

Abstract

In this paper we propose a new lane detection method for expressway lane departure warning. The use of the extended Hough transform and a bird's-eye view image effectively improve the robustness and resolution of lane detection. Hardware cost is reduced by using a rear-view camera from an existing system and by implementing the system on an embedded CPU.

Keywords

Computer vision, Rear view camera, Lane detection, Bird's-eye view image, Extended Hough transform

1. Introduction

Intelligent Transport Systems (ITS) are being developed in many different countries with the aim of improving road traffic efficiency and safety. Many systems have been proposed and some onboard driving assistance and warning systems have already been commercialized. Sensing the surroundings of the vehicle is the key technology for such systems. Machine vision technology, especially, is expected to detect surrounding objects with high space resolution as well as lane markings painted on the road surface.

The lane detection function must be able to estimate lane curvatures and the vehicle's relative position in a lane based on the lane markings in road images captured by an onboard cameras. The information acquired by the lane detection function can be used for lane departure warning systems, steering assistance systems, and adaptive cruise control systems.

Conventional lane detection is not widely used because a forward-facing camera must be mounted in the proximity of the inside rear view mirror and an exclusive processor is required for the system.

In this paper, a new lane detection method for a lane departure warning system is proposed. This system has a wide spread, assuming that the system is used on a major expressway in either cloudy or sunny conditions, when the lane marking detection performance is good.

2. Problems with lane detection

The main problems facing the in-vehicle application using lane detection are as follows.

(1) Robustness against noise

Expressways in Japan use a standardized lane width and lane marking. Regular lane markings consist of white or yellow solid lines or broken lines on both sides of the lane. Essentially, lane detection involves the detection of high-intensity continuous lines in the road image. It is important to be able to distinguish the lane markings from the noise that results from the vehicle's environment and road conditions. There are two situations in which lane detection becomes difficult. The first is when the lane markings are faint as a result of dirt, wear, or low light. The second is when there is noise that is similar to the lane markings, such as that caused by complicated markings, branch lines, or shadows.

(2) High resolution

Japanese expressways use a complicated system of lane markings that consist of parallel lines of blocks either on both sides of the road, so sandwiching the lane markings, or one side only. These conform to a standard and are intended to provide a warning to drivers (**Fig. 1**). These complicated lane markings are formed of two or three lines and extend for continuous distances of several hundred meters to several kilometers. To differentiate these individual lines requires a certain degree of resolution. Given the standard minimum gap between the lines, a resolution of five centimeters or better is needed.

(3) Hardware cost

A basic problem with conventional systems is that the exclusive forward camera increases the cost of the hardware.

Secondly, improving both the resolution and robustness require a greater calculation capacity. In particular, an exclusive realtime processor is needed for lane detection, which again increases hardware cost in conventional systems.

3. Improving robustness and realtime processing

3.1 Conventional method

Dickmanns¹⁾ proposed a realtime lane detection method that tracks lane markings in road images and focuses the image processing on small regions around the lane markings. But it is difficult for this method to distinguish noisy features such as the shadows of leafy trees. Thus, a system should be capable of searching for total lane patterns within an image to cope with such difficult circumstances.

An effective approach involves generating a so-



Fig. 1 Complicated lane markings.

called bird's-eye view image that is used to optimize the matching pattern and processing cost of lane detection. A bird's-eye view image is a back projection of the road image that assumes that the road plane is flat and the camera's height and angle are known. The bird's-eye view image is that that would be seen if the viewpoint had been moved above the target (**Fig. 2** b).

Broggi²⁾ was able to optimize the parallel image processing and lane marking detection based on a bird's-eye view (or a "top view", as he referred to it).It is difficult to achieve better resolution with this method because it uses dilation and contraction of the image to reduce noise and increase robustness. Pomerleau³⁾ proposed a high-speed lane detection method that reduced the total number of pattern matchings by using trial-and-error template matching on a low-resolution bird's-eye view image. But this method presents problems when applied to real-time processing with an increased image resolution because the required number of templates also increases. It is unfortunate that the low resolutions of these methods cannot deal with complicated lane markings.

The authors are proposing a new lane detection method that is based on a high-speed pattern matching technique, namely, the extended Hough





b) Bird's-eye view image



c) Detected lane



transform.⁴⁾ Exclusive hardware needed to realize this method was developed to enable the system to match every possible "curved" line within an entire image in real time. This method could not, however, be put to practical use because the exclusive hardware required tens of megabytes of memory, which made the system expensive.

3.2 Proposed method

3. 2. 1 Use of a rear view camera

The authors' scheme involves using the camera from an existing system to reduce the hardware cost. Specifically, the new lane detection system uses the same rear-view camera as that used in the parking assistance systems⁵⁾ that are becoming increasingly popular in Japan. The camera is mounted at the rear of the vehicle, immediately above the license plate, at a downward-facing angle of around 45° . Thus, the camera captures an image from the horizon to a point immediately below the camera. The camera is a super wide-angle camera with a 130° horizontal viewing angle (Fig. 2 a).

The rear view camera can detect lane markings that are about 5 to 10 meters from the rear of the vehicle. Given that the majority of expressways in Japan have a radius of curvature in excess of 300 meters, any lane markings in this region can be regarded as being straight lines.

Additionally, a super wide-angle camera offers the advantage of being able to distinguish lane markings from surrounding objects (vehicles, guardrails, etc.) because the lane markings immediately under the camera can be detected clearly and accurately. This advantage contributes to the robustness of the lane detection.

3. 2. 2 Speeding up straight-line detection

The lane markings are detected by searching for straight lines in the bird's-eye view image, because lane markings close to the vehicle can be regarded as being straight lines. The Hough transform⁶⁾ is a well known and orthodox technique for detecting straight lines. Although a major merit of the Hough transform is that it is highly robust against noise and data shortfalls, it also incurs a high calculation cost because it calculates all the straight lines passing through the feature points. Additionally, assuming a four-centimetre resolution with a 10×5 meter

bird's-view image, a total of around 20,000 straight lines must be matched. This makes real-time processing difficult.

With the proposed method, the calculation cost is reduced by applying the extended Hough transform. The relationships of the straight lines that correspond to feature points are calculated and memorized as a voting list in advance and then, as part of the processing, the Hough transform is carried out by referring to the voting list (**Fig. 3**).

Alternatively, the conventional Hough transform can be speeded up by referring to a Hough transform calculation table that has been prepared offline. The main feature of the proposed method is that it votes to finite templates (as "straight line" in this paper) generated from a digitized parameter space. A voting list memorizes the voting weights that depend on the distance between a feature point and the corresponding templates in an image. Voting is processed by referring to this list. So, the proposed method reduces the quantization error that is incurred by the conventional Hough transform.

A remaining problem is the amount of memory that the extended Hough transform requires for the voting list. The total amount of memory must be limited to several kilobytes to enable the use of an embedded CPU. The memory requirement is reduced by applying the following technique that is based on the geometrical characteristics of the lane markings.

As the relative angle between lane markings and a vehicle is usually limited when driving on an expressway, the angle of the lane markings as projected onto the bird's-eye view is limited to about 1/8. Therefore the size of the voting list can also be reduced to about 1/8.

Next, a straight-line pattern can be expressed with Eq. (1) on a bird's-eye view (**Fig. 4**).

 $x = p + (q/d)y \cdots (1)$ where

- d : distance of the bird's-eye view image,
- *p* : *x*-intercept of a straight line,
- q: point at which a straight line crosses the line y = d.

By adopting the parameter space spanned by parameters p and q of Eq. (1), the voting list for pixels of the same row can be shared because of the repetition of similar patterns in the image. The details are as follows. When an image pixel axis (x_i, y_i) corresponds to regions in the digitized parameter space $(p_0, q_0), \dots, (p_k, q_k)$, the horizontally distant image pixel axis $(x_i + x_d, y_i)$ corresponds to regions $(p_0 + x_d, q_0), \dots, (p_k + x_d, q_k)$. Therefore, a total voting list can be acquired by adding an operation to only one column of the voting list.

As a result, the amount of memory required for the voting list can be reduced to about 1/1000. This speed-up and reduction in the memory requirement allow the extended Hough transform to be realized as software in an embedded CPU.

3.2.3 Proposed method

Figure 5 shows the flow of the proposed method.

Image input

The image obtained from the rear view camera is digitized and stored in image memory (Fig. 2 a).

Distortion correction

Because the rear view camera has a super wideangle lens, the input image has a barrel-shaped distortion. The image is therefore subjected to a distortion correction transform to remove the distortion.



Fig. 3 Process of the extended Hough transform.



Fig. 4 Bird's-eye view image.

Bird's-eye view image transform

To simplify the process, a bird's-eye view transformation is performed on the image. In fact, the distortion correction transform and the bird's-eye view transform are processed at the same time using a single conversion table (Fig. 2 b).

Lane marking point extraction

An edge point that is a candidate for a lane marking is extracted from the image by horizontal differentiation. Pairs of upper and lower edges for the lane marking are selected. If the intervals are within a range that is equivalent to the width of the lane marking, the object becomes a lane marking candidate point (also called a "lane marking point") (**Fig. 6**).

Straight-line detection

Straight lines in the image are detected by the extended Hough transform.

As stated in our previous paper,⁷⁾ reliable lane boundaries have to be selected from among neighbouring straight lines in a complicated lane marking scene. Generally, the width and layout of the complicated lane markings are painted based on established standards. These standards can be applied to determining the lane boundaries reliably.

Lane marking candidate selection

All pairs of straight lines are obtained and the lane parameters (offset, width, yaw angle, pitch angle) are calculated. The pair whose parameters and voting result are equivalent to those for expressway driving is extracted as a lane marking candidate. If



Fig. 5 Flow of proposed method.

there are no candidate pairs, one straight line is detected as a lane marking candidate assuming that a pitch angle is continuous.

$$e = \frac{1}{2} (p_R + p_L) \cos \theta$$

$$w = (p_R - p_L) \cos \theta$$

$$\theta = \tan^{-1} \frac{1}{2d} \left[(q_R + q_L) - \frac{(q_R - q_L)(p_R + p_L)}{(p_R - p_L)} \right]$$

$$\Delta \phi = \tan^{-1} \frac{h}{d} \left[\frac{(q_R - q_L)}{(p_R - p_L)} \right]$$

where,

e : offset of the center of the lane from the camera [m], *w* : lane width [m],

 θ : yaw angle [rad],

 $\Delta \phi$: pitch angle relative to the standard angle [rad], h: camera height [m],

d : distance of bird's-eye view image [m],

 $p_{R,L}$: x-intercepts of right-and-left straight line [m],

 $q_{R, L}$: points at which right-and-left straight line crosses the line y = d [m].

Parameter estimation

Each lane parameter of the lane marking candidate is filtered using a Kalman filter. The value that compensates for the processing delay becomes the final lane marking position (Fig. 2 c).

4. Experiment

The proposed method was built into an embedded CPU (Hitachi SH2E) as software. Then, processing of the extended Hough transform could be done in less than 66 milliseconds. Moreover, only 3 kilobytes of memory was required for the voting list.



Fig. 6 Lane marking point extraction.

The ROM of the embedded CPU provided adequate space to store the voting list.

5. Conclusion

This paper has proposed a new lane detection system that uses an inexpensive system configuration based on the rear view camera of a parking assistance system. The bird's-eye view transform and the extended Hough transform provide robustness and improved resolution.

It is hoped that the knowledge acquired from this research will lead to the future development of actual driver assistance systems.

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(Report received on May 15, 2003)



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