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Research paper

Experimental Results on Edge-based Lane Detection

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Abstract

This paper evaluated the experimental results of the proposed lane detection framework during heavy rain condition. The framework of the proposed lane detection system covered pre-processing stage and detection stage. A pre-processing stage mainly consists of colour space conversion, selection of region of interest, edge extraction. Whereas, detection stage mainly consists of Hough transform and local maxima detection for lanes. The main contribution of this paper is to extend testing methodology for existing lane detection algorithms on stability, accuracy, and singularity. The experiment is conducted in urban roads of Malacca city. For experimental results assessment, coordinates variation analysis and uniqueness analysis are proposed to evaluate the performance of the proposed lane detection system, in term of stability, accuracy, and singularity. The test results are compared to Canny, Prewitt, Roberts, and Sobel methods for benchmarking. The experimental results shown that the proposed method has lesser fluctuation in coordinates variation analysis and closer coordinates mapping to their respective reference coordinates despite heavy raining weather. In addition, the proposed method has shown higher distinctive rate of correctly detecting the ground truth lanes despite certain frames are having outliers due to other uncertainty factors such as disturbances from wiper and rain drops on the front windscreen.

Keywords: *Edge-based; Hough Transform; Lane Detection; Points Variation Analysis; Uniqueness Analysis.*

1. Introduction

Lane departure crashes count for majority of road accidents and caused loss of human life's, injuries, billions of dollars in loss every year. In Malaysia, it is reported that the country has been ranked as country with highest fatality risk death per 100,000 population, in the world since 1996 [1]. In response to such stern problems, intelligent transport system (ITS) such as lane detection and tracking (LDT) and lane departure warning (LDW) are called for by vehicle manufacturer industries. A lane detection system is a mechanism designed for localizing lane boundaries for road lanes. On the other hand, lane departure warning system aims at providing a warning scheme for drivers when the vehicle crosses forbidden edge lines in an inappropriate moment, which usually functions based on lane detection results.

Lane detection have attracted extensive interests of the automotive industries and computer vision community. Many vehicle safety architectures and commercial systems have been proposed in the literature, namely lane keeping assistance (LKA) [2], lane departure warning (LDW) [3], lateral control (LC), intelligent cruise control (ICC), collision warning (CW) [4], and autonomous vehicle guidance [5].

In this paper, a lane detection system for automotive, aiming at lane detection is proposed. As a lane detection system, it focuses only on pre-processing and detection stages with the highlights such as a relatively simple way of extracting region of interest (ROI) by sub-sampling, without projective model and inverse perspective mapping (IPM) and a relatively lightweight and efficient edge-segmentation and detection scheme. The main contribution of this paper is to extend the testing methodology for existing lane detection algorithms on stability, accuracy, and singularity of the detected lane pixels.

The rest of this paper is organized as follows. Section 2 begins with an overview of the main research works. Section 3 elaborated all the components of proposed method, which includes pre-processing stage and detection stage. Section 4 discussed the experimental methods and the results on edge detection performance. The paper is concluded in Section 5.

2. Overview

The existing research on lane detection is presented in different forms. Systems that have been developed can perform different tasks, namely lane following (LF) [6], lane keeping assistance (LKA) [7], lane departure warning (LDW) [8], lateral control (LC), intelligent cruise control (ICC), collision warning (CW), and autonomous vehicle guidance (AVG). In general, research works can be divides into two types, namely the system without the unit of controllers and the system designed with feedback. The lane detection system proposed in this paper is considered as the system without the controller and mainly deals with lane detection.

Pre-processing is always as the initial stage of image processing. The purpose of pre-processing stage is to enhance the input image in order to increase the likelihood of the satisfactory delivery of areas with useful information to subsequent stages. Conventionally, pre-processing consists of conversion of colour space. Additionally, for the purpose of lane detection, extraction of region of interest (ROI) is usually added into pre-processing steps. The detection stage functioned to extract lane markings from the ROI using feature extraction method like Hough transform. Hough transform is the most commonly used edge extractor for this application [9].

3. Methodology

A lane detection framework is proposed in this paper aiming at lane detection for automotive safety. Apart from the proposed method, edge-based segmentation method (Canny, Prewitt, Roberts, and Sobel) are also introduced to serve the purpose of benchmarking. Because of the similar segmentation methods used for proposed method, the setting of parameters in terms of detecting algorithms are similar. This yields the implementation of proposed method to be conducted in similar manner. The flow chart depicted in Fig. 1 shows the flow of proposed lane detection system.

The flow of proposed lane detection system begins by capturing an RGB colour image frame from a Logitech C525 web-cam at 320x180 resolution. Then, the captured image is converted to grayscale in order to obtain the image intensity. Equation (1) represents the function which is to be applied to an RGB image to convert it to grayscale, where R’ denotes red component of the image, G’ denotes green component of the image, and B’ denotes blue component of the image.

$$\text{Intensity} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} \qquad (1)$$

After that, frame images are prepared with outliers filtering by selecting the bottom half region of the image as region of interest (ROI). Mostly, the unwanted features such as vehicles, road sign boards, and roadside trees are located in the upper half region of the original image. Those unwanted features will be removed by splitting the upper half region while retaining the bottom half of original image as region of interest (ROI).

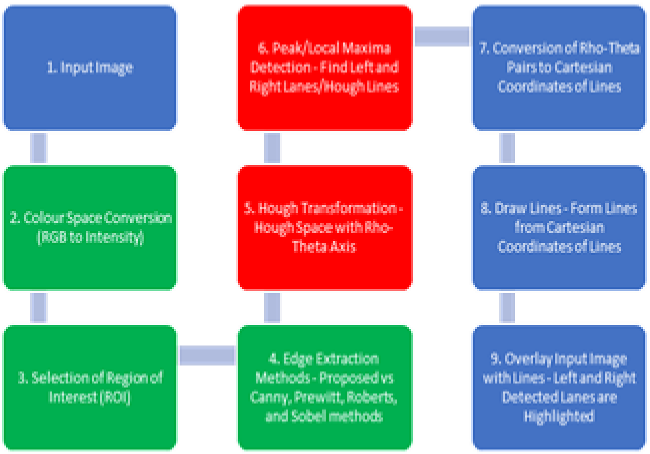


Fig. 1: Flow chart of lane detection system (green background denoted pre-processing stage and red background denoted post-processing/detection stage).

The proposed edge extraction algorithm mainly consists of three important blocks, which are 2-D FIR filter, followed by saturation block and autothreshold block as illustrated in Fig. 2. For 2-D FIR filter, the output signals rely on both previous pixels of current line and pixels of upper lines as shown in Equation (2), where

$$0 \le i < Ma + Mh - 1 \text{ and } 0 \le j < Na + Nh - 1.$$

Fig. 2: Flow of proposed edge extraction algorithm

$$C(i,j) = \sum_{m=0}^{(M_a-1)} \sum_{n=0}^{(N_a-1)} A(m,n) * H(i-m, j-n) \qquad (2)$$

For detection stage, the Hough transform is chosen as the technique that recognize specific configuration of points in an image, such as lane segments, curves, or other patterns. For example, by taking as a representation of straight lanes, the Equation (3), any straight lane is completely specified by the value of the parameters (*a*,*b*). Equivalently, if one takes a different type of representation, as in Equation (4), the straight lane is completely specified by the pair (□□□□.

$$y = ax + b \qquad (3)$$

$$\rho = x\cos(\theta) + y\sin(\theta) \qquad (4)$$

4. Experimental Results

The video sensing device that used to collect video footages is Logotech C525. Camera features are detailed as in Table 1. The camera is attached on the front windscreen at a height above the ground and located in the front of our experimental vehicle.

One video was captured (Clip #4) from urban road in Malacca city during daytime. This video represents common scenarios with raining weather, road surfaces, illumination conditions, and traffic density, which driver might encounter in real life. The details of the captured video Clip #4 footage are tabulated in Table 2.

Table 3 shows the proposed method attained 91.2 % of detection rate (DR) and 8.80 % of false positive rate (FPR) in Clip #4. As seen from Table 3, the detection rate of Canny method is obviously lower than those of proposed, Sobel, Prewitt, and Roberts methods. In addition, Clip #4 only brings a slight ad-vantage in the favour of Roberts method, where it attained 1.09 % higher than proposed method. Also, it is noticed that as a result of poor illumination during heavy rain weather and unpredictable illumination interference of vehicles, lane detection system may perform worse than it does during clear sky weather.

Table 1: Camera parameters

Camera attributes	Camera parameters
Company	Logitech
Model No.	C525
Maximum resolution	1280 x 720 at 30 fps
Interface	USB 2.0

It is concluded that, during raining weather, the successfulness of lane detection scheme in proposed method mainly depends on clarity of the printed lane markings and sometimes on illumination availability on the road. Nevertheless, all the lane detection methods discussed so far are without tracking stage, which could be integrated to the proposed scheme to further enhance the lane detection and tacking (LDT) results.

Table 1: Video clips for testing

Parameters	Clip #4
Weather	Heavy rain
Location	Urban
Traffic condition	Medium
Road surface	Rough
Frame no.	1556
Frame speed	30 fps
Frame resolution	320 x 180
Lane markings/frame	3
Lane colour	White
Dash lane	Yes
Solid lane	Yes

Table 2: Comparison of lane detection methods for Clip #4

Methods	Detection Rate	False Positive Rate	False Negative Rate
Proposed	91.20 %	8.80 %	0 %
Canny	24.87 %	72.62 %	2.51 %
Sobel	90.49 &	9.51 %	0 %
Prewitt	89.65 %	10.35 %	0 %
Roberts	92.29 %	7.71 %	0 %

In addition, uniqueness evaluation is employed for lane detection performance of proposed algorithm, as well as the comparison of different edge detection methods. There are three type of uniqueness evaluations conducted which are proposed meth-od with correct lane detection while other methods show false positive lane detection results as illustrated in Fig. 3, proposed method with false positive lane detection while other methods show correct lane detection as illustrated in Fig. 4, and all methods show false positive lane detection as illustrated in Fig. 5. It is noticed that Canny method produces very noisy edge-segmentation results (see Fig. 3(g), 4(g) and 5(g), respectively) on uniqueness analysis compared to other four methods, where a much lesser noise edge images are produces in Fig. 3 (f), (h), (i), and (j), Fig. 4 (f), (h), (i), and (j), and Fig. 5 (f), (h), (i), and (j), respectively.

The uniqueness analysis agreed with the comparison of lane detection methods result in Table 3, where the Canny method achieved lowest lane detection rate, highest false positive rate, and highest negative rate compared to other methods. Despite under heavy rain weather, the proposed method has been proven in correctly detecting the road lanes with above 90% of detection rate and less than 10 % of false positive rate.

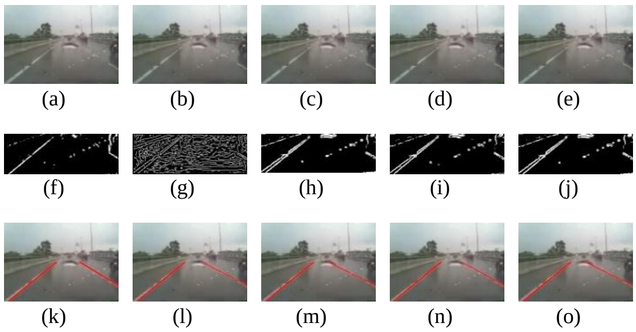
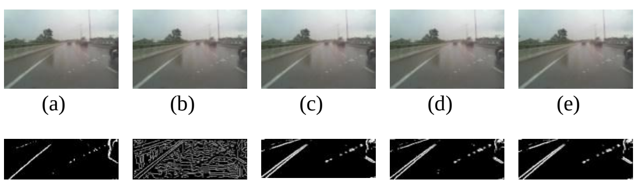


Fig. 3: Comparison of proposed, Canny, Prewitt, Roberts, and Sobel methods. Images (a), (b), (c), (d), and (e) represent the same frame taken from Clip #4. Images (f), (g), (h), (i), and (j) are the results of proposed, Canny, Prewitt, Roberts, and Sobel methods, respectively. Images (k), (l), (m), (n), and (o) are the results obtained after applying Hough transform on (f), (g), (h), (i), and (j), respectively.

Apart from the uniqueness analysis, coordinates variation analysis is introduced, which is aiming to evaluate lane detection performance in term of stability and accuracy. The coordinates variation comparison needs to be done based on the spatial variation of end-coordinates of both left and right lane markings (X_{11}, Y_{11}, X_{12}, Y_{12}, X_{21}, Y_{21}, *and* X_{22}, Y_{22}). Ideally, lane detection results and the testing environment are assumed absolutely ideal, where the camera is set to be stable and the road is perfectly smooth and flat. Based on this assumption, the detected left and right lane markings should almost keep still constantly without lane departure. However, the intention of lane detection application specially on lane departure warning system required the driving with switching lanes to test the effectiveness of the proposed method. Hence, the test environment involved lane switching to demonstrate the stability and accuracy of lane detection.



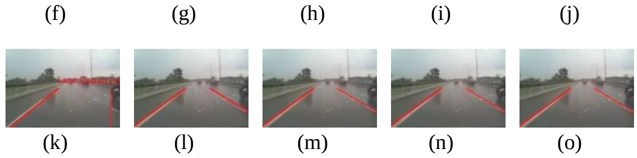


Fig. 4: Comparison of proposed, Canny, Prewitt, Roberts, and Sobel methods. Images (a), (b), (c), (d), and (e) represent the same frame taken from Clip #4. Images (f), (g), (h), (i), and (j) are the results of proposed, Canny, Prewitt, Roberts, and Sobel methods, respectively. Images (k), (l), (m), (n), and (o) are the results obtained after applying Hough transform on (f), (g), (h), (i), and (j), respectively.

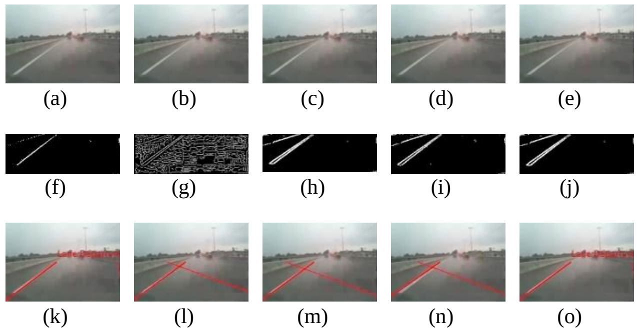


Fig. 5: Comparison of proposed, Canny, Prewitt, Roberts, and Sobel methods. Images (a), (b), (c), (d), and (e) represent the same frame taken from Clip #4. Images (f), (g), (h), (i), and (j) are the results of proposed, Canny, Prewitt, Roberts, and Sobel methods, respectively. Images (k), (l), (m), (n), and (o) are the results obtained after applying Hough transform on (f), (g), (h), (i), and (j), respectively.

This will result that the collected ending coordinates of left and right lane markings will be constant along the image frames, if the variation of these eight coordinates are drawn with their respective coordinates mapping as illustrated in Fig. 6. Fig. 7 shows the comparison of coordinates variation for coordinates X_{11} and Y_{11} with all methods. It is observed that the Y_{11} coordinates fluctuated lesser compared to X_{11} coordinates due to the detected lane marking is truncated in the direction of Y-axis with the region of interest located in bottom half of image. In addition, the Canny method shows minor instability in X_{11} coordinates as several image frames contained deviated X_{11} coordinates from reference coordinate, if compared to other methods. These have largely contributed into higher false positive rate as reflected in Table 3.

A similar scenario can be observed in Fig. 8, where X_{12} coordinate exhibits instability activities on several image frames com-pared to other methods. Due to the consideration of lane switching, the Y_{12} coordinates are differed over the image frames. However, the trend of Y_{12} coordinates from all methods are consistent despite minor instability behaviour is observed at the latter image frames.

Fig. 9 shows a major instability from Canny method compared to other methods in term of X_{21} and Y_{21} coordinates. For X_{21} coordinates, Canny method encountered difficulty in detecting the right lane markings due to the noisy edged image in Fig. 3(g), 4(g), and 5(g). Indeed, heavy rain is one of the major factors that contributed into high false positive rate for Canny method. As for Y_{21} coordinates, the result shows an agreement with Y_{11} coordinates in Fig. 7, where the effect of Y coordinate variation is lesser for all method except Canny method than X coordinate variation.

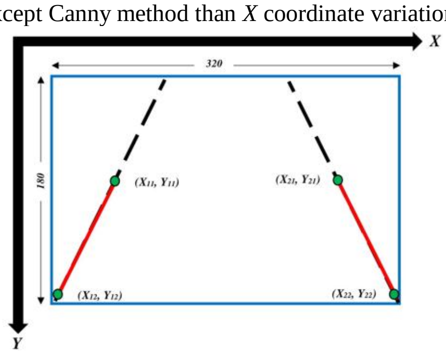


Fig. 6: Ending coordinates of X_{11}, Y_{11}, X_{12}, Y_{12}, X_{21}, Y_{21}, and X_{22}, Y_{22}.

Fig. 10 shows severe instability for X_{22} coordinates throughout the image frames from Canny method and slight instability from proposed method is observed at the beginning of the image frames. The water reflection on the road surface, rain droplet appeared on the windscreen, and the disturbance of vipers swinging are the observed root cause that affecting lane detection performance, particularly during extreme condition like heavy rain weather.

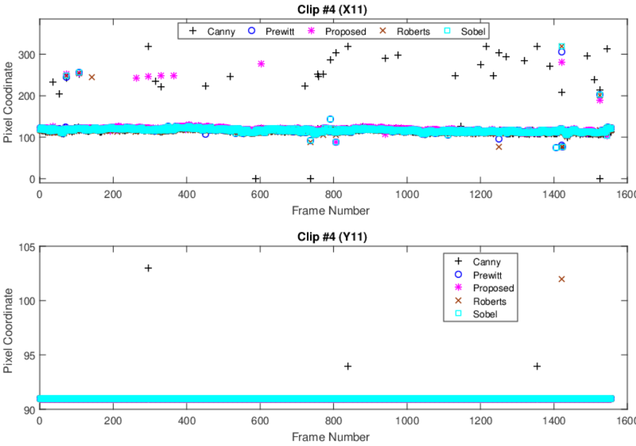


Fig. 7: Coordinates variation analysis for Clip #4 on point X_{11} and point Y_{11} with respect to Canny, Prewitt, Proposed, Roberts, and Sobel methods.

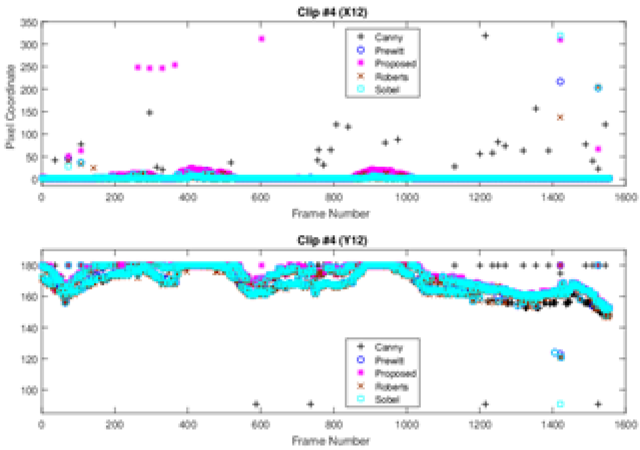


Fig. 8: Coordinates variation analysis for Clip #4 on point X_{12} and point Y_{12} with respect to Canny, Prewitt, Proposed, Roberts, and Sobel methods.

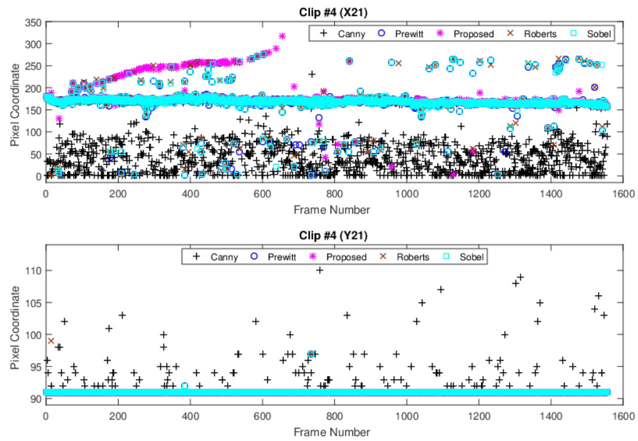


Fig. 9: Coordinates variation analysis for Clip #4 on point X_{21} and point Y_{21} with respect to Canny, Prewitt, Proposed, Roberts, and Sobel methods.

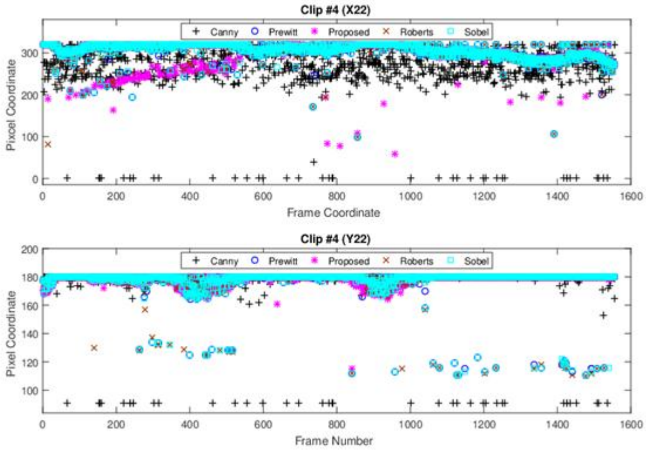


Fig. 10: Coordinates variation analysis for Clip #4 on point X_{22} and point Y_{22} with respect to Canny, Prewitt, Proposed, Roberts, and Sobel methods.

Due to dashed lane markings appeared on the right lane markings, the lane detection performance are found to be poorer in right lane markings (X_{21} coordinates in Fig. 9 and X_{22} coordinates in Fig. 10) as compared to solid lane markings represented by the left lane markings (X_{11} coordinates in Fig. 7 and X_{12} coordinates in Fig. 8). For Y_{22} coordinates, the coordinates variation result is obviously better than Y_{12} coordinates variation result in term of stability in spite of having minor random coordinates fluctuation from Sobel, Prewitt, Canny, and Roberts methods. The coordinates variation results show the lane detection performance solely depends on edge extraction algorithm with some instability behaviour. In order to enhance the lane detection performance, an additional stage of lane tracking is usually incorporated after lane detection scheme for smoothing the lane detection.

5. Conclusions

In this paper, a lane detection framework which is composed of a pre-processing stage and detection stage is proposed. The pre-processing stage consist of colour space conversion from RGB to grey-scale, selection of region of interest (ROI), and edge-extraction. Whereas, the detection stage consists of Hough transform and local maxima detection for lane markings. Experimental results have shown the evidence of proposed method and Hough transform improve the stability and accuracy of the lane detection system satisfactory. Experiments are conducted which included detection rate, false positive rate, false negative rate, uniqueness analysis, and coordinates variation analysis on urban roads in Malacca city to the performance of our system. The future includes mainly the addition of lane tracking component on top of the proposed scheme.

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