Lane Recognition System for Guiding of Autonomous Vehicle

Akihiro Suzuki, Nobuhiko Yasui, Nobuyuki Nakano, Mamoru Kaneko
Matsushita Electric Industrial Co., Ltd., Automotive Products Development Center
3-15, Yagumo-Nakamachi, Moriguchi, Osaka 570 Japan
Phone (81)6-906-4889, Fax (81)6-906-6874, E-mail suzuki@apdc.mei.co.jp

Abstract

A lane recognition system has been developed with a transputer network. This system includes two algorithms for the lane recognition and for the vehicle location recognition in relation to the lane. Hough transform was used to fit the extracted numerical white line data to a straight line for the lane boundary. The location of the vehicle was identified in relation to the lane which is expressed as a triangle that consists of two white lines being recognized and the lower side of the image frame.

1. System configuration

The major component of the system is a network of four transputers (T801-25) as shown in figure 1. The CCD video camera takes the image data into the superimposed board in the PC and also into the frame memory installed into the transputer TP-A. TP-A processes the road image data first to set the threshold for the extraction of the outline of the white lines and then the outline is actually extracted. Next, the numerical white line data is sent to the two transputers TP-L and TP-R through a data line that is called "LINK". There Hough transform is used to fit the numerical white line data to a straight line as a form of an equation. The two transputers TP-L and TP-R operate independently, and TP-L is for the left white line and TP-R is for the right. The recognized two straight lines are then sent, via LINK, to transputer TP-DG where the lane is recognized by using the two white lines. All the data are then sent back to TP-A from TP-DG via LINK. These data are sent, through RS232C serial interface, to the PC where the numerical data are changed into an image that is then superimposed onto the original video image. This offers the driver visual information about the lane and the location of the car in relation to the lane.

2. Road image data

The road image data is stored as gray scale image data in the field memory of 373 pixels x 238 pixels x 8 bits brightness signal. The angle of view of the CCD video camera is set to place the vanishing point at four fifths of the height of the image frame. This enables minimizing the background image in the frame. Figure 2 shows an example of the road image data being stored in the field memory and then being analyzed.

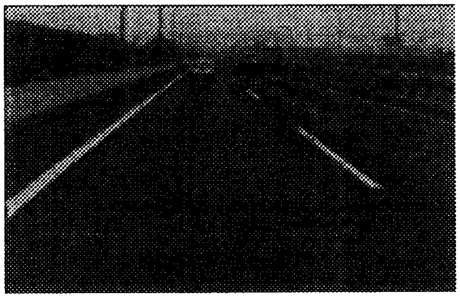


Fig.2 The road image data

3. Algorithms

The software of the system mainly consists of a series of argorithms for the lane recognition and the vehicle location recognition. The argorithm for the lane recognition includes processes for the threshold setting, the white line extraction,

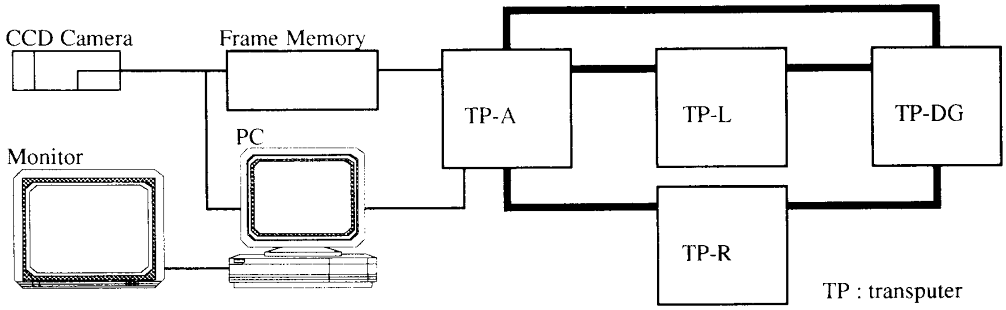


Fig.1 Schematic diagram of system

the lane recognition and the prediction of the lane boundary when the lane recognition fails. They are as follows.

3.1. Threshold setting

First the nine scanning lines, with a limited length, are chosen for each side, left or right, as shown in figure 3, and the maximum value of the brightness signal along each scanning line is detected

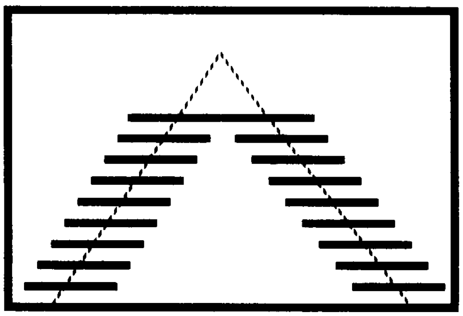
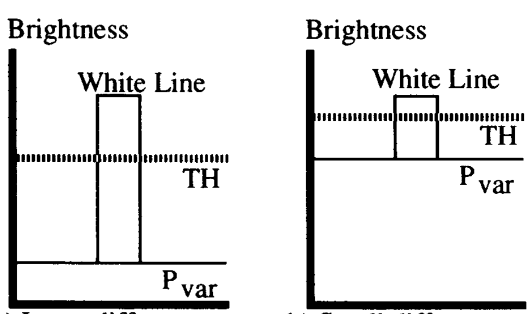


Fig.3 Limited sampling lines for the maximum brightness

The length of each scanning line is 80 pixels long and the center of each line corresponds to the location of the recognized lane for the previous image data. Next, the average value of those nine maximumvalues are calculated for each side and they are called Pl_{var} for the left and Pr_{var} for the right, respectively.Finally the threshold value is calculated as a weighted average of Pl_{var} or Pr_{var}, and the average brightness P_{var} over the limited scanning lines. They can be as in equation (1) or (2).

$$THl = 0.75Pl_{var} + 0.25P_{var} \quad (1)$$
$$THr = 0.75Pr_{var} + 0.25P_{var} \quad (2)$$

This enables evaluation of the brightness of the white line relative to the average brightness of the road surface as shown in figure 4.



a) Large difference b) Small difference

Fig.4 Relation between brightness signal and threshold

3.2. Extraction of outline of white line

The outline of the white line is determined by using the threshold value. First a parallelogram shape area, 80 pixels wide and its height corresponding to the 150 scanning lines across, is cut for each side as being illustrated in figure 5.

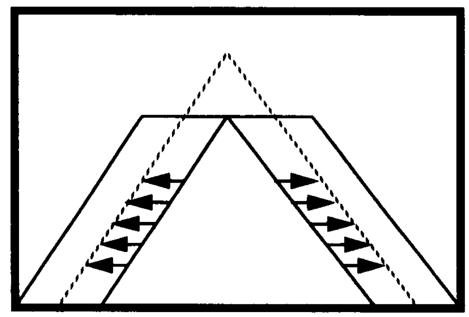


Fig.5 Extraction of outline of white line

The center of the width corresponds to the recognized white line in the previous image frame. The brightness data is then compared to the threshold value along each scanning line from the inner end to the outer end as shown in figure 5. This is continued along each scanning line until the first pixel that is brighter than the threshold is found or the compared pixel reachs the outer end of the limited scanning line, and then moves to the next scanning line. Finally the outline of the white line is obtained as the location of 150 pixels for each side, 300 altogether at most.

3.3. Straight line fitting

The numerical white line data is fit to a straight line by using Hough transform. Hough transform is a projection of a point in x-y plane into a curve in $\rho - \theta$ plane as being written in equation (3).

$$\rho = x \cdot \cos\theta + y \cdot \sin\theta \quad (3)$$

The characteristic of transform is that any of the points on the same straight line in x-y plane are projected into the curves in $\rho - \theta$ plane which cross each other at the same point; the unique point. This point represents the straight line in x-y plane and this nature is used to recognize the white line in x-y plane. Here the distribution of crossing points are obtained instead of a unique point as the recognized numerical white line data are not exactly on a straight line. And thus the most dense point was chosen as the unique point. Then the straight line in x-y plane can be determined. However, it is usually time consuming, and also the noises cause problems. These problems are successful solved when the calculated area in $\rho - \theta$ plane is restricted to minimum as following. First the origin of the coordinate system in the road image was set at

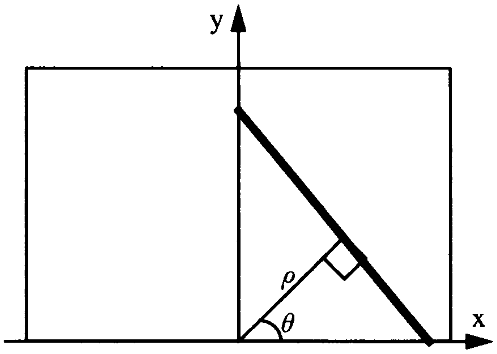


Fig.6 x-y coordinate system

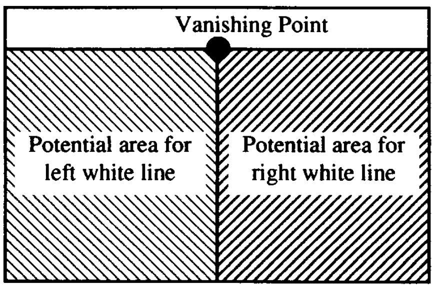


Fig.7 Potential area for white line

the center of the lower side of the image with the x axis along and the y axis across the lower side as shown in figure 6. It is easily understood that the white line on the left always exists in the left half of the image frame as shown in figure 7. So the θ domain for the left line can be limited to [90, 180] and [0, 90] for the right. The area was reduced further to a small rectangular area whose center is the previous unique point being found as shown in figure 8.

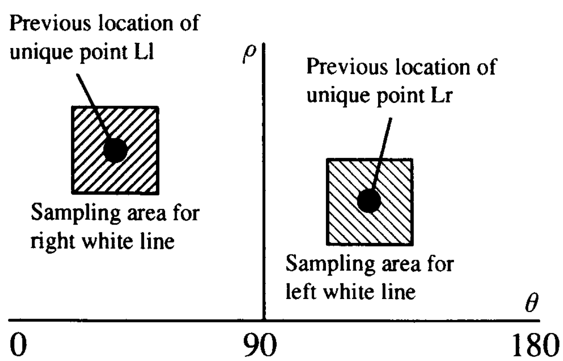


Fig.8 Reduced sampling area in ρ - θ plane

Hough transform is applied only to this small area and the new unique point is found very quickly. This was possible as the sampling rate was high enough to keep the change of the location of the unique point in the limited rectangular area.

This algorithm was effective to reduce the time significantly and also to avoid the interference of the data between the two lines on both side. The time was reduced futher when the increment of the θ was set to 3 degree.

3.4. Lane recognition

The lane was recognized as a triangle surrounded by the two white lines and the lower side of the frame. Set the unique point Ll(ρ l, θ l) for the left and Lr(ρ r, θ r) for the right and then the three apexes of the triangle can be determined by the following equations. This is also illustrated in figure 9.

Pl(xl, 0) $\quad xl = \rho l/\cos\theta l$ (4)

Pr(xr, 0) $\quad xr = \rho r/\cos\theta r$ (5)

Pv(xv, yv)

$$xv = \frac{\rho r \cdot \sin\theta l - \rho l \cdot \cos\theta r}{\sin\theta l \cdot \cos\theta r - \cos\theta l \cdot \sin\theta r} \tag{6}$$

$$yv = \frac{\rho l \cdot \cos\theta r - \rho r \cdot \cos\theta l}{\sin\theta l \cdot \cos\theta r - \cos\theta l \cdot \sin\theta r} \tag{7}$$

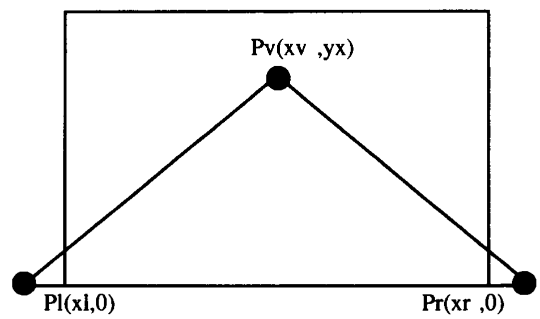


Fig.9 Recognized lane as a triangle

Finally the lane was recognized from the road image data and this was expressed as a triangle in the x-y plane in the image frame.

3.5. Location of vehicle

The new system can recognize not only the lane but also the location of the vehicle in relation to the lane. The relation between the coordinate system for the image data and that for the three dimensional "real world" is illustrated in figure 10. This can be written as a equation (8).

$$x = \frac{FX}{Z \cdot \cos\theta - Y \cdot \sin\theta} \tag{8}$$

Assuming that the angle between the camera lens axis and the road plane is constant and also that the camera is always at

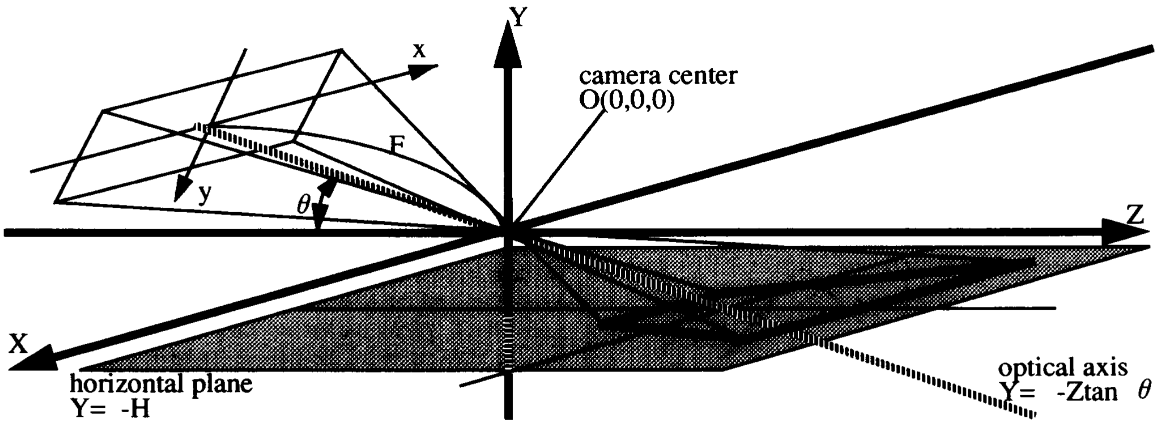


Fig.10 Three dimensional coordinate system for real world

the same height, the term Y · sin θ in equation (8) becomes constant. Taking the lower side of the image frame as a reference line and assuming that the distance between this reference line and the vehicle is constant, the term Z · cos θ also becomes constant. Considering that the focus distance of the camera lens F is also constant, ther is a linear relation between the x coordinate in the image plane and that for X in the three dimensional real world. This is written as the following equation (9) and also illustrated in figure 10.

$$x = C \cdot X \qquad \text{where C is constant} \tag{9}$$

That is the x coordinate of the two apexes Pl and Pr of the triangle on the lower side of the image shows the location of the lane relative to the vehicle, and the x coordinate of the midpoint Pc of these two apexes can be used as a parameter to represent the location of the vehicle. The principle is also illustrated in figures 11 a) and b). When the vehicle is in the center of the lane as shown in figure a), the x coordinate for Pc is on the center of the image frame. The point Pc moves to the left when the vehicle is off the center to the right as shown in figure 11 b). There are linear relation between the distance in the image and the actual distance as shown in figure 12. Then the location of the vehicle Vp can be written as the following equation (10),

$$Vp = -1.4x \tag{10}$$

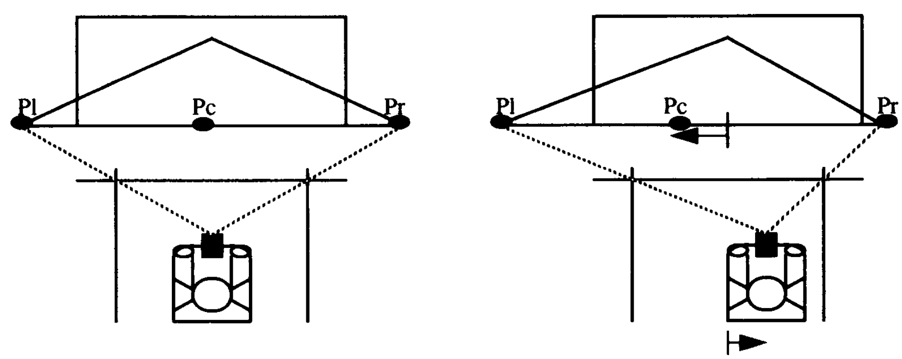
where x is the distance between the parameter Pc and the center of the image frame.

3.6. Prediction of the lane

It becomes difficult to recognize the white lines when the white lines are not clear or they are broken lines. However it is still possible to predict the location of the white line if at least either of the two lines is recognized. The principle is that the width and the height of the triangle are constant for the same lane. Thus coordinates for the other two apexes can be calculated if at least one apex is known. This assures stable lane recognition even under difficult conditions.

4. Experimental results

A CCD video camera was installed in a one box car that ran



a) Vehicle is in the center b) Vehicle is off the center to the right

Fig.11 Schematic diagram to show location of vehicle

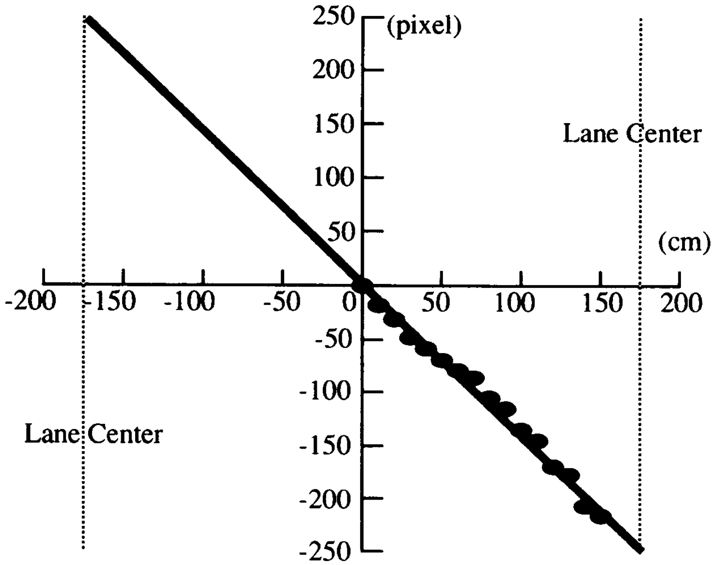
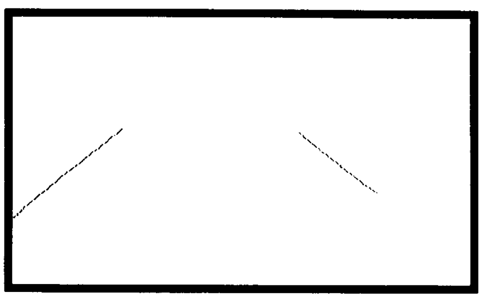


Fig.12 Linear relation of distance between two dimensional image frame and three dimensional real world

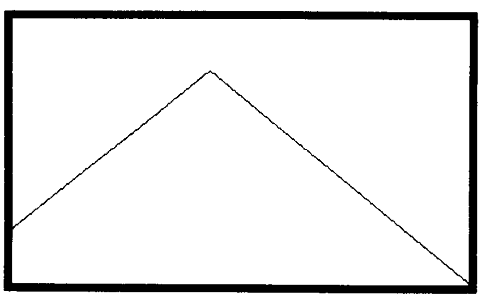
Condition	%
Daytime Fine/Cloudy	97
Daytime Rainy	76
Twilight Fine	26
Night Fine/Cloudy	98
Night Rainy	12

Table1 Accuracy of lane recognition

on a highway. An example of the road image is shown in figure 1. The outline of white line extraction and the straight line fitting to the white lines were performed and their results are shown in figure 13 a) and b), respectively.



a) Numerical data for outline of white line



b) Straight lines fitted to numerical white line data

Fig.13 Results for lane recognition

The white line being recognized by the system agreed well with the original image. To quantify the accuracy of the results, the recognition was judged to be correct when the difference between the actual and the recognized white line is less than the distance of five pixels. The straight line being fitted to the white line was used to represent the location of the white line. The experiments have been carried out under various weather conditions at different times of day. For example, the combination of fine, cloudy or rainy weather conditions and different times, in the daytime, in the twilight or at night, were chosen. The results of the accuracy of the recognition are summarized in table 1 for these conditions. The accuracy was as high as 97 to 98 % when the road was dry, except in the twilight. The major reason for reduction of accuracy in the twilight was that the road reflected the sunlight well, when it was shone at a shallow angle, and the reflected light came directly into the video camera. This made it difficult to recognize the white line. The same trouble occurred when the road was wet where the light was also reflected well. And it was even worse in the night when the road was lit by the headlights. Currently the study is concentrated on these difficult conditions that reduce the accuracy, and it is planned to improve the algorithm further.

The results for the location of the car in the lane were also evaluated as shown in figure 14. There were two lanes on each side and the car was on the left lane in the experiment. The car was first on the left one of the two lanes, then it changed to the second lane and back to the left one again for a taking over process. The coordinate of figure 14 shows the progress of time. The lane was changed twice in 13 seconds and this showed the taking over condition well. It was noted that the recognition of the location failed for several frames

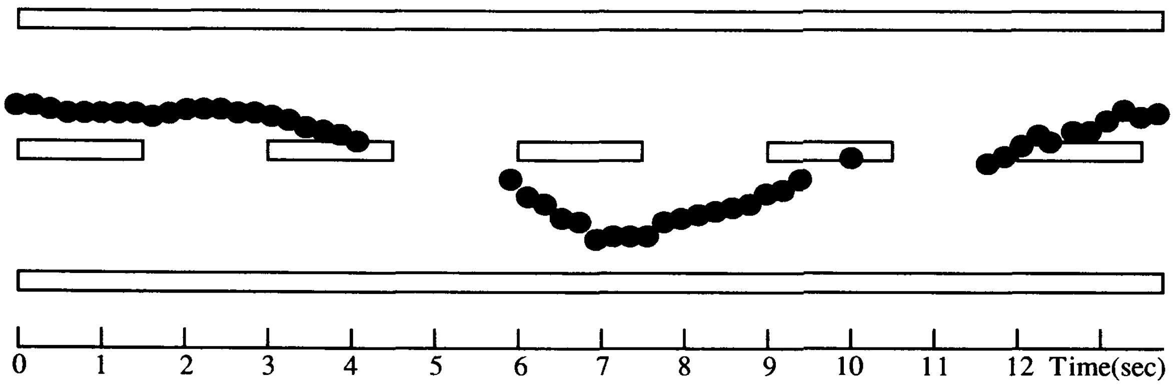


Fig.14 Results for recognition of vehicle location against lane

when the car crossed the white line. This occurred because the system could not identify the lane in which belong.

5. Summary

A lane recognition system, using a transputer network, has been developed, and two aigorithms for the recognition of the lane and the location of the vehicle have also been developed. The sampling area was limited to a minimum to improve the speed and the accuracy. Currently it is possible to process one set of image data within 100 ms and the results showing the accuracy have been presented. Stable results were obtained when the algorithm to fit the recognized numerical white line data to a straight line was introduced. This was found to be effective, especially when the white line was broken or was not clear. The algorithm for the recognition of the location of the vehicle in the two dimensional image data was developed. Then the location of the vehicle in the three dimensional world was easily calculated from its location in the two dimensional image data, as there is a linear relation between them. The next aim of the study will be to improve the accuracy of the system under difficult conditions and then it will be possible to extend the system further.

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