LiDAR-Based Detection and Tracking of Pedestrians and Vehicles on Road : Literature Review

Aman Kumar Singh
Indian Institute of Technology Kanpur
amanks20@iitk.ac.in

April 2024

1 Problem Statement

With the advent of autonomous vehicles and ongoing research growing by leaps and bounds, it is evident that this technology will surely be implemented successfully on public roads. But, the main concern for autonomous vehicles is the safety of all road users. In urban road scenarios, the most vulnerable of all the road users are "pedestrians". If autonomous vehicles don't effectively detect and track pedestrians and other road users, including vehicles then it can be a fatal failure of autonomous vehicles. Therefore, the major concern for autonomous vehicles is to correctly detect road users, including pedestrians and vehicles. Moreover, track them to ensure their safety and adjust its own behaviour i.e. speed and trajectory accordingly [11].

2 Summary of Studies

2.1 Types of Dependent Variables Considered

- Zhao et al., 2019 have used categorical variables to classify a road user as pedestrian or vehicle [15].
- Wang et al., 2017 just focused on binary classification problem i.e. whether a cluster is pedestrian or not, therefore they used binary variables only to classify whether a cluster is pedestrian or not [13].
- For tracking purpose, researchers like Zhao et al., 2019 have also made use of continuous variables like speed, direction and location of road users primarily pedestrians and vehicles [15].
- Some researchers exploit lidar-based features to detect pedestrians in a urban scenario, in such case they used AUC (Area under ROC curve) and Accuracy as their classification performance metrics to correctly detect pedestrians with certain level of confidence [6].

2.2 Statistical Techniques Employed

1. Background Filtering to clean and segment out the background from foreground i.e. road users. Researchers have made models by implementing advanced filtering methods like Automatic Background Filtering Method for Roadside LiDAR Data proposed by Wu et al., 2018. This techniques automatically extract the background from roadside lidar data of urban scenarios including both the static and moving background efficiently using threshold learning and real-time filtering [14].
2. Data Clustering to cluster the data points belonging to each road user using unsupervised learning. The commonly used algorithms are mainly graph-based clustering algorithms, K-means clustering, DBSCAN clustering and others [7, 12].

3. Classification of road users as pedestrians and vehicles using supervised learning. Researchers make classification models using Backpropagation artificial neural network (BP-ANN) to distinguish between pedestrians and vehicles [15]. Some research works including Premebida et al., 2009 and Wang et al., 2012 also leverage the use of Support Vector Machines (SVM) classifiers to classify the road users as pedestrians and vehicles [6, 10, 12].
4. Tracking the pedestrians and vehicles using discrete time Kalman Filter. The Kalman Filter is one of the most important optimal estimation algorithms used in manifold ways in varied navigation and tracking problems by implementing its beautiful predictor-correcter approach [15].

2.3 Key Traits Influencing Study Objectives

1. Traffic conditions like mode-specific volumes, speed, etc directly influence the study objective as they determine the interaction between pedestrians and vehicles along with the likelihood of near crash events. More number of pedestrians and vehicles, more the congestion and complexity, less accurate the detection and classification. Higher the speed, more the distortions and lesser the time available to detect and classify [8, 15].
2. Road geometry like the number of lanes, horizontal alignment, presence of sharp turns or bends play a role as well. More number of lanes or presence of sharp turns might hinder the line of sight between the sensor and road user. This can reduce the lidar data quality and deteriorate data collection [1, 2, 9].
3. Traffic Operations like signalization, speed limits and signage influence the study objectives. Presence of signalization and proper placement of signages make the traffic movement ordered and smooth, leading to proper detection and tracking. Also, lesser the speed limit, more smoother and safer the environment and interactions are, leading to accurate detection and tracking [5].
4. Socio-demographic factors like population, income and age also play a role. Higher the population, more traffic volumes that likely result in inaccurate clustering of data, More the income, more is vehicle ownership rate and hence the number of vehicles will be more that will make the interactions congested and lead to inaccurate clustering [2]. Moreover, Behavioural Considerations like perception of how safe and unsafe also influence the behaviour when they interact with other road users especially vehicles [4].
5. Weather conditions when harsh with poor visibility due to fog, rain etc reduce the effectiveness of LiDAR sensors as the data collected is poor and not optimal for detection and tracking of pedestrians and vehicles. [2].

3 Hypothetical Study Design for India

3.1 Data Collection

Data collection setup involved Velodyne LiDAR (3D sensors) mounted an a vehicle. The spatial resolution of observation i.e. FOV is 360 degrees horizontal and ranges from 30 to 40 degrees vertical for Velodyne sensors [3]. The temporal resolution for observations is frame rate which is 5 to 20 fps (frames per second) for velodyne [3]. The collected data is LiDAR Data over successive frames for an intersection or road that has varied pedestrians along with other road users.

3.1.1 Dependent Variable

- Categorical variables to detect and classify the road users as pedestrians and vehicles.
- Position, speed and direction (continuous variables) to track the road users.

3.1.2 Explanatory Variables

- Total number of points (discrete) in a cluster because the number of data points in a vehicle cluster are more than that in a pedestrian cluster if they are in vicinity of each other.
- 2D distance (continuous) of the position reference point of a cluster to the location of the LiDAR sensor, calculated using the coordinates of reference point of each cluster.
- Spatial distribution or geometry of the clustered points (categorical) in the 3D space. The spatial distribution of clustered points of a pedestrian is usually along the vertical direction (z-axis), while the distribution of vehicle clustered points is along the horizontal direction (parallel to the x-y plane). The least-square linear regression method can be applied to generate a linear function that describe the main distribution direction of each cluster.
- Change in position (continuous) along X, Y, Z direction, i.e., ΔX, ΔY, ΔZ, along with the time information and frame ids. This basically represents the changes in LiDAR point clouds across the frames to be used for tracking over the consecutive frames using Kalman Filter along with estimation of speed, position and direction.

3.2 Analysis Technique

1. **Background Filtering:** Implement some of the models like Automatic Background Filtering Method for Roadside LiDAR Data proposed by Wu et al., 2018 [14]. Selecting a particular region of interest (ROI) will reduce computational efforts needed.
2. **Clustering (Unsupervised Learning):** Implement some widely used spatial clustering algorithms such as K-means clustering algorithm or DBSCAN (Density-Based Spatial Clustering of Applications with Noise). This will create clusters of the road users based on closeness of the data points.
3. **Classification (Supervised Learning):** Use some supervised learning methods to label data like Backpropagation - Artificial Neural Networks (BP-ANN) or Support Vector Machine (SVM) classifiers. This will label the clusters of road users as pedestrians and vehicles based on first three explanatory variables.
4. **Referencing:** After clustering and classification, a reference point needs to be found to locate the position of each cluster. To do this, take the average of all data points for pedestrians. For vehicles, a bounding box can be made and the center of that bounding box will serve the referencing purpose.
5. **Kalman Filter (Optimal Estimation Algorithm):** For tracking the clusters of pedestrians and vehicles, Kalman Filter will be implemented which will use its predictions and apply corrections using the observations to find the optimal estimates of position, velocity and direction of pedestrians and vehicles.

3.3 India-Specific Emphasis

1. Indian Traffic has many nuances along with its disordered traffic movement. Most of the individuals also do not comply with the traffic rules and regulations so predicting their behaviour and tracking is challenging. The traffic operations including signalization, signages and speed limits are also often not adhered to on Indian public roads.

2. Indian road infrastructure has varied lane configurations and intersections along with varied road quality. There are also varied vehicles like carts and horses in India. The background filtering techniques proposed by researchers abroad might not work efficiently.

3. Weather Conditions including fog, rain and other harsh weather scenarios also challenging scenarios since LiDAR sensors won't work effectively during such harsh conditions and the quality of data will be low making the detection and tracking challenging.

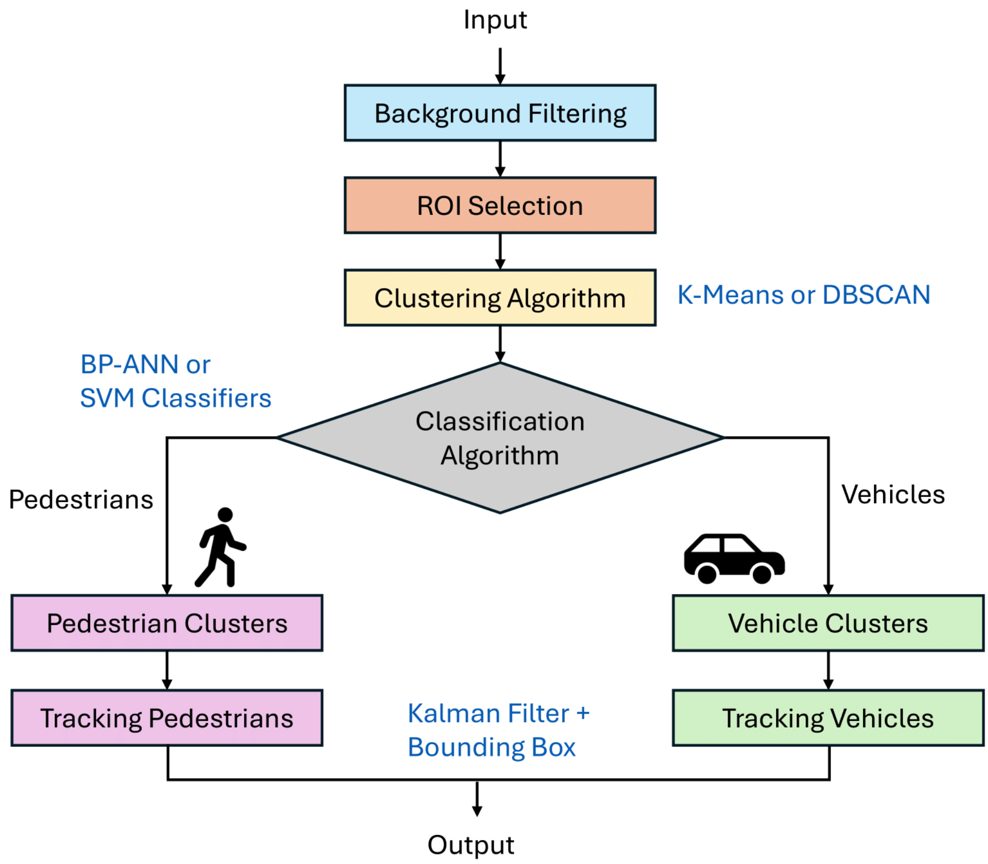

Figure 1: Flow Chart of the LiDAR Data Processing for Detection and Tracking of Pedestrians and Vehicles on Road using LiDAR Sensors.

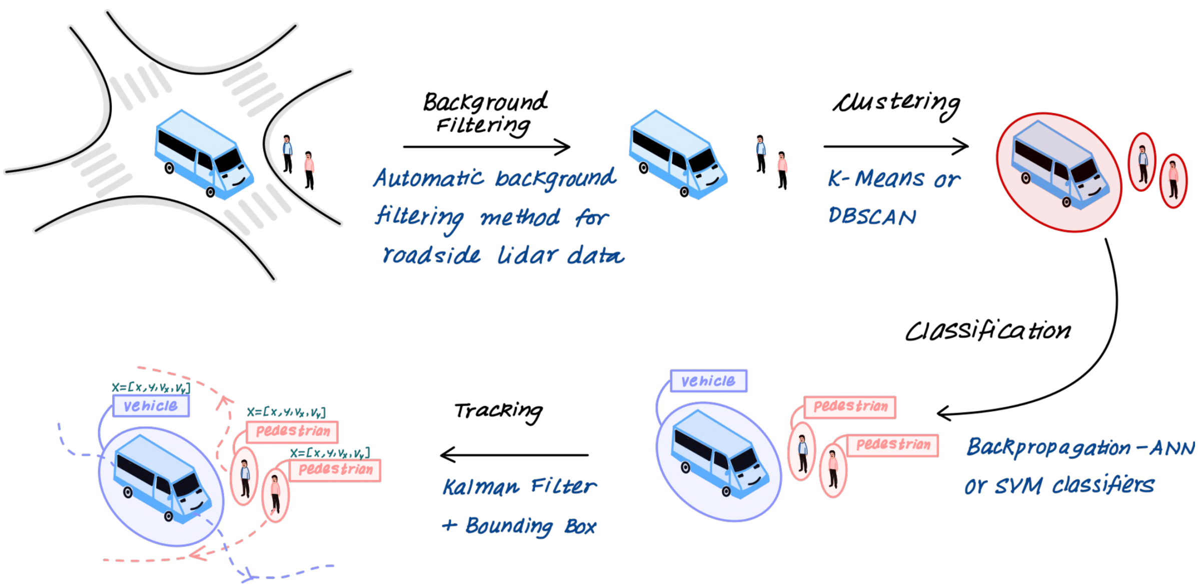

Figure 2: Illustration of Analysis Techniques used for Detection and Tracking of Road Users as Pedestrians and Vehicles using LiDAR Sensors.

References

[1] Marcin Budzynski, Anna Gobis, Lucyna Guminska, Lukasz Jelinski, Mariusz Kiec, and Piotr Tomczuk. Assessment of the influence of road infrastructure parameters on the behaviour of drivers and pedestrians in pedestrian crossing areas. *Energies*, 14(12), 2021.

[2] Luiz G. Galvao, Maysam Abbod, Tatiana Kalganova, Vasile Palade, and Md Nazmul Huda. Pedestrian and vehicle detection in autonomous vehicle perception systems—a review. *Sensors*, 21(21), 2021.

[3] Velodyne LiDAR. Vlp-16 user manual. *Velodyne LiDAR*, 2019.

[4] S. Marisamynathan and P. Vedagiri. Pedestrian perception-based level-of-service model at signalized intersection crosswalks. *Journal of Modern Transportation*, 27(4):266–281, Dec 2019.

[5] Mohammad Pourhomayoun. *Automatic Traffic Monitoring and Management for Pedestrian and Cyclist Safety Using Deep Learning and Artificial Intelligence*. Mineta Transportation Institute Publications, 2020.

[6] Cristiano Premebida, Oswaldo Ludwig, and Urbano Nunes. Exploiting lidar-based features on pedestrian detection in urban scenarios. In *2009 12th International IEEE Conference on Intelligent Transportation Systems*, pages 1–6, Oct 2009.

[7] John Shackleton, Brian VanVoorst, and Joel Hesch. Tracking people with a 360-degree lidar. In *2010 7th IEEE International Conference on Advanced Video and Signal Based Surveillance*, pages 420–426, Aug 2010.

[8] Mitali Swargiary and B Raghuram Kadali. A study on meta-analysis approach for pedestrian-vehicle interaction using lidar. *Transportation Engineering*, 13:100191, 2023.

[9] Sehyun Tak, Sari Kim, Hwapyeong Yu, and Donghoun Lee. Analysis of relationship between road geometry and automated driving safety for automated vehicle-based mobility service. *Sustainability*, 14(4), 2022.

[10] Pedro Torres, Hugo Marques, and Paulo Marques. Pedestrian detection with lidar technology in smart-city deployments–challenges and recommendations. *Computers*, 12(3), 2023.

[11] Timothé Verstraete and Naveed Muhammad. Pedestrian collision avoidance in autonomous vehicles: A review. *Computers*, 13(3), 2024.

[12] Dominic Zeng Wang, Ingmar Posner, and Paul Newman. What could move? finding cars, pedestrians and bicyclists in 3d laser data. In *2012 IEEE International Conference on Robotics and Automation*, pages 4038–4044, May 2012.

[13] Heng Wang, Bin Wang, Bingbing Liu, Xiaoli Meng, and Guanghong Yang. Pedestrian recognition and tracking using 3d lidar for autonomous vehicle. *Robot. Auton. Syst.*, 88(C):71–78, feb 2017.

[14] Jianqing Wu, Hao Xu, Yuan Sun, Jianying Zheng, and Rui Yue. Automatic background filtering method for roadside lidar data. *Transportation Research Record*, 2672(45):106–114, 2018.

[15] Junxuan Zhao, Hao Xu, Hongchao Liu, Jianqing Wu, Yichen Zheng, and Dayong Wu. Detection and tracking of pedestrians and vehicles using roadside lidar sensors. *Transportation Research Part C: Emerging Technologies*, 100:68–87, 2019.