 70° with respect to the surface. It also uses a normalized eigenvalue equals to 0.7. The efficiency of the proposed is recorded as 93.7%, and the time taken to process the data and detection of the pole-like structures from the dataset is 15 min and 30 sec.

Keywords: LiDAR; Terrestrial LiDAR; PCA; Pole like object; Object detection.

1. Introduction

In the last few decades, Light Detection and Ranging (LiDAR) technology has brought revolutionary achievements in the area of photogrammetry and sensing remotely. LiDAR technology is also referred as Airborne Laser Radar. It works on the principle of measuring three-dimensional coordinates of the objects present on the ground. The work is done using airborne detection and ranging system which is mounted over aircraft and using that laser is projected on the ground. When an airborne system detects the return signal, it measures the spatial altitude of the object, flight altitude and time of the aircraft using GPS (Ground Positioning System) and IMU (Inertial Measurement Units) and LiDAR data is generated [1].

Basically, two types of LiDAR data capturing systems are available, which are airborne and terrestrial. In airborne LiDAR, the image capturing system is installed in a helicopter or a fixed-wing aircraft. When a flight is hovering over the ground, the infrared light is emitted towards the ground and the laser strikes on different objects. After striking with the object, the laser light returns to the airborne LiDAR sensor and high-resolution image data is generated. These days, the airborne LiDAR has become a standard tool for the industry to collect accurate data at high speed [2]. Another type of LiDAR data is generated using a terrestrial LiDAR system. Basically, there are two types of terrestrial LiDAR which are known as mobile and static. Collecting data using a moving platform is done in mobile LiDAR. It includes mounting different light sensors on movable vehicles such as; trains, cars, or even boats. It consists of cameras, GPS, LiDAR sensor, and an Inertial Navigation System (INS) similar to an airborne LiDAR system. Data captured through mobile LiDAR can be used to analyze road infrastructure and locate poles, overhead wires, and road signs [3]. Static LiDAR refers to
collecting LiDAR points from static locations. In this method, a tripod is mounted with light sensors is used which is fully portable. It can be used to collect LiDAR points inside any building as well. The approach can be very useful in the field of engineering, archaeology, mining [4]. These days, this technology is gathering much attention to acquire data efficiently in developed countries because of the ease in handling and portability [5].

In general, airborne LiDAR systems are being used to capture accurate and efficient data to generate high terrain maps, urban planning, generating different terrain models, etc. [6]. But, the terrestrial LiDAR gained its popular momentum a few years back and carried a huge scope for research in this field. Two main features of the terrestrial LiDAR system is that the data capturing is performed with high precision and high resolution. The second feature is that the data captured by the system is of high density. There are certain hurdles associated with LiDAR dataset, such as; huge size, high cost in capturing data, reliability, and range of data. LiDAR technology is widely used in a variety of fields, designing hydraulic dams, traffic management, inspection for road safety, planning roads, study of streets for better traffic management, military assistance, etc. [1].

Generally, LiDAR data is huge in size and it is stored in binary form which carries 3-D coordinates x, y, z and intensity of laser [1]. The data can be interactively viewed in 3-D way while processing it using different algorithms such as; Analytic hierarchy process (AHP), Neural network algorithm (NNA) etc. [7–9]. Several researchers used LiDAR data to extract different properties from the data after applying different algorithms. In [10], the authors have proposed a method to detect pole shaped objects from mobile LiDAR system using PCA and achieved 95.12% of efficiency. Yadav et al. [11] proposed a five-steps process to detect pole like structures and got the efficiency equals to 92.5%. In [12], authors have used AHP (Analytical Hierarchy Process) algorithm to detect pole like objects using terrestrial LiDAR data and a 98.18% of correctness was achieved in the process. Recognizing several road objects on a small area using SVM (Support vector machine) with 99% accuracy is proposed by [13]. There are several algorithms and methods have proposed by different researchers to extract different properties from LiDAR dataset.

It has been observed that existing PCA based approaches are taking large processing time and due to that the approaches are limited to fixed sizes of datasets. In this paper, we have proposed to detect pole-like objects or structures from LiDAR dataset. The dataset used in this paper is generated by a terrestrial LiDAR system. The proposed approach is based on PCA where the target is to enhance the efficiency and processing time to detect pole-like structures. The approach follows a five-step strategy which includes the following steps:

1. Range Search is used to form multiple small clusters among the dataset.
2. Calculation of covariance for establishing linear relationships among 3-D coordinates.
3. Generation of eigenvalues and eigenvectors using the covariance matrix.
4. Normalization of eigenvalues, applying PCA to detect target objects.
5. Calculation of the angle of the target objects with respect to the x-axis and z-axis in order to detect the pole-like objects.

The proposed approach is used to identify the pole-like objects which uses a threshold value for the angle of the objects with respect to the x-axis and z-axis, and it also uses a normalized eigenvalue as a threshold.

The remaining parts of this paper are organized as follows. In Section 2, the survey of object detection methods in LiDAR system have been described. Section 3 explains the LiDAR technology. In Section 4, the proposed methodology has been discussed. Section 5 presents the implementation and result analysis of the proposed work, followed by the conclusion in Section 6.

2. Literature review

There are various methods have been proposed for object detection from different types of LiDAR datasets [3]. In [14], the authors have proposed to identify different occurrences of cloud at Nauru
island using LiDAR and radar technology. It extracted clear sky conditions, less dense clouds and high dense clouds. The study is carried out in a stable air condition where wind speed is not more than 15 kmph. Veneziano et al. [15] presented a planned methodology to utilize LiDAR in concurrence with photogrammetric mapping to pace up the location of the highway and the design activities, including estimates of cost and time saving. The main observation in the paper is that LiDAR technology may not completely replace photogrammetric data, but it can accelerate the location process. In [16], the authors have used mobile laser scanned data. It uses onboard sensors to capture the data. From the dataset, it extracts different PLO such as street lights, signposts, traffic lights. After digging out the features, it focused on the quality assessment of those features. In [17], authors have used mobile LiDAR data collected at small scale unit. Using LiDAR technology, the authors studied characteristics of plant structure, its height and volume.

Using terrestrial LiDAR data [5], captured 3D model for urban modelling. Different modelling approaches are used by the authors. It also highlighted indoor data modelling and new ongoing sensor developments. In [13], the authors focused on reducing the cost of conventional method cost by using machine learning which recognizes different road objects and extracts data from a large amount of 3D point data. It mainly focuses on local areas. Their method finds out different walls, guardrails and poles. This also reduced the difficulty which arises due to segmentation. The authors, in [18], mainly focused on suggesting an algorithm which will detect PLO from a dataset which is captured through a mobile laser. After detection, it will then sort the data into three major parts viz., poles with utility, lamp posts, and signs on the streets. The whole work is carried out using Laplacian smoothing through the K-Nearest Neighbour Graph. The principal component analysis has also been used for other works. In [10], authors have detected pole shape objects along the road by dividing the methods into three stages that is gridding, vertical segmentation, region growing. The LiDAR data used in this paper is captured using StreetMapper 360. This method failed to perceive poles blocked by tree branches. In [11], structures like pole (PLS) from LiDAR data is identified. This is achieved through 5 step process. Rural, peri-urban, urban were the sites which were taken into account for testing the mentioned method proposed with the data from cloud. 3D coordinates were only used from the dataset so that dependency on the neighbourhood structure and scanning of geometry can be vanished. K-Nearest Neighbour (KNN) approach is taken into account for finding neighbours around different seed voxels[19].

In all the available literature, the main issue was the efficiency and computation time for object detection using high dimensional LiDAR datasets. There are some issues many researchers have faced while detecting objects which are hidden by trees, wires, buildings, hoardings, etc. That motivated us to propose a PCA based method to detect pole like objects which can give high efficiency in terms of correct detection and takes less processing time.

3. LiDAR technology

Light Detection and Ranging (LiDAR) is a technology which takes light wave or light source to measure the distance between source and objects in order to create 3D image data. It is first used in 1960’s to find out the distance between our planet and the moon[20]. A LiDAR instrument consists of three main components. A laser, which is used to find the distance between object and source, a scanner that scans objects by a wide range of 360 degrees, and a GPS system, which determines the spatial position. The LiDAR system can be mounted on any vehicle, train, boat, etc. In the pulse form, the laser is targeted on any of the objects then reflection or scattering from the object is being measured by a detector. Next, the timing between transmitted pulse and received pulse is measured at the detector site. When data is processed by the receiver, the data is stored in binary format. This raw data is contained in a file having four columns containing 3D coordinate of the point cloud and the intensity value of the laser. The data which is generated using LiDAR can carry huge scope and vary in size. This large set of data can be analyzed using different tools. In this paper, we have used CloudCompare to analyze our data. This data then can be converted to ASCII format using LAS tools and then can be processed using different algorithms on any of the programming languages [17].
A LiDAR system usually consists of three parts: transmitter, receiver, and detector as shown in figure 1. The transmitter projects laser in pulse or continuous beam of a variety of wavelengths from infrared to visible to ultraviolet beams. This large variety of wavelengths gives LiDAR the capacity to detect a number of atmospheric variables. LiDAR receiver then collects the scattered photons and directs them to a photodetector that changes them into an electronic signal. LiDAR detector at the end calculates and stores the intensity of light received by the receiver [21]. We prefer LiDAR technology over radar technology for gathering data because RADAR uses radio waves which are millimetre waves whereas, LiDAR uses light waves which are three orders less than radio waves in terms of wavelength. Therefore radio waves have a larger wavelength than light waves [22], and thus it cannot detect very small objects while LiDAR can detect such objects with much more precision. The reason that LiDAR technology is used for 3D mapping of the object or even surface scanning. Radar is used where the exact shape and size of target objects are not important, but the actual distance is important. Therefore, RADAR is commonly used in ATC and Military operations while LiDAR helps us to identify the actual shape, size and depth profile of the target objects [23]. In LiDAR, if we take a smaller scanning angle that will result in more the number of samples, which will finally give a more accurate depth profile of the objects [14].

![Figure 1. Block diagram of a LiDAR system](image)

4. Proposed methodology
Several researchers have used different concepts to detect vertical structures in LiDAR data. In [10], the authors have used a three-step approach which is gridding, segmenting vertically and region overgrowing and achieved more than 95% correctness in identifying pole-like objects. In [11], authors have proposed a five-step process that includes ground filtering, voxelization followed by three steps for identifying pole-like structures from the LiDAR data. The approach achieved 94.9% completeness. As described earlier, most of the available works for vertical object detection from LiDAR datasets have limitations such as low efficiency and high processing time. In this paper, we have proposed a PCA-based approach for vertical or pole-like object detection. The proposed work majorly focused on reducing the processing time and getting good efficiency. The proposed approach uses a high-resolution LiDAR dataset for detecting vertical linear objects. A graphical representation of the proposed work is shown in figure 2. The approach identifies vertical objects using five steps. The steps are range search, calculating covariance, generating eigenvalues and eigenvectors, applying PCA, and then calculating angles which are described as follows:

- **Range search:** The collected LiDAR raw data have an enormous number of points which are distributed in 3D space, having x, y, and z coordinates. Now, we have to divide our big data into small chunks or clusters so that we can work on a single cluster at a time rather than working on the whole of the data. We select a single point which is referred to as seed point
and then fix a radius or range. All the points present within the radius from the seed point are calculated and is stored in a single file. This way, we make a small cluster of 3D points and further analyze this cluster to detect the pole like structures. It is very difficult to process the complete set of points altogether; therefore, we break our data into small clusters to improve efficiency. The approach used for range search is based on KNN algorithm. In our experiment, we took every point as seed point one by one and the value of radius as 1.

- **Covariance calculation:** After performing the range search using seed point and radius, we have now a small cluster of 3D points having x, y, and z coordinates. Now, the linear relationship between variables is to be calculated. For that, we need to find the covariance for each of the clusters identified in the range search step. The output of this step will be 3 by 3 matrices.

- **Generate eigenvalue and eigenvector:** After generating the covariance matrix, we will find the eigenvalues and eigenvectors. Eigenvalues and eigenvectors will tell us that in which direction and by which factor points are stretched in a certain direction. Here, we will get three eigenvalues $\lambda_1$, $\lambda_2$, and $\lambda_3$ and a 3 by 3 eigenvector matrix. The first column of the eigenvector matrix represents the vector corresponding to $\lambda_1$, the second column represents the vector corresponding to $\lambda_2$, and the third column represents the vector corresponding to $\lambda_3$. The resulting eigenvalues and eigenvectors are further used by PCA in the next step.

- **Apply PCA:** Here, we first normalize all three eigenvalues using the PCA algorithm. After normalization, the greatest eigenvalue, out of $\lambda_1$, $\lambda_2$, and $\lambda_3$, is chosen. The greatest value is then checked whether it is greater than the threshold value or not. We have taken 0.7 as the threshold value. If it satisfies the condition, we will consider the cluster’s points and proceed to check what angle the eigenvector makes with the x-axis and z-axis.

- **Calculate angle:** After the above condition is met, the angle of the cluster’s points with x-axis is calculated and if the value is greater than 70° then we consider it as a pole like object directing upwards. Another angle with the z-axis is calculated and if the value is greater than 70° then we consider it as a pole like object which is lying on a surface.

After implementing all the mentioned steps, if a cluster’s points i.e. target object meets the desired conditions mentioned above then we will take all the 3D coordinates of those points as output. Then all the duplicate points are removed from the final output. The collected points will then be projected as vertical or horizontal pole like objects.

Figure 2. A block diagram of the proposed pole like object detection method

5. **Implementation and result analysis**

In this section, we describe the experimental setup and the LiDAR dataset used for the detection of pole like structures. Here, we also present the results of the experiment.

5.1. **Dataset**

The data which is used for the experimental study in this paper is collected from Mahatma Gandhi Marg, Civil Lines, Prayagraj City, Uttar Pradesh, India (25°27’03.8”N, 81°49’40.6”E). The dataset is captured by a static terrestrial LiDAR technology known as FARO Focus3D X 330 TLS. It captures raw data using 360-degree view. Dataset used in this paper contains 7243654 points in total. Figure 3 shows different views of the dataset.
5.2. Environmental Setup

The proposed work is carried out on a computer system having 64 bit Windows-8 operating system, 8 GB of RAM, 1 TB of HDD drive. For experimental tasks used in this paper, we have used a different set of software such as; Cloud Compare, MATLAB R2021a and LAS Tools. Cloud Compare [24] version 2.10 is used to visualize the dataset and to carry out different segmentation process on the dataset. For the implementation of the proposed work, we have used MATLAB R2021a [25]. To convert the LiDAR dataset file into a text file so that we can work on the dataset smoothly and vice versa. We have used LAS Tools software version 1.0[26].

5.3. Result Analysis

After implementing the above method on the LiDAR dataset, we will get the pole like objects as output. We have achieved an efficiency of 93.7%, and the running time of our code is 15 minutes 30 seconds in our experiment. Maximum efficiency can be achieved with a change in radius and seed points. Figure 4 shows different outputs of detected poles. It shows vertical poles with large heights, and the poles present near the boundaries and occluded poles by trees and webs of wires.

6. Conclusion

In the urban areas, the major cause of accidents is crashing with the poles present beside the roads and trees on the roads. Proper planning and the right displacement of these objects can be helpful in avoiding these accidents. In this paper,a five-step approach based on PCA is proposed to detect pole like objects from the terrestrial LiDAR generated data. The proposed approach is used to detect pole like structures such as poles, trees, utility poles located nearby road boundary and pole like objects which are hidden by trees or other elements. The detection of such objects can be helpful in planning the roads to avoid frequent accident occurs. The proposed work can be useful in road planning, town
planning and even reducing the electrical wiring cost by using the pole and pole like objects at correct locations. Although the proposed work has given a good efficiency and reasonable processing time, there is a scope for improving the efficiency and processing times. The work is carried on a small LiDAR dataset that limits the proposed work efficiency. Different methods can also be applied to this dataset, or using a large dataset by the proposed work can be used to get better efficiency and processing time.

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References

[1] Lv D, Ying X, Cui Y, Song J, Qian K and Li M 2018 Research on the technology of LiDAR data processing 1st Int. Conf. Electron. Instrum. Inf. Syst. EIIS 20172018-Janua 1–5
[2] Lohani B and Ghosh S 2017 Airborne LiDAR Technology: A Review of Data Collection and Processing Systems Proc. Natl. Acad. Sci. India Sect. A - Phys. Sci.87 567–79
[3] Elhousni M and Huang X 2020 A Survey on 3D LiDAR Localization for Autonomous Vehicles 2020 IEEE Intelligent Vehicles Symposium (IV) pp 1879–84
[4] Li Y and Ibanez-Guzman J 2020 LiDAR for Autonomous Driving IEEE Signal Process. Mag.37 50–61
[5] Böhm J 2009 Terrestrial LiDAR in Urban Data Acquisition Photogramm. Week ’09 169–78
[6] Baltasvias E P 1999 Airborne laser scanning: Basic relations and formulas ISPRS J. Photogramm. Remote Sens.54 199–214
[7] Nalavade A, Bai A and Bhushan M 2020 Deep Learning Techniques and Models for improving Machine Reading Comprehension System 29 9692–710
[8] Mangla M, Kumar A, Mehta V, Bhushan M and Mohanty S 2022Real-Life Applications of the Internet of Things: Challenges, Applications, and Advances (CRC Press, Taylor & Francis Group)
[9] Singh A, Ranjan R K and Tiwari A 2021 Credit Card Fraud Detection under Extreme Imbalanced Data: A Comparative Study of Data-level Algorithms J. Exp. & Theor. Artif. Intell.0 1–28
[10] Yadav M, Husain A, Singh A K and Lohani B 2015 Pole-shaped object detection using mobile lidar data in rural road environments ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.2 11–6
[11] Yadav M, Lohani B, Singh A K and Husain A 2016 Identification of pole-like structures from mobile lidar data of complex road environment Int. J. Remote Sens.37 4748–77
[12] Husain A and Vaishya R C 2018 An AHP based automated approach for pole-like objects detection using three dimensional terrestrial laser scanner data vol 826 (Springer Singapore)
[13] Ishikawa K, Tonomura F, Amano Y and Hashizume T 2013 Recognition of Road Objects from 3D Mobile Mapping Data Int. J. CAD/CAM13 41–8
[14] Comstock J M, Ackerman T P and Mace G G 2002 Ground-based lidar and radar remote sensing of tropical cirrus clouds at Nauru Island: Cloud statistics and radiative impacts J. Geophys. Res. Atmos.107 AAC 16-1–AAC 16-14
[15] Venezziano D, Souleyrette R and Hallmark S L 2002 Evaluation of LiDAR for Highway Planning, Location and Design Pecora 151. Satell. Inf. IV/ISPRS Comm. I/FIEOS
[16] Hofmann S and Brenner C 2009 Quality assessment of automatically generated feature maps for future driver assistance systems GIS Proc. ACM Int. Symp. Adv. Geogr. Inf. Syst. 500–3
[17] Loudermilk E L, Hiers J K, O’Brien J J, Mitchell R J, Singhania A, Fernandez J C, Cropper W P and Slatton K C 2009 Ground-based LiDAR: A novel approach to quantify fine-scale fuelbed characteristics Int. J. Wildl. Fire18 676–85
[18] Yokoyama H, Date H, Kanai S and Takeda H 2013 Detection and Classification of Pole-like Objects from Mobile Laser Scanning Data of Urban Environments Int. J. CAD/CAM13 1–10
[19] Verma K, Bhardwaj S, Arya R, Islam S M, Bhushan M, Kumar A and Samant P 2019 Latest tools for data mining and machine learning Int. J. Innov. Technol. Explor. Eng.8 18–23
[20] Sharma B 2021 LiDAR Technology, https://www.geospatialworld.net/blogs/what-is-lidar-technology-and-how-does-it-work/ (accessed Feb. 10, 2021).
[21] Jaynes D W, Manwell J F, McGowan J G, Stein W M and Rogers A L 2007 MTC Final Progress Report: LiDAR Renew. Energy Res. Lab. Dep. Mech. Ind. Eng. Univ. Massachusetts.
[22] Smits J, Confalone G and Kinnaar T 2020 Laser, Radar and LiDAR Technology, https://www.qualitymag.com/articles/96083-Whats-the-difference-between-laser-radar-and-lidar-technology (accessed Mar. 10, 2021).
[23] Neal A 2018 LiDAR vs RADAR, https://www.fierceelectronics.com/components/lidar-vs-radar
(accessed Jan. 10, 2021).

[24] CloudCompare 2020 CloudCompare, https://www.cloudcompare.org/release/notes/20190106/
(accessed Aug. 10, 2020).

[25] Matlab2020 R2021a at a Glance,
https://in.mathworks.com/products/new_products/latest_features.html (accessed Dec. 05, 2020).

[26] LASTools 2020 LASTools: award-winning software for rapid LiDAR processing,
http://lastools.org/ (accessed Oct. 24, 2020)