A lane detection method based on 3D-LiDAR

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Abstract. Lane detection is crucial information for driving autonomy. To build a safe and robust lane detection system, 3D LiDAR based lane detection, capable of detecting all direction and working in all lighting condition, is an ideal sensor redundancy in addition to camera-based lane detection. The LiDAR can detect the intensity of road surface points, so the lane mark will appear as high-intensity point segment in each scan layer. The regrouping of clusters into lanes is a challenging task due to the discontinuity of road lane, the variety of road direction and configuration, and the presence of other road marks beside lane marks. A method has been proposed to incorporate road edge detection to predict local road geometry model which assists mark-segment regrouping into lane and unrelated mark filtering. Experiments show the method is efficient, and can run in a real-time environment.

Keywords: Lane detection, 3D-LiDAR, Intensity, Road geometry.

1 Introduction

3D-LiDAR are used in many field recent years, based on the precisely position detecting ability. The LiDAR sensor emits the laser light to detect the surface of objects and send the return back. The information included in the back data are the position and intensity of each laser point. LiDAR point clouds could show the properties of objects and these properties could be analyzed in many ways. Sensors play an important role in the field of driving autonomy, and lane detection is also a big issue in the road environment surveying.

Most approaches used in lane detection are based on camera [1][2], input images into the system and detect the lines. The advantages using image to detect lines are the color and the whole environment feature, and it is common using gray scale or full color in analyzing the image to catch the line. However, using image to evaluate the depth of the lines is inaccurate, therefore some method starting to combine LiDAR sensor to increase the accuracy of the result of detection. Sensor fusion is a trend in driving autonomy, and the usage of incorporating low level LiDAR with camera are wide. Some research uses one-dimensional LiDAR and camera tracking lines [3] or uses multiple two-dimensional LiDARs and cameras to acquire the variously directional information doing sensor fusion [4]. Applying camera to extract lanes and LiDAR to extract road edges, fusing the two type data to track lanes over time is a kind of method in some studies [5].

Few researches use only LiDAR as detecting sensor to catch the lane lines, and the intensity of point clouds is a notable feature which be usually analyzed to detect lane lines or curb based on the high reflective road paint [6]. Some studies use high-emitting-density LiDAR to track the road marks [7]. However the price of this kind of LiDAR sensors is too expensive and the point clouds data are too huge to deal with in breal time, therefore it is not suitable using on autonomous vehicles. Preceded only by high-emitting-density LiDAR, Velodyne 64-layer and 32-layer LiDAR are widely applied in driving autonomy according to the volume and fast-scanning frequency of the sensor.

The detection of road edge is also instrumental to driving autonomy and especially uses LiDAR as tool on the basis of its ability of precise position measuring. As discussed above, ground segmentation is often made use of Velodyne 64-layer and 32-layer LiDAR in many studies [8][9][10], and the recognized area could assist in different ways. However, as many as the layers of emitting, the price of the sensor is high. Consequently, it is important to select between cost and effect of the sensor.

In this paper, Velodyne VLP-16 LiDAR is used as the main sensor, and the point clouds which it emitted distribute in high-density arrangement on x-direction and low-density arrangement on y-direction. Depends on the geometry properties of road boundary and the distribution of point clouds, a road model is constructed. As mentioned in the previous paragraph, the lane lines are detected by the difference of the intensity of point clouds between asphalt and road paint. After detecting road edge and lane lines, the relationship of both objects is build and the lane lines could be predicted even if the lane lines disappear such as intersection.

The application of lane detection often used in LFS, LCS, LDW, and even used in SLAM technology to decide the location of a vehicle [11]. Therefore, an effective lane detection method is important and necessary in autonomous driving system. The next section will discuss the main method in this research.

2 Method

2.1 Overview

For autonomous vehicles, the emergency situations always happen in a very short time interval. Therefore the system is designed to active in real time and this is also applied in the approach of this study. In this chapter, the main method would be described in different paragraphs to achieve lane detection in real time.

The method in the paper is divided into few parts, and the flow chart is shown as **Fig. 1**. First acquire the point clouds data, and do pre-processing including coordinate transformation and static calibration with the raw data. The next steps are lane lines searching and road surface searching, both of the procedures deal with synchronously. Finally combine the results processed by the previous steps, the lane lines would be detected and predicted.

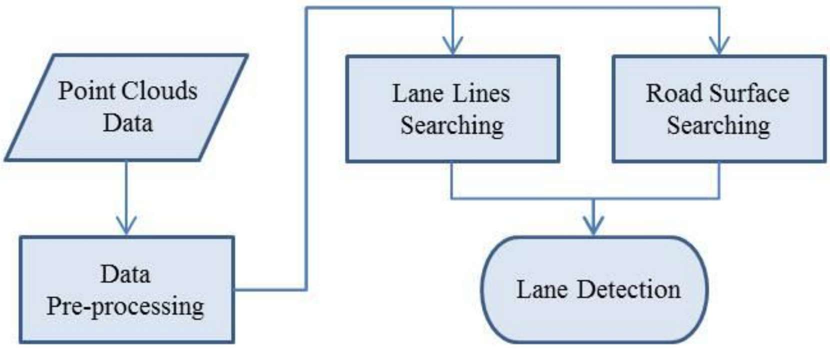

Fig. 1 Above figure is described the flow chart of the lane detection method.

2.2 Data Pre-processing

Velodyne VLP-16 LiDAR has 16 channels and the angle between two emitting beams is 2 degrees with 360 degrees rotation scanning mode. The data is transmitted through an Ethernet cable and the information included in the raw data is azimuth, distance, coordinate and intensity of each point. In the experiment the rotation frequency is 10 Hz, and the acquiring number of the points in 0.1 second is about 28000.

The center of the coordinate system is the central of LiDAR sensor, and according to the different mounting position, coordinate transformation and calibration is necessary. In order to survey the surrounding environment, LiDAR sensor would be installed at top of the vehicle and adjusted the angle to match the range of scanning. The **Fig. 2** shows the schematic vehicle coordinate system and the mounting position. To transform the coordinate $[x', y', z']$ of scanned point observed by LiDAR sensor into vehicle coordinate $[x, y, z]$ needs to calculate by a translate matrix shown as below. The coordinate $[x_0, y_0, h]$ represents the mounting position of the sensor, α is the azimuth of the point and β is the roll angle of the mounting sensor.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ h \end{bmatrix} + \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix} \times \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} \tag{1}$$

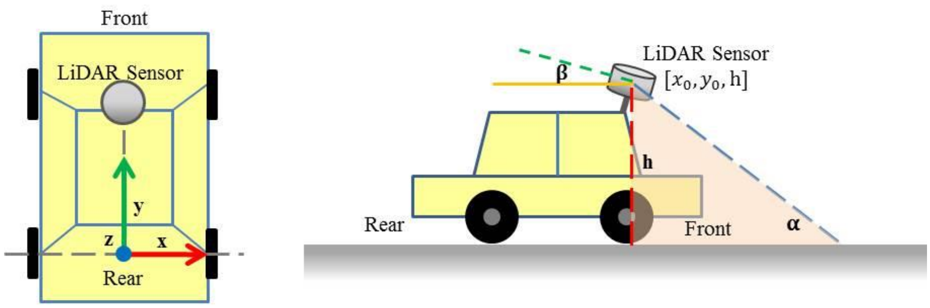

Fig. 2 The center of vehicle coordinate system is at the middle of rear wheel axis (Left). The scheme is the configuration of LiDAR sensor and angles for reference (Right).

2.3 Lane Lines Searching

The usage of the intensity of point clouds is crucial in this method and the range of intensity is 0 to 255 without unit. The material of road paint has high reflectivity therefore the intensity of lane lines is higher than the objects beside it. Based on the property, the lines could be distinguished by the difference of the intensity. **Table 1** shows the intensity of different items based on the samples acquiring in this study. In general, the value of intensity is irregular. However, every kind of materials has a rough range of the intensity.

Table 1. This table shows the distribution of intensity on different items (The values are based on the samples collected in the study).

Item	Intensity of point clouds
Asphalt	1-5
Tree	1-10
Pavement	5-20
Lane line	30-70
Vehicle	20-80

To compare the values of asphalt and lane lines, the difference between both items could reach 25 in minimum and 70 in maximum. Set the threshold of height to limit the searching range near ground and width range of the lane line to identify the lines. Due to the arrangement of point clouds as mentioned in section 2.1, the catching parts of the lane lines are little, thus it is not easy to extract the whole lane lines. Find the middle point of each lane line of one layer according to the little part which extracted by the properties of intensity and width. At least 3 middle points in different layer are found, the coordinate of the middle points would substitute into a curve equation and the linked line is drew as shown in **Fig. 3**.

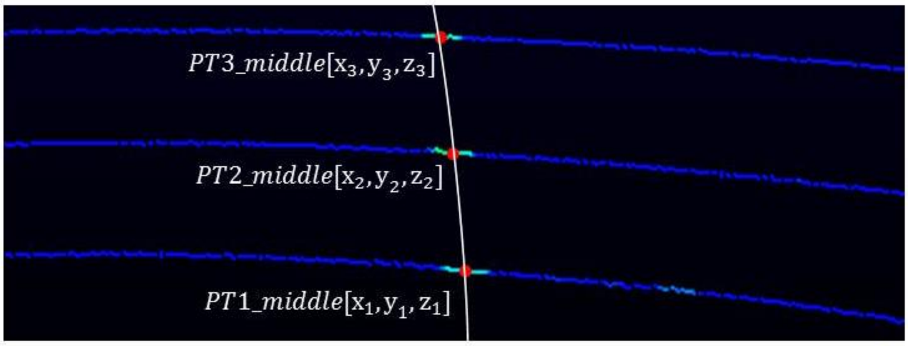

Fig. 3 This figure shows the linked line of the middle points extracted by the lane lines of each layer.

2.4 Road Surface Searching

In order to search the road surface, the property of road geometry displayed by the point clouds is crucial in this section. The main steps are reference slope estimation, scanned line continuity filter, scanned line smoothness filter and road surface recognition, and would be described in the next paragraphs.

Reference slope estimation. For each scanning frame, the area in front of the vehicle is divided into 20 blocks (Each of a blocks is 16 meters × 1 meter). Compare the number of points in the block with threshold N and the slope 30% between the points of two blocks, after that determine to keep the minimum height of points or replace the value by the interpolation of the height in the previous and next block. The options mentioned above are shown in the **Table 2**. Based on the result, a y-z relation curve is estimated and this curve will be considered as the reference slope (**Fig. 4**).

Table 2 This table shows the options regarding to result of the comparison of threshold N and slope 30%.

Result of comparison	Description of determination
Number of points > N	Find the minimum height of the points within the block.
Number of points < N	Find the minimum height with interpolation.
Slope between two blocks < 30%	Mean the points belong to the ground therefore keeping the minimum height of the points within the block.
Slope between two blocks > 30%	Mean the points may belong to some large objects therefore replacing the height with interpolation.

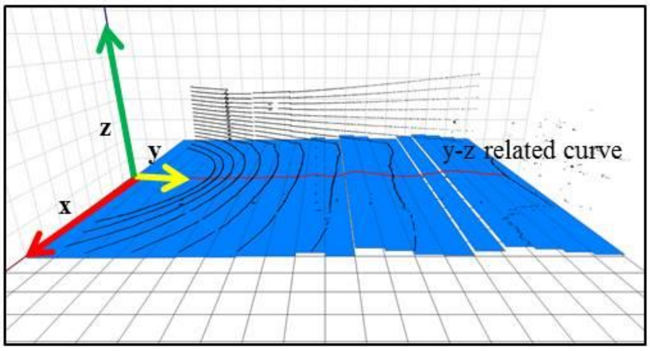

Fig. 4 The figure illustrate the estimated reference slope(y-z related curve), and each of blue area is 16 meters × 1 meter.

Scanned line continuity filter. To observe the continuity of the scanned line is a useful method on road boundary determination. The change of the rapid angle of the scanned line and the break in the scanned line are the basis of the determination. Points on LiDAR system are described in polar coordination P(R, θ, φ) which R means distance, θ means the azimuth and φ means the vertical angle. As the scanning frequency is 10HZ, the angle between two adjacent beams is 0.16 degree. Thus distance R (θ) is considered as regular since the angle is constant. The discontinuity result of distance R (θ) differential on θ is shown as below, and ε_c is the threshold to determine to continuity between the adjacent distance of R_{i-1}, R_i , and R_{i+1}.

$$\frac{R(\theta + \delta) - R(\theta)}{\delta} \xrightarrow[\delta \to 0]{} \infty \tag{2}$$

$$| R_i - R_{i-1} | \geq \varepsilon_c \ \& \ | R_i - R_{i+1} | \geq \varepsilon_c \tag{3}$$

Based on the function above, the scanned line is continuous would be determined by the function below.

$$\text{Max}(| R_i - R_{i-1} | , | R_i - R_{i+1} |) < \varepsilon_c \tag{4}$$

There are some exception appearing after using continuity filter such as the edge between road and pavement. In the next paragraph the smoothness filter will be used to reduce the quantity of exception.

Scanned line smoothness filter. Since the road is smooth in general, the smoothness of the scanned line must be considered. Use the value of distance R (θ) to differentiate double on θ to find the rapid change to decide the smoothness of road surface. S_a and S_b are the slope of ρ_a and ρ_b , the slope means tangent value of the angle. The corner angle ρ_c is the determined angle and could be represented as the formula $\rho_c = \rho_b - \rho_a$, according to the trigonometric function the calculation is written as below.

$$\tan\rho_c = \frac{\tan\rho_b - \tan\rho_a}{1 + \tan\rho_b \cdot \tan\rho_a} = \frac{S_b - S_a}{1 + S_b \cdot S_a} \tag{5}$$

Based on the result of ρ_c and the threshold ε_s, the scanned line is smoothness would be determined by the function below.

$$|\tan\rho_c| = \left|\frac{S_b - S_a}{1 + S_b \cdot S_a}\right| < \varepsilon_s \tag{6}$$

In contrast, the scanned line is uneven would be determined by the function below.

$$|\tan\rho_c| = \left|\frac{S_b - S_a}{1 + S_b \cdot S_a}\right| \geq \varepsilon_s \tag{7}$$

Road surface recognition. The method to identify the road surface is region growing algorithm. This method need to choose a seed point first, and extending from the seed point to the road boundary. According to the arrangement of the scanned line, selecting the center point from the nearest scanned line as seed point is appropriate. The point which chose as the seed point is filtered by the equation (4). However, if the point does not fulfill the condition, the algorithm will find another point from its left and right until found. Searching the road boundary from the seed point, using the continuity and smoothness filter to identify the road surface until reach the edge.

Every layer will form a segment, and every segment contains many properties including length, height, slope…etc. If the segment with too short length, high relative elevation and steep slope will be discarded from the candidate segment sets. The segment will find a new seed point in next layer to form new segment, thus the scan layer would be included in multiple segment. **Fig. 5** shows the result of region growing, red lines mean the connected segments, the green arrow means the searching direction and the green points represent the terminal of discontinuity.

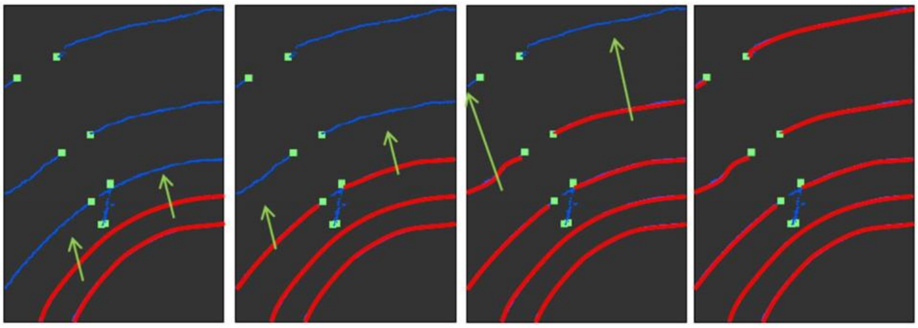

Fig. 5 This figure displays the process of region growing.

2.5 Lane Detection

Depends on the results of lane searching and road surface searching, the lane lines could be predicted and the location of lane could be detected. The relationship between lane lines and road boundary is supposed to be fixed, therefore the range of lane is contained in a curved surface on the basis of the calculation of the central lane line and road boundary. In ideal environment, the direction of a moving vehicle is supposed on y-direction, thus both of the lines are close to y-z curve line. The fitting area is a parabolic surface which approximates to a flat surface.

As mentioned above, when the lane lines disappear at some environment the relationship of lane line and road boundary is used to evaluate the position of the lane line which without road paints. **Fig. 6** shows the relationship between central lane line and road boundary, the yellow area is the road surface which contained by the red boundary lines and central line divides the road into left lane and right lane.

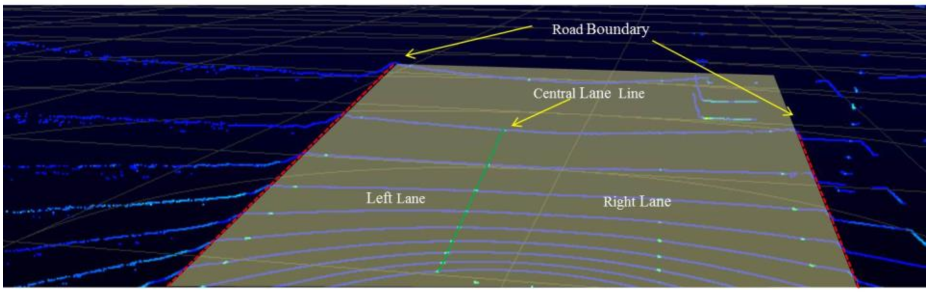

Fig. 6 The figure describes a relationship of the lane line and road boundary.

3 Experiment

The LiDAR sensor is installed in front of the vehicle about 1.73 meters from ground and the angle of pitch is 8 degrees. The experimental field is in Automotive Research & Testing Center and there are many cars parking on the both sides of road. One section of the road is chosen with lane lines and road marks on it. The method runs in real time to test the effect and the result of detection could be show in below.

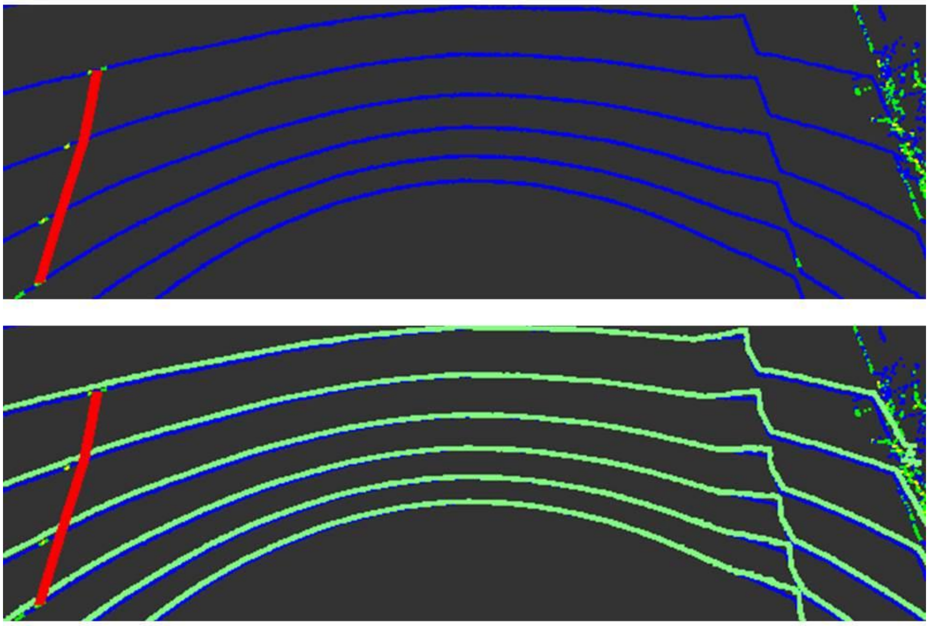

Fig. 7 This figure shows the lane lines and road surface detection of experiment.

Fig. 7 shows the lane line and road surface drawn by the method. The red line in the figure represents the drawn lane line by the intensity of the point clouds, and the different between the above and below part is that the green line is the road surface determine by the continuity and smoothness filter in the below part. As the result, it is easy to detect the lines in the simple scenario, and the position of the lane could be indicated by adding the road surface. In some complicated scenario such as many road paints on the ground would influence the detection, therefore using different scenarios to find the suitable parameters is important.

4 Conclusion

Lane detection is a crucial topic in driving autonomy, and also applied in driving security widely recently. In this study, the method is used by LiDAR sensor rather than camera which common on lane detection. The price of 16 layer LiDAR is cheaper other high resolution LiDAR, however the number of points is less. With sparse distribution of point clouds, whole lane lines are not easy to search. Therefore, the road surface is built to assist lane detection.

According to the feature of road geometry, the slope, continuity and smoothness of the point clouds are considered to be analyzed to define the definite road surface and boundary. Since the road boundary is definite, the relationship between lane lines and boundary is easy to construct. The direction of lane lines is almost identical as the road boundary in ideal environment. Thus the road surface searching by this method could define as the whole lane, and the central lane line could divide the lane into left part and right part.

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