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Road Edge Detection Based On Lidar Laser

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***Abstract* - Research about vehicle recognition and adaptive cruise control is emerging recently, using various sensory resources. There are many sensors like cameras, GPS, accelerometers, radars etc., which are used for detecting edges of the road, traffic signs, cars or pedestrians. There are many different sensors to access the objects' data information. This paper presents defining the width of the road and cars. To accomplish this task the multilayer LIDAR (Light, Detection and Ranging) sensor is used. All data is graphically represented in two-dimensional space. In this paper such methods like k-mean clustering, canny edge detection, Hough method, Theil–Sen estimator are using. The process is conducted in MATLAB environment.**

Keywords* − *drivable road recognition; Theil–Sen estimator; multilayer LiDAR; k-mean clustering; Hough method; canny edge detection.

I. INTRODUCTION

The detection edges of the road and the cars is in great interest of many researchers. Mostly video vision is used to detect edges of the road and track an object. In many projects, the implementation of this tasks two sensors are using - camera and LIDAR sensor as presented in [1]. In [8], [9] shown good idea of object tracking and classification by using a multiple hypothesis approach. The same idea is taken as a basis in this paper, however, other methods are used to obtain the results. Some authors prefer to use the Hough methods or fuzzing method. This approach has been “quite reasonable” but it requires a fairly clear image and additional options, which makes the work difficult so it’s requires many treatments images and different methods for determining the edges of the road. Most experiments use two sensors: LIDAR sensor and camera [1], [5-7]. On the one hand it can improve quality of results but on other hand makes work more time-consuming, memory requirements etc. Another disadvantage is the cost of acquiring the necessary sensors.

Due to above comment in this project only used LIADR radar. It makes this experiment unique, since few of these were conducted experimentation in the field of 2D space road edge detection. LIDARs are similar unattached to different light conditions like FIR cameras.

Using the sensor requires some basic knowledge about laser parameters.

Therefore, the necessary information about the laser and the steps for installation will be discussed in sections *A* and *B* Working with big database it is necessary to reduce noise, more about this is stated in section II. Once the processed database collected, the section III - defining the edges of the road can be considered. The most common method for determining lines is Hough method. Hough method discussed in section *A*. Hough method works well for straight lines, with points that have the same *x*-values or *y*-values.

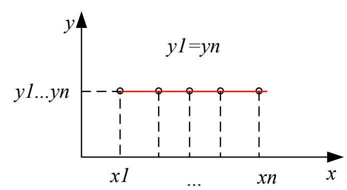


Fig. 1. Perfect representation of a straight line

The database used in this project contains points which are located at different coordinates. Therefore, for the detection of cars it is necessary to use methods that calculate the average distance between them and hold the line. To solve this assignment task Theil–Sen estimator and Least squares methods are used and discussed in sections *A-C*. After the lines and curves were drown through the points of the edges of the road and the point indicating the cars, results should be clustered. Therefor k-means clustering is used (Section IV). Section V presents the results of above mentioned methods.

A. General Familiarity with Laser

The LiDAR sensor was developed for the distance warning system in 1996 and improved for Adaptive Cruise Control functionality in 1997. In this paper we investigate the potential of using laser scanning technology for traffic monitoring and other transportation applications and using ibeo LUX Laserscanner, parameters of which presented below.

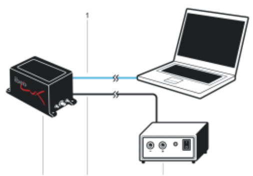
TABLE I. IBEO LUX LASERSCANNER PARAMETERS

Working range horizontal	100°
Detection range	200 m
Scan levels	4 parallel
Vertical opening angle	2.4°
Horizontal angle resolution(main range):	0.125°/0.25°/0.5°
Scan frequency	12.5 Hz/25 Hz/50 Hz

As an active sensor the LIDAR measures distances directly and more precisely than vision based sensors. And so this sensor has all the necessary data for accurate determination of the road and can be used as the only sensor in order to reduce costs.

B. Installation of the Sensor and Receiving Data

To start working with sensor and basic operation requires the following components:



1 Ethernet connection to network or PC **3** Supply line

2 ibeo LUX 2010® **4** Power supply

Fig. 2. Required components

After installing all of the necessary cables like ethernet connection to network or PC, power supply etc., we need to hold the connection to program the equipment to obtain the reading data. The function of the ibeo LUX is based on a process detecting the surroundings of the sensor and/or the objects located within the field of view. This yields the position of the object in the coordinate system. So the principle of multi-layer technology can be demonstrated as follow:

TABLE II. DESCRIPTION OF SYMBOLS

1	ibeo LUX 2010®
2	Scan level
3	Object

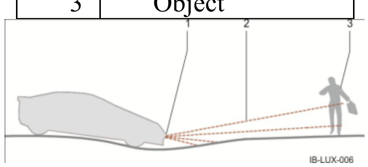
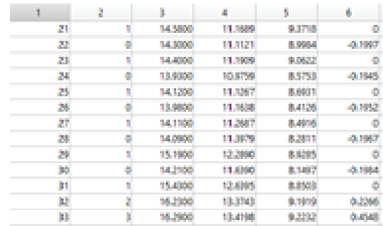


Fig. 3. Principle of multi-layer technology

The transmitted laser pulses are reflected by objects within the measuring range. Then these echo pulses are received and analyzed by the laser. Every detected echo pulse is represented by a scan point with the following main properties:

- Scan point number
- Scan level
- Distance from laser to object
- Points coordinate x, y, z

An example of a received data are presented in Fig.4.



1	2	3	4	5	6
21	1	14.3800	11.1689	9.3718	0
22	0	14.3000	11.1121	8.9984	-0.1997
23	1	14.4000	11.1909	9.0622	0
24	0	13.9300	10.9759	8.5753	-0.1945
25	1	14.1200	11.1267	8.6931	0
26	0	13.9800	11.1638	8.4126	-0.1952
27	1	14.1100	11.2687	8.4916	0
28	0	14.0900	11.3979	8.2811	-0.1967
29	1	15.1900	12.2890	8.8285	0
30	0	14.2100	11.6390	8.1497	-0.1984
31	1	15.4300	12.6395	8.8503	0
32	2	16.2300	13.3743	9.1919	0.2266
33	3	16.2900	13.4198	9.2232	0.4548

Fig. 4. Examples of obtained data

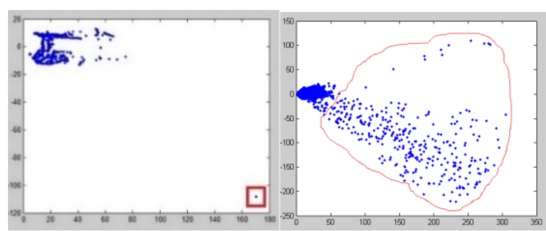
TABLE III. EXPLANATION OF THE NUMBERING IN FIG. 3

1	*Scan point number*
2	Scan level
3	Distance from laser to object
4-6	Points coordinate x, y, z

The amount of points in one cycle is the approximate number which is about 800. Received and processed results are displayed in two-dimensional space.

II. DATA PROCESSING

The goal and one of the main tasks of this project is directly handling the data. Simultaneous processing of data from four layers is a rather time-consuming task and contains a large amount of noise. This is due to the fact that laser has a certain range of emitted beams and it is not possible to read the data outside this range. Noise affects the quality of the result. Example of an error which we got in the project shown on Fig. 5. This kind of error implies the need to limit the area of pattern recognition, see Fig. 6.



(a) (b)

Fig. 5. (a) Results of error in range of <100; (b) Result of error in range of <200

Specified algorithm is described as following diagram:

```
X=zeros(size(B(:,1)),2);
for i=1:size(B(:,1))
    if B(i,3)<50.0
        X(i,1)=B(i,4);
        X(i,2)=B(i,5);
```

Fig.6. Determination of the threshold

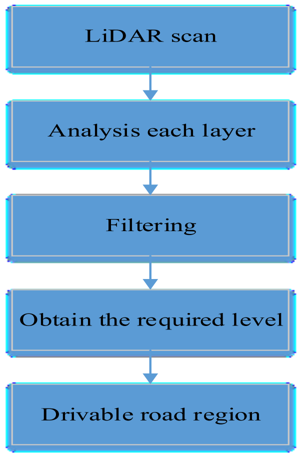


Fig. 7. Algorithm of data processing from LIDAR sensor

III. Objects Edge Detection

The system referred in this paper is designed to drive on the road with a border that gives the chance to define the edge of the road. The most common methods for recognizing edges of the object are Sobel, Prewitt and Laplacian, Hough transform.

The Hough transform method has been chosen because it allows to find plane curves given parametrically on a monochrome image, for example: lines, circles, ellipses, etc. a Monochrome image is defined as an image consisting of dots of two types: background points and points of interest. The Hough method is not always suitable for detecting objects such as cars and pedestrians. So Theil–Sen estimator and the least square method were used. The results of these methods are similar but they work differently. In order to understand which method is more practical and get better results, both methods were used.

A. Hough Method

The task of the Hough transform method is to select a curve formed by points of interest. Basic algorithm shown below.

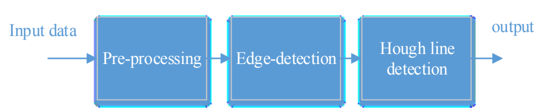


Fig. 8. Edge line detection flow chart

Line in the plane can be set as follows:

$$x\cos\Theta + y\sin\Theta = R \qquad (1)$$

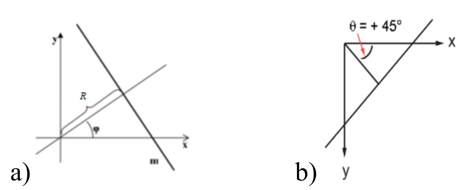


Fig. 9. a) representation of R; b) representation of angle Theta

The variable *R* is the distance from the origin to the line along a vector perpendicular to the line. *Theta* is the angle of the perpendicular projection from the origin to the line measured in degrees clockwise from the positive x-axis (see Fig. 9. b). The range of theta is $-90°\leq\theta<90°$. The angle of the line itself is $\theta+90°$, also measured clockwise with respect to the positive x-axis. So the function that specifies the drench of straight lines, has the form:

$$F(R,\Theta,x,y) = x\cos\Theta + y\sin\Theta - R \qquad (2)$$

Through each point (x, y) of the image you can draw a few lines with different R and θ, and every point (x, y) in the image corresponds to a set of points in phase space (R, θ), forming a sine wave. In turn, each point in space (R, θ) corresponds to the set of points (x, y) in the image forming direct.

Due to the discreteness of the machine representation and input data, we need to convert the phase space in discrete. The HT is a parameter space matrix whose rows and columns correspond to *rho* and *theta* values. The elements in the HT represent storage cells. Initially, the value in each cell is zero. Then, for every non-background point in the image, *rho* is calculated for every *theta*. *R* is rounded off to the nearest allowed row in HT. That storage cell is incremented. At the end of this procedure, a value of *Q* in HT *(r,c)* means that *Q* points in the *xy*-plane lie on the line specified by *theta(c)* and *rho(r)*. Peak values in the SHT represent potential lines in the input image.HT method works with images which makes it necessary to convert graphs (figures) obtained in Matlab area to image format.

B. Theil–Sen Estimator

The method presented above is more often used for images where gaps between lines are much smaller than between points we get with laser. Therefore, to receive a more accurate result, other methods were used in addition.

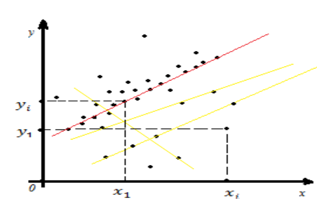


Fig. 10. The principle of the method

The Theil–Sen estimator of a set of two-dimensional points(x_i, y_1) is the median *m* of the slopes $(y_j - y_i)/(x_j - x_i)$ determined by all pairs of sample points. A confidence interval for the slope estimate may be determined as the interval containing the middle 95% of the slopes of lines determined by pairs of points, and may be estimated quickly by sampling pairs of points and determining the 95% interval of the sampled slopes. According to simulations, approximately 600 sample pairs are sufficient to determine an accurate confidence interval

C. The Method of Least Squares

In the project one of the main tasks is the recognition of objects such as cars and people in particular. In two-dimensional space, objects can be associated with the signs like " — " (the position of the object opposite to the laser), " ┘ "(to the left of the laser), " └ " (to the right of the laser). Therefore the least squares method can be used as fitting method.

Consider x as a set of m unknown variables (parameters), $f_i(x), i = 1, \dots, n, n > m$ - the set of functions from this set of variables. The challenge is in selecting such values of x to values of these functions were as close to certain values of y, it is necessary to find a polynomial of n degree:

$$p^n(x) = p_1 x^n + p_2 x^{n-1} + \cdots + p_n x + p_{n+1} \qquad (3)$$

Coefficients of which are the solution of the following problem minimize:

$$p_1, p_2, \dots^{min}, p_{n+1} \sum_{i=1}^{N} (p^n(x_i) - y_i)^2 \qquad (4)$$

So, in other words, the polynomial needed is the one that least deviates from the given data in the sense that the sum of the squares of the distances from two given points (x_i, y_i) till $(x_i, p^n(x_i))$ will be minimal (see Fig.11).

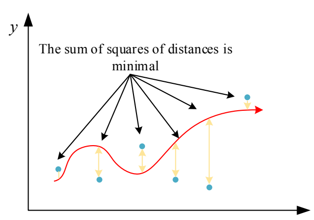


Fig. 11. Example of counting distance between points in LSM

Then the problem of constructing a polynomial approximation is reduced to finding the minimum of the following function:

$$F(p_1, p_2, \dots, p_{n+1}) = \sum_{i=1}^{N} (\sum_{n+1} (p^n(x_i) - y_i)^2)^2 \qquad (5)$$

With variables $p_1, p_2, \dots, p_{n+1}$. The function $F(p_1, p_2, \dots, p_{n+1})$ is a quadratic function (with nonnegative coefficients of the unknown squares).

IV. Clustering Method

To reduce the time and reduce errors in the article will first consider one layer and after achieving a satisfactory result, will apply the same methods to the remaining layers. In this case we will get more accurate and clear results.

From Fig.3 it can be seen that the first two layers scan a quite low level. To work with more precise result, let us consider the third level. As the system starts counting scan points number from 0 we will consider scan level number 2 from Fig.4. An example of selected elements is shown in Fig.12.

1	2	3	4	5	6
32	2	16.2300	13.3743	9.1919	0.2266
36	2	16.5900	13.8328	9.1557	0.2316
40	2	16.9500	14.2941	9.1063	0.2367
44	2	16.5800	14.1354	8.6622	0.2315
45	2	20.5500	17.5200	10.7363	0.2869
49	2	16.3900	14.1207	8.3177	0.2288
50	2	20.3100	17.4980	10.3071	0.2836
54	2	20.1300	17.4751	9.9879	0.2811
59	2	20.0100	17.4569	9.7764	0.2794
64	2	19.8900	17.4364	9.5659	0.2777
68	2	19.7700	17.4135	9.3566	0.2760
72	2	19.7300	17.4591	9.1857	0.2755
76	2	19.6000	17.4230	8.9735	0.2737
80	2	19.8900	17.7596	8.9516	0.2777

Fig. 12. An example of third scan level

The next step after sorting the points we need, is considering the clustering method. This paper has applied the k-means clustering method. The effect of this algorithm is that it tries to minimize the total quadratic deviation of cluster points from the centers of these clusters:

$$V = \sum_{i=1}^{k} \sum_{x_j \in S_i} (x_j - \mu_i)^2 \qquad (6)$$

Where is k- number of clusters, S_i- the obtained clusters, $i=1,2,\dots,k$ and μ_i - the centers of vector's mass $x_j \in S_i$

The best way to understand how the method works is explaining by example. Let's take 3 points:

TABLE IV. Example of Used Points

A	(61.0, 100.0)
B	(64.0, 150.0)
C	(70.0, 140.0)

To choose which of these points is the centroid (cluster's center) we need to calculate the mathematical average of the data. The point which is the closest to average is centroid.

V = ((61.0 + 64.0 + 70.0) / 3, (100.0 + 150.0 + 140.0) /3) = (195.0 / 3, 390.0 / 3)= (65.0, 130.0) (7)

There are various ways of calculating the closest point. One of them is to use the Euclidean distance. The Euclidean distance between A and the average V is:

$$dist(V, A) = \sqrt{(65.0 - 61.0)2 + (130.0 - 100.0)2} = 30.27 \qquad (8)$$

The same must be done with the rest of the data. Then we will have the result:

$$dist(V, B) = 20.02 \qquad (9)$$

$$dist(V, C) = 11.18 \qquad (10)$$

The smallest of the three distances is the distance between the math average and tuple C, so C - centroid. The basic idea is that each iteration recalculates the center of mass for each cluster obtained in the previous step, then the vectors are divided into clusters again, in accordance to which new center is closest on the selected metric. Graphically, this method can be represented as follows:

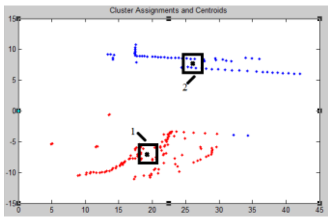


Fig. 13. The result of K-mean clustering

Where is 1 and 2 – centroid of cluster.

Fig.13 shows the result of clustering. In this case, it is sufficient to base processing only on two clusters (k=2).

When cars will be associated with the signs like "_", "┘", "└" this method can be applied for clustering objects, marking pedestrians, machines and side of the road in different colors.

V. Experimental Results

In this section, we present the experimental evaluation of the proposed road detection and recognition algorithms. The results are presented independently in three sections. Hough Line transform object detection is represented in section *A*. Theil–Sen estimator and ordinary least squares are represented in section *B*. Section *C* shows the result of least squares method with a specified error and a polynomial of different degrees.

The main advantage of the work is choice of simple and common methods. It can increase productivity and this means that this project can be used in real time with minimal errors, while other experimenters use labour-intensive methods and they require more time or equipment with powerful options.

A. Object detection with Hough Line detection

Experiments are conducted on a road in Beijing University of Technology, China. The two-lane road has cars parked on both sides which makes detecting the curves more difficult. But the presented results prove the efficiency of the chosen methods and give the ability to conduct research in places where the curves will be visible.

When working with Hough method, it is necessary to remember that it works with images, where the lines have a smaller gap. But there are bigger gaps between the points we collected during the experiment, which means that the method might not work properly. For this it is better to mark the data with squares.

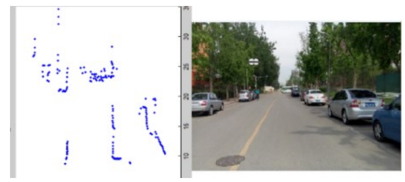
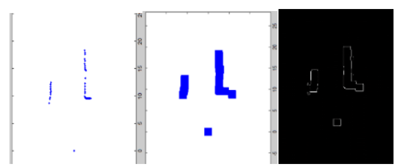


Fig. 14. Original data received from laser

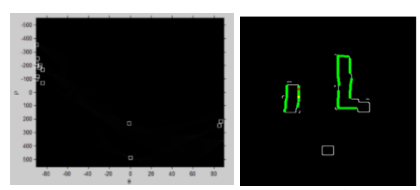
To reduce noise, our data can be restricted to the working range of the laser beam (range to target with 10%- remission 50 m) as we can see from Fig.15.(b). The application read in the color frame. It transforms color images into gray images for every frame as shown in Fig.15.(c).



(a) (b) (c)

Fig. 15. (a) Restricted data relative to the working range of the laser beam; (b) marking data as squares; (c) The definition of boundaries.

As mentioned above, each line has a corresponding point in the phase space. It allows to search for peaks in the Hough transformation matrix H (see Fig.16 (a)). The efficiency of this method is shown in Fig.16 (b). If necessary, another parameters can also be used. Our case can be set to a specific number of peaks of the matrix and the *max_len (*maximum line length) that gives the opportunity to get remove unnecessary data and errors.



(a) (b)

Fig. 16. (a) Peaks in the phase space; (b) Result of Hough line detection.

B. Theil–Sen Estimator and Ordinary Least Squares

The Theil–Sen estimator is an unbiased estimator of the true slope in simple linear regression. For many distributions of the response error, this estimator has high asymptotic efficiency relative to least-squares estimation. Estimators with low efficiency require more independent observations to attain the same sample variance of efficient unbiased estimators. The Theil–Sen estimator is more robust than the least-squares estimator because it is much less sensitive to outliers: It has a breakdown point of $1-\frac{1}{\sqrt{2}}\approx 29.3\%$ meaning that it can tolerate arbitrary corruption up to 29.3% of the input data-points without degradation of its accuracy.

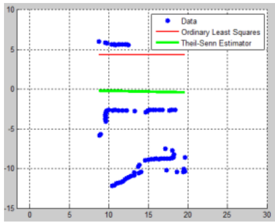


Fig. 17. Result of OLS and Thail-Sen Estimator

Fig.17 presents the results of the two methods: Ordinary Least Squares method (red marking) and Theil-Senn Estimator (green marking). Our goal is to draw lines through the points in order to define the road edge and edge machines, respectively. From the graph it can be seen that the result is not satisfactory. Line obtained by using these methods located far from the object of interest. However, least squares method the closest to the object so this method will be modified and used in the future.

C. Least Squares Method

In the ordinary method of least squares approximation to our point does not meet the requirements. As we can see from the Fig.17, the approximation of LSM is quite far from our data. The reason for this is high sensitivity to outliers (*i.e.,* extreme observations$\{y_i, x_i\}$). This is a consequence of using *squares:* squaring exaggerates the magnitude of differences and therefore gives a much stronger importance to extreme observations. In order to improve our result, the method was modified by adding errors $10^3$and approximation of data by a polynomial of n-th degree (n=16).

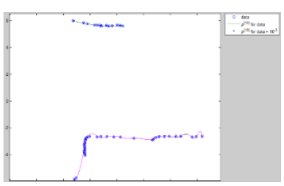


Fig. 18. LSM with errors $10^3$and approximation of data by a polynomial of n-th degree

The result satisfied our requirements. This method works with a sufficiently accurate approximation. Method does not require time, memory requirements and further action the same thing cannot be said about multiple hypothesis systems in [8].

VI. Conclusions

From the results above we can conclude that this project requires a lot of work and multiple methods should be used in order to obtain the best result. Data obtained from the laser corresponds to the real time but requires data processing.

Result of Hough line detection shows that method works well. However, the disadvantage of this method is that the result contains the gaps between the lines, what prevents to display the entire line of edges of the road.

Since our database contains a large number of points and all of them have different coordinates in a 2D plane, it was decided to use the method of Least Squares and Theil–Sen estimator method for detecting cars. These methods are good because of interference-resistant and it can processing a large amount of points. However, the result showed that even the ordinary least squares method gives better result than Theil–Sen estimator. Therefore, the ordinary least squares method was modified by adding error. The result was satisfactory.

Experimentally k-means clustering method has been tried and it is proved to be working. This method is used to distinguish objects which have been detected by the Hough method and least squares method. However, the ultimate goal was not achieved, it requires much more computation.

In General, the results of the work completed successfully with minor errors which will be modified in the future.

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