ACTION-BASED ROAD HORIZONTAL SHAPE RECOGNITION

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Abstract This paper presents a new action-based shape model concept for road horizontal shape recognition using monocular color image obtained by vehicle-mounted camera. It classifies the road horizontal shape into straight, curve, curve-in and curve-out four models in order to obtain the simple road shape description relating to the vehicle control actions directly. Contrary to other road shape recognition methods, this approach is simpler, faster and directly relating to vehicle control actions, by taking the driving experiences of human being and the highway construction rules into account. Experiments on synthetic images and real outdoor road scenes show the effectiveness of this approach.

Keywords: action-based shape model, static image processing, autonomous vehicle, image analysis, visual navigation

1 INTRODUCTION

For safe and efficient driving, research on autonomous driving and driver supporting system have attracted more and more attention worldwide in recent years. Especially with the deployment of some national projects like PROMETHUS in Europe, IVHS in America, and ARTS, ASV in Japan (NAHSC, 1995; Komoda N., 1995) , significant developments have been made in improving the vehicle's intelligence and the performance of autonomous driving systems.

As the basic and core part of these systems, vision-based navigation part is always designed to undertake following main tasks. 1) To detect and trace road lanes in a wide and near viewing area for keeping no deviation from the road. 2) To extract the 3-D road shape from both horizontal and vertical mapping in a tele-viewing area for the control of vehicle's speed and direction. 3) To detect obstacles and other moving objects on the road. In this paper, we confine ourselves to focus on the recognition of road horizontal shape using static road scene images in order to obtain the simple road shape description relating to the vehicle control actions directly.

To handle the speed and direction of a moving vehicle with the upcoming road scene, a forward looking long focus camera is always employed to detect the road shape in a range of 20m to 100m (further if higher speed needed). According to this road shape recognition problem, as the basic static image processing, many systems and algorithms have been proposed in last 10 years. A recursive 3-D road shape recognition method has been developed in [3], using a high-speed road construction curvature model called clothoid model in both horizontal and vertical shape. Kluge and Lakshmanan (1995) introduce the prior likelihood function to match the road shape curves in the image plane, and show its robustness in noise and poor contrast environment. The straight road following problem can be found in Liou and Jain (1987) and in Thrope *et alii* (1988) , which is solved via vanishing point on the projection image. Nohsoh and Ozawa's system (Nohsoh and Ozawa, 1993) presented a two independent polynomials road shape model for detection of both horizontal and vertical curvature of road, depending on the result of at least three white lines' recognition result.

However, there are still two main problems remained. Firstly, previous methods are used under the very limited road conditions (e.g., some of these methods can only be used on clearly marked highway or expressway), and have to pay the heavy computational cost to obtain the accurate road shape parameters. Secondly, these previous methods seem to pay more attention to the geometric representation of road shape than the autonomous driving action controls, which is the true purpose of road shape recognition instead.

To settle the above problems, this paper proposes a new action-based shape model concept which classifies road horizontal shape into straight, curve, curve-in and curve-out four models in consideration of human being's driving experiences, sight distance and section of speed down. These four simple shape models cover most cases of road shape, and corresponds directly to human being's driving action controls like slowing down, turning left (right), or just holding on. In contrast with the geometric shape representation of other methods, this concept adjust the recognition result using human driving experience, and need not compute the detail complex shape parameters. Therefore, it leads to obtain more accurate and simple human-liked shape recognition result. This approach also includes a previous processing which combines lane marks and road region boundary information, in adaptation for both marked and unmarked roads.

2 ROAD HORIZONTAL SHAPE MODEL

The road considered in this paper is confined to the ordinary roads paved with asphalt or concrete surface, and designed mainly for automobiles. To make the problem simple, we assume that the road is flat and without forking or crossing parts and the boundary lines of road region are parallel to the centerline of road.

According to design and construction rules of highway, the shape of road is always classified into horizontal shape which indicates road's curvature and direction under a bird-eye view, and vertical shape which represents gradient relations on vertical cross section along the road center line (AASHTO, 1995) . Since the road is assumed to be flat in this paper, the road shape called here will only consider the horizontal shape. In general, the high-speed road layouts are defined in curvature terms by the civil engineers to guide vehicles driving safely (Dickmanns and Mysliwetz, 1992). Because the road curvature is limited to changing slowly for vehicles' steering control, we can divide the road shape into connected straight segments and circular curve pieces, which can be recognized much easily than normal curves and related to the driving actions directly. Detail description about this model is given as follows.

Let us consider a driving scene as shown in Fig.1, a driver is driving through the road consisting of straight segment AB, circular curve BC and straight segment again CD. According to his comprehensive judgment using road's curvature, vehicle's speed, his driving experiences, road pavement conditions, the weather and other factors, his usual actions will be: 1) From somewhere in AB (labeled as P), he starts to slow down to enter the curve; 2) He starts to turn right near B, and holds on with that angle; 3) Near the exit of curve (labeled as Q), he starts to accelerate; 4) On point C, he restores the wheel, and holds on. Obviously, if we use the usual geometric-based road models, we can not link the road shape recognition result with these actions directly.

In contrast, we propose here an action-based shape model concept, which classifies the road shape into straight, curve, curve-in and curve-out 4 classes, and directly correspond to driving action controls. As shown in Fig.2, within the sphere of driver's sight distance on horizontal plane, the straight model consists of parallel straight lines, the curve model consists of concentric circle arcs, and the curve-in or curve-out model combines concentric circle arcs and their tangent parallel straight lines. For that example shown in Fig.1, on each point from P to B, the forward road shape within the driver's sight distance consists of straight segments and curves, and therefore is belonging to the curve-in model. In the same way, the shapes from B to Q correspond to the curve model, and the shapes from Q to C correspond to the curve-out model, the straight model can represent other segments.

Because of the correspondence to human being's driving experiences and driving action control judgments, this new shape model concept is available to obtain more human-liked road shape recognition results. And for the real steering control case, this concept may also be used for the generation of fuzzy control signals.

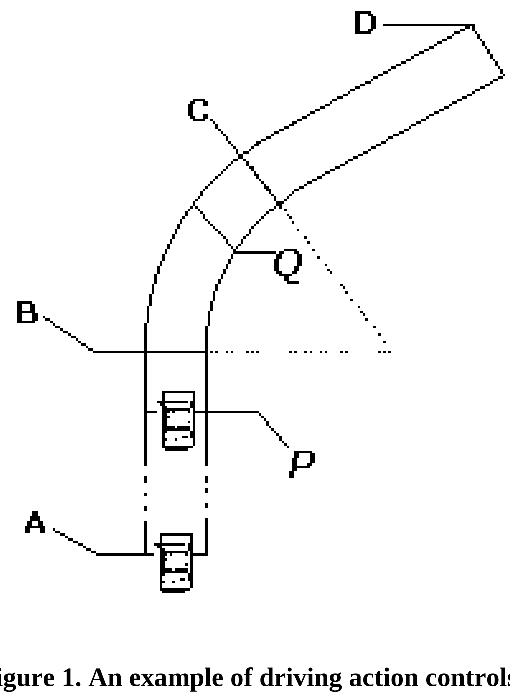


Figure 1. An example of driving action controls

3 EXTRACTION OF GENERAL ROAD SHAPE INFORMATION

One problem of the previous road shape recognition methods is that these methods are over-depended upon the extraction result of road white lane marks. For this reason, they are generally used only on clearly marked highway or expressway and unavailable to the roads without lane marks or the lane marks are not so distinct because of the tires' rubbing off, or covered by water or mud.

For this study, a previous image processing is performed to obtain the shape information not only from lane mark but also from road boundary, and therefore it is robust to most cases of road like unmarked countryside roads, partly marked urban streets or clearly marked highways. The inputted original color image will be firstly segmented by color gradient method, and then some of the interest regions like road surface, lane marks, shadows on road will be recognized based on a correlated knowledge database. Because of the limited space, only layout of these processing steps is outlined in Fig.3. More details can be found in our earlier paper (Uchimura and Hu , 1998) .

The original image, region segmentation and recognition results are shown in Fig.4, Fig.5 and Fig.6 respectively.

4 ROAD SHAPE RECOGNITION USING THE ACTION-BASED SHAPE MODEL

To obtain more accurate and human-liked road shape recognition result, the inverse perspective mapping is implemented by recovering the shape information obtained from both lane mark and road region boundary into a bird-eye view plane. Then the road horizontal shape will be recognized based on a pattern matching technique which relies on the transformed points. A fast Hough transform is introduced here to reduce the computation cost.

A. Perspective Relationship between 2 Coordinate Systems

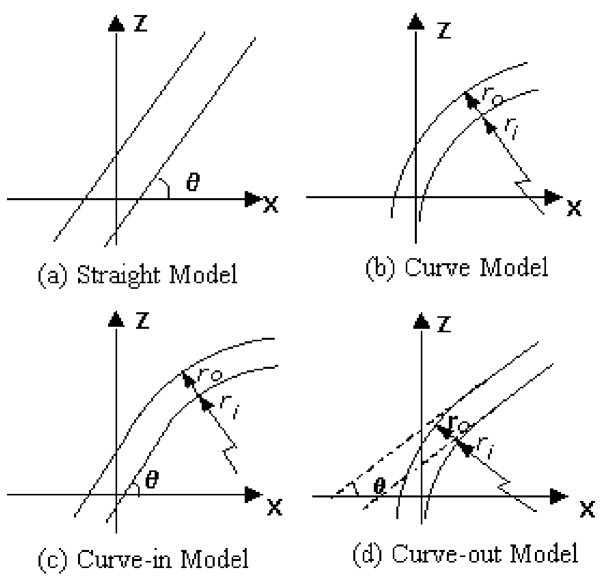


Figure 2. Action-based road shape models

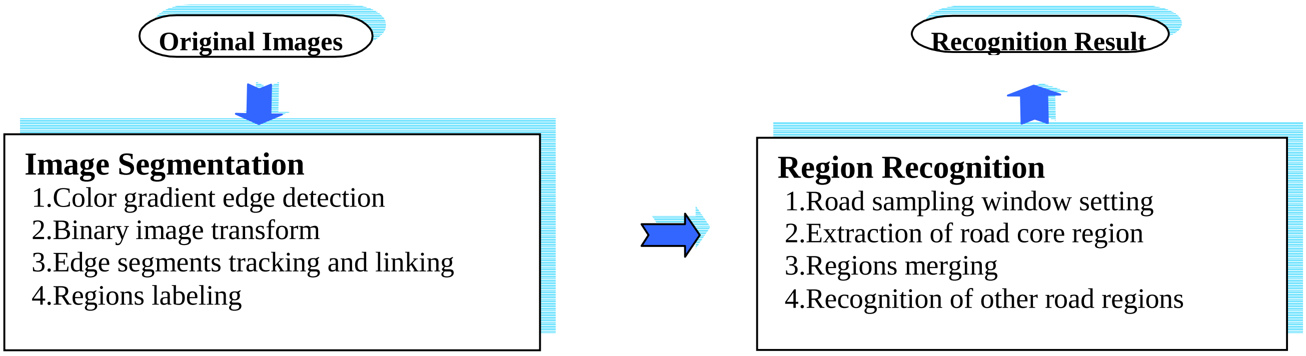


Figure 3. Flowchart of previous image processing steps

Figure 4. Original image

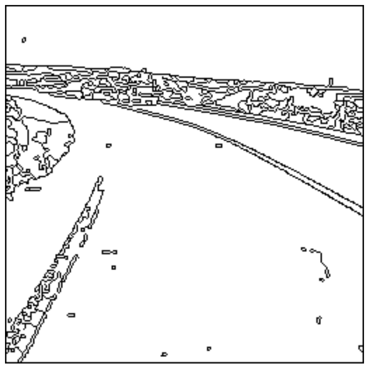


Figure 5. Region segmentation

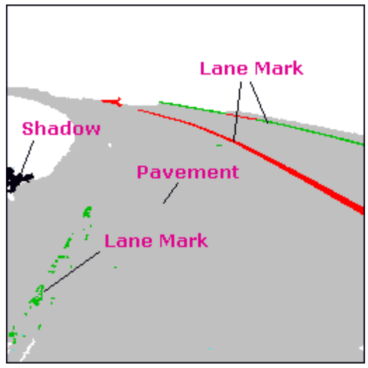


Figure 6. Region recognition

In the following analysis, it is assumed that the camera is mounted on an ordinary vehicle, which is driving on normal roads. Suppose the vehicle coordinate system (VCS) X_n-Y_n-Z_n and the projection image coordinate system (ICS) x_n- y_n are fixed with respect to the camera as shown in Fig.1. Assume the center point of camera's lens is at the origin of the VCS, and the *Z*-axis is the orientation axis of the vehicle. The perspective relationship of VCS and the image coordinate system (ICS) is shown at Fig.7. The perspective point p' of a static point *P(X, Y, Z)* in VCS can be transformed by the well-known perspective transformation as follows:

$$x = \frac{fX}{Z\cos\theta - Y\sin\theta} \quad \text{and} \quad y = \frac{f(Y\cos\theta + Z\sin\theta)}{Z\cos\theta - Y\sin\theta} \qquad (1)$$

where f is camera's focus and θ is the pitch angle of the mounted camera. There is a built-in assumption that all these state parameters of the camera are known and the road surface is plain.

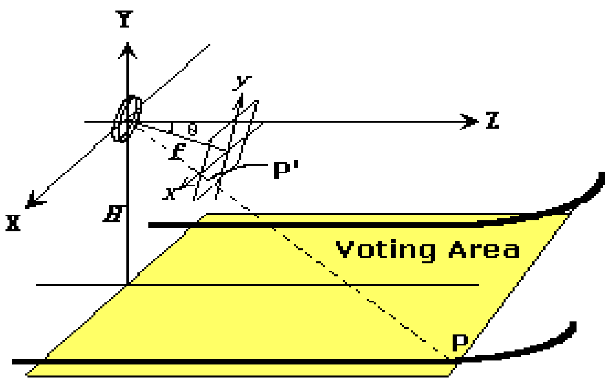


Figure 7. Relationship between VCS and ICS

B. Inverse Perspective Transform from Image to 3-D Space

A bird-eye view of road shape is obtained by the inverse perspective transform of image data to real 3-D space coordinates using the perspective relationship between two coordinate systems. If the elevation of the camera is known, the points on the road surface can be calculated by:

$$X_n = Y_n \cdot \frac{x_n}{y_n\cos\theta - f\sin\theta}$$
$$Z_n = Y_n \cdot \frac{f\cos\theta + y_n\sin\theta}{y_n\cos\theta - f\sin\theta} \qquad (2)$$

where Y_n= -*H* indicates camera's elevation above the road surface, (x_n, y_n) is the image coordinate in ICS, and (X_n,Y_n,Z_n) is the 3-D coordinate in VCS.

The road surface points used here include the points on the boundary of road region, and the points on the skeleton lines of road lane mark regions. Figure 8 shows the boundary lines of road region and the skeleton lines of road lane marks.

C. Hough Transform and Road Shape Recognition

As shown in Fig.7, the direction of Z-axis on X-Z plane is the vehicle's moving direction, and the origin is at the vehicle's

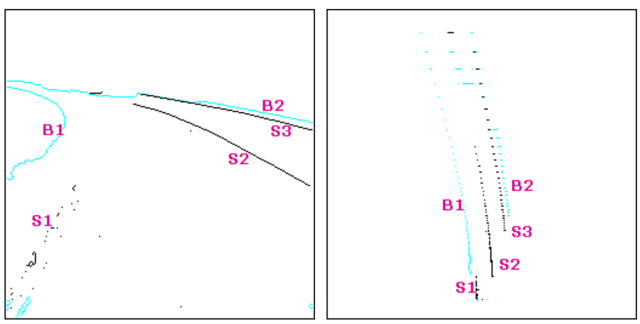


Figure 8. Boundary lines and skeleton lines

present location. Since straight lines and circular arcs can describe the road shape, to which our analysis has been confined up to now, the Hough transform is introduced to extract parallel straight lines and concentric circular arcs from the inverse transformed points. The voting area is a $\sigma \times \sigma$ square, where σ is considered to be equal to driver's sight distance. Each point inverse transformed on X-Z plane can be treated as the vote point (VP). Because skeleton points of lane marks carry more accurate road shape information comparing to the boundary points of the road region which include much noise, the voting value of skeleton points is larger than the one of boundary points, not the same as that in normal Hough transform. Also, for the fact that perspective projection makes spatial location estimation more sensitive to the more distant points, we change the voting value of each VP as a location-vary function, the nearer the higher.

The straight line Hough Transform is firstly carried out to extract of parallel straight lines on X-Z plane. Because the road lane-marks and the boundary lines are generally parallel and interposed certain distances between each other, we extract the set of parallel straight lines with maximum vote value and suitable interval between each neighbor lines as the candidate straight road shape lines.

As the evaluation value of estimation error of straight line Hough transform, the cover rate of whole vote points λ_{all} and the cover rate of nearby vote points λ_{nearby} are employed, and also used to classify the road shape into four shape models explained above. Here the cover rate is the ratio (expressed as a percentage) of the number of points on the candidate shape lines to the number of whole points, and the nearby vote points refer to the points within a certain distance from origin point (vehicle's present location). The evaluation expression is shown below:

If $\lambda_{all} \geq \lambda_a$ then *straight model;*
Else if $\lambda_{all} < \lambda_b$ then *curve model;*
Else if $\lambda_a > \lambda_{all} \geq \lambda_b$ *and* $\lambda_{nearby} \geq \lambda_c$ then *curve-in model;*
Else if $\lambda_a > \lambda_{all} \geq \lambda_b$ *and* $\lambda_{nearby} < \lambda_c$ then *curve-out model;*
End

Where $\lambda_a, \lambda_b, \lambda_c$ are the threshold values determined by preliminary experiment results. This expression shows the same classification principle with human's driving experience.

When the straight candidate lines can not be extracted, λ_{all} and λ_{nearby} are set to 0 and classify the road shape into the curve model.

To obtain the detail shape model parameters (radius, center coordinates of concentric circular arcs, and vehicle's deviation angle, etc.), the specially designed high-speed probability Hough transform for circular arc is performed to whole vote points, nearby vote points or other vote points depending on the recognition result of curve, curve-out or curve-in model.

In case of curve-in and curve-out model, another constraint can be used because the straight parts have the tangent relationship with the curve part in real road construction.

$$r \approx \left| x\cos\theta + y\sin\theta - \rho_i \right| \tag{3}$$

Where r is circle's radius, x, y are center point's coordinates, and ρ_i, θ are Hough transform parameters of the extracted parallel straight lines.

D. Vehicle's Deviation Angle

In general, the vehicle's deviation angle between Z-axis (vehicle's moving direction) and road centerline's direction is a very important parameter in dynamic lane keeping control. In case of straight or curve-in mode, the road centerline's direction is equal to the extracted parallel straight line's direction. Thus the vehicle's deviation angle ω is:

$$\omega = \theta - 90^o \tag{4}$$

Where θ is the parameter of the straight line Hough transform.

And in case of curve or curve-out mode, the road centerline's direction is equal to the direction of extracted circular curve's tangent line at the original point. Thus ω is:

$$\omega = 90^o - \tan^{-1}\frac{|y - \sigma/2|}{|x - \sigma|} \tag{5}$$

Where x, y are center point's coordinates, and σ is the width of voting area.

5 EXPERIMENTS AND DISCUSSION

Experiments on both synthetic images and real road scene images are carried out to show the effectiveness of the new shape model concept and the recognition approach.

A. Experiments on Synthetic Images

To evaluate error rates of the proposed shape models and to compare the classification of road shape with human being's judgments, we hypothesized a simulation test course with 1.3km total distance. The synthetic images on this test course are used in our experiments.

As shown in Fig.9, this hypothesized test course has three straight segments *ab*, *cd* and *ef* with the length of 300m, 200m and 200m respectively, and also has two circular curve segments *bc* and *de* with the radius of 150m and 80m.

Figure 10(a) shows an example of the synthetic image of shape line seen from point A (see Fig.9), and Figure 10(b) shows the recognition result by the proposed method. As shown in the figure, the road forward on point A is a right curve-out road, the cover rate for reverse projection points is 94.4%, the radius is 159.7m which obtains 6.5% error rates to real curve radius 150m, and vehicle's deviation angle is -2.5^o. By adding this action-based road shape model, the recognition result does not only represent the geometric shape, but also indicate the driving state that the vehicle should be taken (for this case, the vehicle should be accelerated for the leaving of a curve). Another advantage of this shape model is the less computation cost, which is much lower than the previous methods with complicated geometric equation shape models.

The accuracy rate of road model classification with human being's judgments as standards and average cover rates are shown in Table 1.

According to Table 1, the proposed approach obtains the accuracy rate of more than 93.7% and the cover rate of 92.4% on average, and it shows the accuracy and similarity to human being's judgment of this road shape recognition method.

B. Experiments on Real Road Scene Images

There are various kinds of road in our real world, highway, urban street, clearly marked road, unmarked road, etc. And pavement materials, shadow on road, light reflection, and even the weather or time zone will greatly influence the features of road region. In this paper, we have the following experimental conditions: 1) the outdoor weather is fine or cloudy; 2) in the daytime; 3) pavement roads using concrete or asphalt. And we choose the scene images on highway, urban street and alleyway with various circumstances like shadows, lane marks and road paintings. Some examples are shown in Fig.11(a) - Fig. 13(a), which have 256x256 pixels size, and each pixel is digitized to 256 levels in RGB color component.

Parameters of camera are: focus distance f =50mm, lens center's elevation H=1300mm, and pitch angle θ = -5^o - 5.6^o.

Table 1. Results of synthetic images

Shape Model	Accuracy Rate(%)	Cover Rate(%)
Straight	125/130	98.1
Curve	95/101	85.4
Curve-in	18/21	92.6
Curve-out	16/19	95.4
Average(%)	93.7	92.4

Table 2. Expression parameters in this paper

Expression(3)	λ_a	71%
	λ_b	20%
	λ_c	75%
Expression(6)	σ	120m

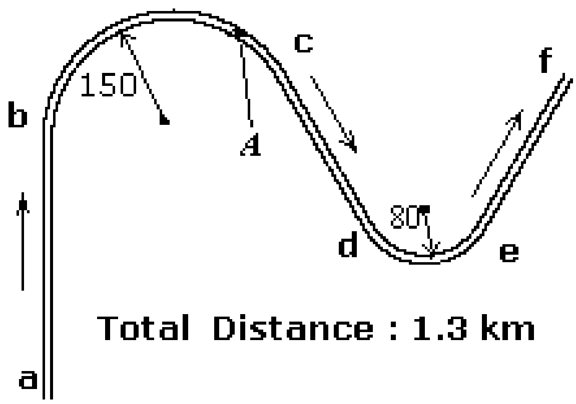
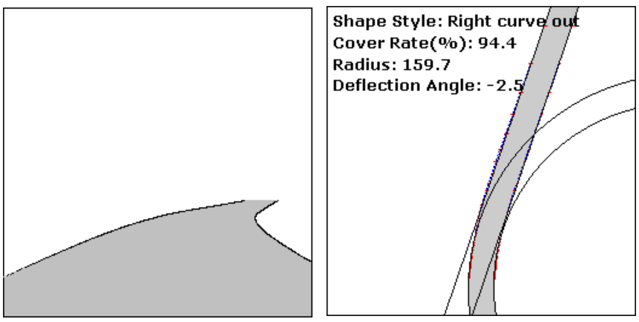


Figure 9. A hypothesized test course



(a) (b)

Figure 10. Synthesized image and processing result

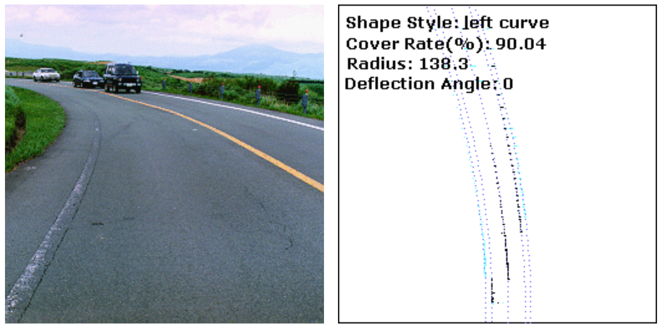
Other parameters used in this paper are described in Table 2.

Figure 11(b) - Fig. 13(b) have shown the shape recognition results of these example road images.

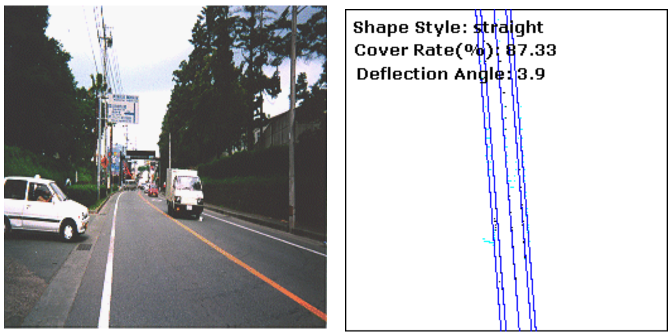
As shown in Fig.11(a), even the left lane mark is almost invisible because of vehicle tires' wear and tear, which means we can not use the lane-mark for the recognition of road shape, but the road shape can still be recognized accurately as the result of combination of both lane marks and road regions (see Fig.11(b), it was recognized as left curve road, extracted curve model covers about 90% of whole shape lines, radius of road center curve is 138.3m, and the deviation angle is 0, which means the vehicle is driving in an accurate steering angle).

An urban street, which contains complicated background scene and without regular road area boundary, can also be given a good recognition result (see Fig.12, it was recognized as the straight road, extracted shape model covers 87.33% of whole shape lines and the deviation angle to the road center line's direction is 3.9^o).

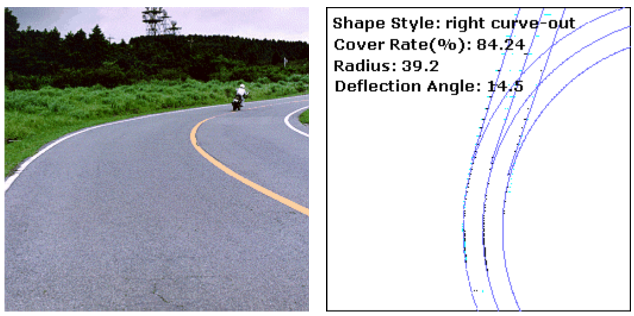
On the case of sharp curve road as shown in Fig.13(a), it is recognized as the right curve-in road, straight lines cover 84.24% of the whole shape lines, and curve radius is 39.2m, the deviation angle to the road center-line is 14.5^o. The shape model and shape parameters have represented the road shape



(a) Original image (b) Recognition result
Figure 11. Test road (countryside road)



(a) Original image (b) Recognition result
Figure 12. Test road (urban street)



(a) Original image (b) Recognition result
Figure 13. Test road (highway)

accurately, and are similar to the human being's judgment.

According to these results, it can be shown that, 1) the proposed action-based shape model concept is available to real road scenes and leading to obtain more human-liked road shape recognition. 2) The shapes of unmarked road or partially marked road can also be recognized correctly. 3) Vehicle's deviation angle and other shape parameters, which are very useful for dynamic lane keeping, can be obtained accurately.

6 CONCLUSIONS

The new action-based road shape model concept and the model-based shape based on this concept are presented in this paper. The main advantages of this approach are: 1) the new shape model concept represent the road shape in driver's view using four kind of shape models that make it easy to link the shape recognition results directly to driving action control, 2) contrary to other road shape recognition methods, we obtain the recognition results with more accuracy and more similarity to human being's judgment, 3) we use shape information from both lane mark and road region's boundary, thus it is available to most kinds of road and various experiment conditions. Experiments on synthetic images and real road scenes show the effectiveness of our approach.

Because of the weakness of vision sensor itself and the complexity of road environment, our method is still weak to bad weather like fog, heavy rain or snow, and can not deal with the low illumination, low contrast cases like in the dusk or at night. For unpaved roads, such as forest paths or roads on the farmland, although it can be recognized theoretically by our method, the noise is too high to obtain a stable shape result in real experiments. These problems will be discussed in our future works.

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