Efficient Ground Truth Generation based on Spatio-temporal Properties for Lane Prediction Model

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Abstract: Automobile safety has developed rapidly to prevent traffic accidents. Because of these techniques, traffic accidents are decreasing year by year. There are however more than 4,000 fatal traffic accident cases per year in Japan. Many lane detection systems are investigated. Those systems should be evaluated precisely and ground truth is generally used for evaluations. Ground truth generation is however very hard and time-consuming work. In this paper, an efficient ground truth generation method for reducing manual operations is proposed. Firstly, time slice images are obtained from an in-vehicle video. Secondly, meanderings of the vehicle against a lane are corrected by minimizing sum of squared differences of adjacent rows in the nearest time slice image. Then, lane markers in all time slice images are extracted by propagating lane marker information from the bottom time slice image to the upper one. Ground Truth is generated with contour information of the lane markers offline. Offline ground truth generation methods are often used for constructing the lane prediction model.

1 INTRODUCTION

The mobility industry is spreading around the world in emerging countries as well as in developed countries. Traffic accidents are also in downward tendency by developing automotive safety technologies and tightening of traffic regulations. Traffic accidents, however, occur as often as ever. Fatal traffic accidents during rainfall become 1.67 times as many as those during non-rainfall, because visibility worsens at rainy days. Recently, headlights of cars are brighter than ever with white and wide lights. It is easy to recognize lane markers at night of fine weather because visibility is good. On the other hand, reflection occurs on lane markers at rainy night because oncoming vehicles give off bright lights. Lane marker denotes a center or outside line of a roadway, and lane represents a road which vehicles are cruising between lane markers. A primary factor of the high mortality in traffic accidents is the lane departure accidents. The lane departure accidents on the road cause serious situation, against pedestrian, head-on collision and fall accident. Lane keeping assist system (TOYOTA MOTOR) prevents lane departure accidents. The system detects a lane and alerts a driver with a buzzer, alert lamp and a small counter-steering force when the vehicle faces to deviate from the lane. The alert, however, does not work well sometimes, when the lane cannot be detected. It is difficult to recognize lane markers by reflecting on oncoming vehicle's light in rainy days. Many researches have adressed the problem (Meuter et al., 2009) (Linder et al., 2009). In these research, ground truth is used to evaluate the performance of those lane detection algorithms. Ground truth means accurate data sets to evaluate accuracy of an algorithm. Lane ground truth is usually generated by setting points on lane markers manually, one frame by one, and interpolating them. It, however, takes an enormous amount of time and feels mentally overloaded.

A lot of ground truth which become the lane informations is necessity of constructing the lane model. This paper proposes an offline efficient ground truth generation method based on shape changing features of lane markers at time slice images for constructing the lane prediction model.

2 RELATED WORKS

Many lane detection methods using a lane model are proposed. Canny/Hough Estimation of Vanish-

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ing Points (CHEVP) (Wang and Teoh, 2004) is used for B-snakes lane model. This algorithm is robust to noises, shadows, and illumination variations in the captured road images. Firstly, an image is divided into multiple regions with horizontal lines. A lane is detected by Hough transform and its contours are extracted by Canny edge detector. Secondly, the center line of the lane is calculated by using the extracted contours and smoothed by B-spline. Finally, the lane is extracted by using B-snakes with a lane model derived from the center line.

A lane detection algorithm based on several lane features for low visibility conditions is proposed by Iwaki et al. (Iwaki and Takahashi, 2012). Images are transformed into bird's eye views in order to make a lane marker into uniform width. Then the lane is extracted by tracking points that are arranged on lane markers since the lane width is defined by the traffic law. Furthermore, in order to improve accuracy in low visibility conditions, this algorithm approximates the extracted lane markers with a quadratic curve. Road shapes are, however, varied, generally, roads have various shapes. In particular, highway roads are designed by clothoid, which is also known as a cornu spiral. The segments are used as transition spirals forming c-shaped and s-shaped curves and continuous curvature between circles as well as straight lines in various situations (Sasipalli et al., 1997).

Lane detection systems are evaluated using ground truth, and six representative road feature extractors are evaluated using two variants by Veit et al. (Veit et al., 2008). An efficient method to generate ground truth is proposed by Borkar et al. (Borkar et al., 2010). Firstly, it generates time slice images which are sliced parallel to time axis and horizontal axis of spatio-temporal image. Secondly, a user manually marks some points with any intervals on the centers of the lane markers on a few time slice images. Then, those points are interpolated by spline interpolation. Other points on lane markers in a frame are obtained by this operation. Manual work, however, still remains. Since a few control points are used as the interpolation, accuracy is not sufficient secured.

Edge or contour detection algorithms have been proposed. Snakes, or active contours, are contours extraction method which is adaptive for shape variations (Michael et al., 1988). Oike et al. (Oike, 2001) proposes a road edge tracking method based on a constraint that moves only in the horizontal direction to the control points of the snakes. Sawano et al. (Sawano and Okada, 2007) proposes a lane marker tracking method by using snakes. A lane marker has two edges of inner and outer a lane. In a road scene, if the road has lane markers on both sides, it is totally four edges. Parameters of snakes can be respectively given for their edges. Those approaches are applicable for a lane image directly. It is, however, hard for wavy or uncontinuous contours to extract correctly.

3 CREATING TIME SLICE IMAGE

3.1 Camera Configuration

The camera attached on a rearview mirror as shown in Fig.1. In-vehicle videos are taken in good visibility. The camera uses a digital camera which has $29fps$ and $1,920 \times 1,080 pixels$.

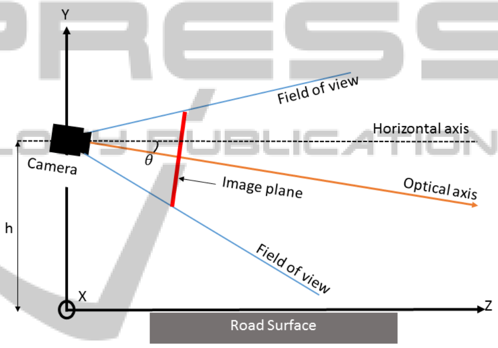

Figure 1: Camera configuration.

3.2 Process Overview

A video is a set of multiple images taken continuously in time domain. A spatio-temporal image is three dimensional data that combines images in the time axis direction. Time slice images are obtained by cutting away parallel to the horizontal and the time axis of spatio-temporal image. The time slice image is composed by stacking a specific rows in each frame. The vertical axis of the time slice image denotes time domain. This paper proposes an efficient algorithm which generates ground truth by using spatio-temporal image. Fig.2 shows the process overview of the proposed algorithm.

Time slice images are obtained by spatio-temporal image of a video where a lane exists since our aim is to generate lane ground truth. Lane width is regulated by the road traffic law. Ideally driving in a straight road makes lane markers in all time slice images straight line. Driving a car usually, however, meander slightly on the lane. Moreover, roads are not only straight but also curved. Lane markers in a time slice image which is obtained from even the bottom of the spatio-temporal image, therefore, become wavy. Similarly, lane markers in time slice images which are obtained from the top of the spatio-temporal image are affected by both a lane shape and erratic drive. Thus, the wavy effects by the erratic drive should be corrected. Lane markers in a time slice image, which is obtained by the bottom-most image in spatio-temporal image, are corrected to straight lines. Those are the nearest lane markers to the vehicle. Then, lane marker's contours are extracted at the time slice image, and center lines of lane markers in time slice images are obtained by the contours. Center lines of lane markers in all time slice images are obtained by propagating the extracted contours of lane markers from the bottom-most image to the top-most image. Lane ground truth is generated by reconstructed lane markers, which are the obtained center points in time slice images in a frame.

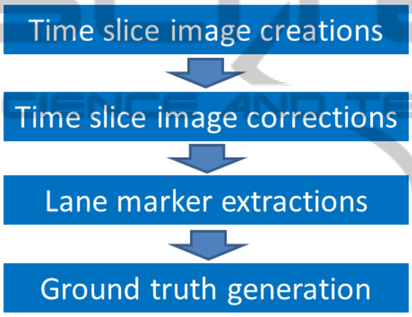

Figure 2: Process overview.

4 WINDING LANE MARKERS CORRECTION IN TIME SLICE IMAGES

Driving a vehicle whilst keeping the center of the lane is generally difficult. The vehicle, therefore, moves by slightly meandering against the lane. As a result, lane markers in time slice images which are obtained from near the vehicle become wavy ones by the effect of meandering. Lane markers in time slice images become simple straight lines if a vehicle is always driven on the center since lane width is uniformly regulated by the traffic law. Fig.3 shows one frame of a computer generated video. Usually, lane markers in the time slice image obtained from the bottom-most row become wavy as shown in Fig.4(a). If it is assumed that a car moves at the center of the lane, lane markers are almost straight lines as shown in Fig.4(b). If the car cruises at the center of the lane, lane markers in the time slice image obtained from the bottom-most row as shown in Fig.4(a) become like straight lines as shown in Fig.4(b). Based on this property, lane markers in the bottom-most time slice image are corrected to straight lines. SSD (Sum of Squared Differences) is employed to correct lane markers. Lane markers can be approximated to straight lines by minimizing SSD of adjacent rows in the time slice image with the formula(1). Time slice image correction is performed by calculating the minimum SSD for all pairs of adjacent rows.

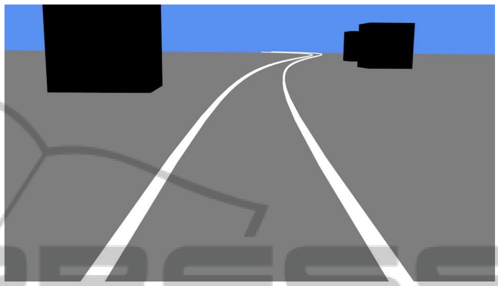

Figure 3: A computer generated image.

(a) Time slice image with general driving.

(b) Time slice image to keep driving in lane's center.

Figure 4: Examples of synthesis time slice images.

$$x_s(t) = \begin{cases} \arg\min\limits_{s} \sum\limits_{x=s}^{W-1} (I(x,H-1,t) \\ \qquad -I(x-s,H-1,t-1))^2 & (s \geq 0) \\ \arg\min\limits_{s} \sum\limits_{x=0}^{W-1-s} (I(x,H-1,t) \\ \qquad -I(x+s,H-1,t-1))^2 & (otherwise) \end{cases} \tag{1}$$

where, W and H represent a width and a height of Region of Interest in an original image illustrated in Fig.5, respectively. $I(x,y,t)$ denotes a pixel value at a coordinate (x,t) in a time slice image with height y. Equations are divided into two cases where a vehicle moves to the right or the left. The row at t is shifted by $x_s(t)$ where the amount error between t and $t-1$ is minimized. An original time slice image as shown in Fig.6(a) becomes close to straight lines as shown in Fig.6(b).

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Figure 5: An original image.

(a) A generated time slice image.

(b) A corrected time slice image.

Figure 6: An example of a time slice image correction.

5 GROUND TRUTH GENERATION BASED ON SPATIO-TEMPORAL PROPERTIES

5.1 Lane Marker Region Extraction

Contours are extracted from the corrected time slice image in order to obtain the center lines of lane markers. The time slice image obtained from the most bottom row has few noise such as a guardrail by perspective projection. Therefore, contours of lane markers in the most bottom row are extracted. Two lane markers are extracted by applying binarization. Threshold for binarization is decided by histogram in the time slice images. It is difficult to extract only lane markers, if noises remain in the binarized time slice image. It, however, can be assumed that lane marker regions are connected from the top-most to the bottom-most in the time slice image. Contours of the lane markers are searched by raster scan order. The left lane marker region is detected by the raster scan which meets a white pixel for the first time. The right marker region is detected by the second white pixel except for pixels in the left line marker region. Then, contours are extracted by tracing the contours on the two lane marker regions. The center line of the lane marker is obtained by using two long sides of the approximately rectangular lane marker region. Contour search is performed counterclockwise from the start pixel at the upper left of the region and back to the start pixel around the region. Here, in order to extract the center line of the lane markers in time slice images, only the contour lines of lane markers in the long side are used. The extracted contours, which are colored with blue and green, for a lane are shown in Fig.7.

Figure 7: An example of extracted contours of lane markers.

5.2 Lane Marker Extraction by Propagating Extracted Lane Marker

Lane markers mainly have two types a dashed line and a solid line shape. It is classified in the shape of each lane width. In this section, extraction method on the shapes of the two types is discussed.

5.2.1 Solid Line Shape

Contours of lane markers in all time slice images are extracted by propagating the extracted contours, which are obtained in section 5.1, from the bottom-most to the top-most time slice image. Namely, contour points from the nearest against a vehicle to the farthest one are extracted in a frame. Initial contour of snakes (Sawano and Okada, 2007) is propagated. At first, four contour lines of the long sides of the extracted lane markers in section 5.1 are used as the initial contour of snakes at $y = H-1$, where $H-1$ denotes the bottom-most plane in the spatio-temporal image. Then snakes is applied to the time slice image at y and two lane markers are extracted. In the same way, extracted contours on time slice image at $y-1$ propagate the time slice image at $y+1$ as initial contours of snakes. Repeating the procedure enables extraction of contours in all time slice images. Lane markers in all time slice images even in including much noise are, therefore, extracted correctly by this procedure. The center lines of lane markers are calculated by the following equation(2).

$$\frac{x_L(t)+x_R(t)}{2} \tag{2}$$

where $x_L(t)$ represents x coordinates in the left long side contour of a single lane marker at t and $x_R(t)$ represents that of right long side contour. Fig.8 shows the extracted center lines.

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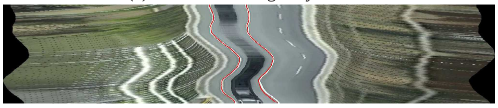
(a) Time slice image at $y = 904$.



(b) Time slice image at $y = 407$.

Figure 8: Center lines of solid shape lane makers.

5.2.2 Dashed Line Shape

Dashed line shape detects based on the size of dashed line region in time slice image of the bottom. Each detected region is obtained center of gravity, and those points are interpolated by spline interpolation. Then, the interpolation line is propagated the adjacent time slice image, extracted region around the interpolation line distinguished as dashed line. The center line of all time slice images is obtained by repeating above procedure.

(a) Time slice image at $y = 890$.

(b) Time slice image at $y = 421$.

Figure 9: Center lines of dashed shape lane markers.

5.3 Ground Truth Generation

The center lines of all time slice images obtained by correcting meandering effect for the time slice image of the nearest a vehicle, and propagating the extracted lane marker's information permits extracting the farthest time slice images. All the extracted center lines are integrated into spatio-temporal image and then the spatio-temporal image is separated into frames. Brokar et al. (Borkar et al., 2010) generate center lines in a time slice image by interpolating points assigned manually. Moreover, it is necessary to interpolate center lines in space domain again. The proposed algorithm does not need to interpolate center lines. The algorithm extracts center lines of lane markers directly. Generated ground truth images are shown in Fig.10. Obtained lane markers represent appropriate lane shape.

Figure 10: Ground truth.

6 EVALUATION

Generated ground truth based on spatio-temporal properties is evaluated. Ground truth in this evaluation is generated manually. Evaluation criteria (Borkar et al., 2010) given by the following formula (4) is employed.

$$\lambda(y,t) = |G_{y,t} - X_{y,t}| \tag{3}$$

$$E(t) = \sum_{y=1}^{H} \frac{\lambda(y,t)}{H} pixel. \tag{4}$$

$$\begin{cases} Correct & E(t) < \frac{M_{Real}}{2} \\ Incorrect & otherwise \end{cases} \tag{5}$$

where, $X_{y,t}$ is coordinate x in proposed ground truth of frame t with height y, and $G_{y,t}$ is coordinate x in ground truth generated by hand of frame t with height y. $\lambda(y,t)$ is, therefore, the difference of coordinate x between these two points. Formula (4) represents the average of $\lambda(y,t)$ in a frame. The unit is *pixel*. Borkar et al. (Borkar et al., 2010) use formula (5) to evaluate the accuracy of ground truth. M_{Real} represents the number of pixels of real lane markers width. The lane marker is regarded as correctly extracted when average error $E(t)$ is smaller than half of M_{Real} since the extracted center line is almost within the actual lane marker. Lane markers width of the bottom-most in a frame is $21 pixels$. Ground truth is also extracted by using Borkar's method (Borkar et al., 2010) for comparison. Straight and curved roads with continuous lane markers and dashed line shape are captured, and dashed line lane markers are calculated the accuracy of the ground truth of the white line on. The results are shown in Table1. Three and five time slice images are used to generate ground truth by using Borker's method (Borkar et al., 2010). The average errors are obtained for 30 frames in each road shape. Examples of the road conditions and the visibility of the data set for the evaluation are shown in 11(a) and 11(b).

By comparing the error of the proposed ground truth with the ground truth generated from three time

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(a)An example of local roads.

(b)An example of highway roads.

Figure 11: Examples of data set for evaluation.

Table 1: Average of error in a frame(*pixels*).

	Straight	Curve
Proposed ground truth	1.44	4.78
Borkar's(time slice of three)	1.27	5.42
Borkar's(time slice of five)	1.33	3.66

slice images, we can notice that the error is almost same for straight roads. The error of the proposed method is, however, small comparing with the previous method because the previous one employs interpolation with a few control points. The accuracy of the proposed method is almost same that of the previous method with five time slice images. The result shows that the proposed ground truth gets good accuracy for both straight and curved roads. The best thing is possible to reduce manual operations for obtaining lot of lane informations to construct the lane prediction model.

7 CONCLUSIONS

In this paper, we proposed an offline ground truth generation method based on spatio-temporal properties that reduces tedious tasks. Meanering effects on time slice images are corrected based on the spatio-temporal properties of lane markers. The proposed method does not need any interpolation since center lines of lane markers are generated directly by using all time slice images. The error of the generated ground truth becomes small for both of straight and curved roads. The proposed method will be applied to the variety of road situations and the limitation of the method should be discussed. We are planning to construct precise geometrical lane prediction models using ground truth generated by this method, and perform lane detection in low visibility based on the models.

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