Lane Departure Warning

Dmytro Konobrytskyi

dkonobr@clemson.edu

Dec 2011

Abstract

The Lane Departure Warning system based on a windshield mounted camera is described in this this work. Algorithms used for implementation of the system, testing results and description of possible problems are provided as well as possible ways of future improvement.

1. Introduction

A safety is one of the most important problems of the automotive industry today. Many mechanical and electronic systems were added to modern cars in order to make them safer for drivers, passengers, pedestrians and other vehicles. A Lane Departure Warning (LDW) is one of the newest systems which try to make a highway driving safer and prevent accidents related to a moving vehicle outside of its lane due to driver's inattention. The idea behind this system is to notify a driver in a situation when a car is moving outside of its lane but this movement is not desired by a driver.

Researches

It is possible to notice one of the earliest works in the area of LDW system by Sukhan Lee [1]. Later Joon Woong Lee [2] presented a feature-based machine vision system for estimating lane-departure of a traveling vehicle on a road. Keisuke Suzuki [3] investigated a driver steering behavior for improving a design of LDW systems. In his work Claudio Rosito Jung [4, 5] has proposed to use an Uncalibrated camera and a Linear-Parabolic Lane Model.

Commercial systems

First versions of LDW systems were introduced by Japanese car manufacturers like Nissan, Toyota and Honda in 2001-2003 on top-end vehicle models for Japanese market and were based on a windshield mounted camera. Newer version of these systems from Japanese manufacturers have got an ability to apply steering torque or use breaks in order to keep a vehicle in a lane without drivers input. In 2005 the Citroen has introduced a LDW system based on down-looking infrared sensors used for detection a lane directly under a vehicle. Later in 2007-2009 Audi, GM, BMW and MB also introduce LDW system which sound, vibration and visual notification of a driver but not intervene in driving. At the current moment a LDW system is only available as option on to-end vehicles of all OEMs.

Current work focus

Implementation of a Lane Departure Warning system can be divided in two parts: detection of a car position on a lane and detection of a driver behavior in order to notify a driver only if a car movement is not desired. This work is mainly focused on a first problem due to an absence of additional data input from a driver like turn signal state, direction of a driver attention, positions of other vehicles on a road or information from a navigation system. A simplified version of driver notification is used and a driver is notified when a car is moving close to a lane border or when a car has actually passed a border.

2. Algorithm

In the current work a prototype of a Lane Departure Warning system was designed and implemented in Python language with OpenCL library used for image processing operations.

A process of detection of a car position on a lane can be represented as 3 main steps:

1. Lane marker detection
2. Lane model reconstruction
3. Car position detection

Lane marker detection with color model

There are many approaches are possible for lane marker detection including detection in each frame or detection and tracking. It is possible to notice that before any image processing operations an original image has to be cropped in order to save processing time and also limit the area where lane markers can be found by excluding areas like a car hood or sky. The crop region has to be selected based on car geometry and a camera position and orientation.

The first approach used for this problem was construction of a lane marker RGB color model and segmentation of all pixels based on a Euclidian distance of each pixel and this model. However this approach produces quite good results in stable lighting conditions (

Figure 1) it is not enough robust in case of changing lighting conditions. There were found two main situations which make problems with this approach. First problem is related to a shadow and multiple bright or dark areas related to shadows on a road which are detected as a part of lane markers (

Figure 2). The second problem is related to a camera automatic exposure selection which may significantly change a brightness of an image in a very short time. As result a color model constructed on previous frames may become invalid and significantly decrease a number of correctly segmented pixels (

Figure 3).

In order to improve segmentation quality at different lighting conditions a Hue component of a HSV color model was used in addition to a Euclidian RGB distance. However hue is independent from brightness which means that a significantly changes of an exposure do not affect it as they do with an RGB model (Figure 4), a significant level of noise at high and low brightness values significantly limits cases where this approach improves a segmentation quality. It is also possible to notice that a hue value of a grass may be exactly the same as a value of a lane marker.

Figure 1 – Color model: good conditions

Figure 2 – Color model: shadow and bright areas

Figure 3 – Color model: auto exposition effect

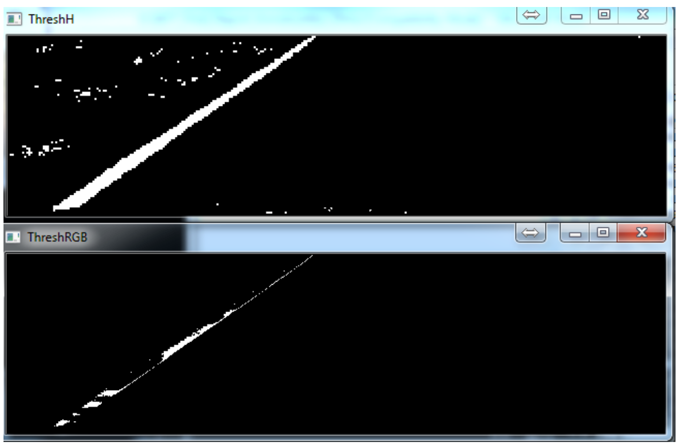

Figure 4 – RGB vs. Hue after an exposure change

However a combination of a Euclidian distance from a RGB model with a Hue model make a lane marker segmentation more accurate, there are still many cases where this approach does not work mainly due to a main tradeoff related to a speed of a model change. Rapid lightning condition changes require a fast change of a lane marker models but at the same time it may result in building a model of a road itself if road pixels are marked as a lane marker pixel by mistake in some frames which means that a system becomes unstable and rapidly starts segment a road as a lane marker.

Lane marker detection with geometry model

The color model based segmentation algorithm does a pretty good job at a constant lighting but it is not reliable enough with shadows, auto exposition and extreme brightness. An alternative approach for detecting lane marker is utilization of their geometrical properties. It is easy to see that lane markers may be represented as straight lines, curves, squares and short parts of a line. However all of them have different topology and may have different colors the width of a lane marker is always constant. Considering a perspective distortion it is possible to notice that a length of a line segment given by intersection of lane marker borders with a horizontal line is relatively constant for a given Y position of a horizontal line. The algorithm used for lane marker detection uses a geometrical model which includes a lane marker width and tries to find a horizontal segment with the same width. In order to improve performance and eliminate noise a search area is limited by a neighborhood around a previous position of lane marker. Implementation of this approach uses architecture with multiple virtual sensors (Figure 5) where each sensor is represented as a segment of a horizontal line where it is trying to find a segment with a width corresponding to a lane marker.

Figure 5 – Virtual sensors

The algorithm includes these steps:

1) Apply Canny algorithm to an initial image
2) For each virtual sensor:
    a. Find all regions
    b. Select regions with a length equal to a lane marker width
    c. For each possible region find an average region color
    d. Select the region which is the closest to a lane marker color model

The described approach actually combines both color and geometrical models together and allows detecting lane markers quite well (Figure 6).

Figure 6 – Virtual sensors values

The used architecture also allows selecting a performance by varying a number of virtual sensors. However there is a minimum number at which a system is stable, significant increasing of sensors number does not provide additional benefits. In this case a tradeoff between a stability and performance was solved by using about 50 virtual sensors.

Lane model reconstruction

The next step after detection of all available lane marker parts or absence of them at virtual sensor positions is a reconstruction of a lane border model. In this work a linear approximation for a lane borders is used which is accurate enough near a car (Figure 7). The least square algorithm is used for fitting based on data of each virtual sensor. In the implemented system a feedback is used for updating sensors position based on a reconstructed lane model. This approach allows updating a correct sensor position even if there is no lane marker at a sensor or if a lane marker is not detected properly.

Figure 7 – Linear lane markers model

Car position detection

In this work a simple approach for detecting a car position on a road by calculation of an intersection point between a lane marker model and a horizontal line was used. However this approach does not provide an exact car position, after an appropriate calibration for each car and camera position, it allows detecting a situation when a wheel is right on a lane marker. This approach uses 3 main zones (Figure 8) for classification of a car position as safe (green), close to a border (orange) and on a lane marker (red).

Figure 8 – Car position detection

A calibration process is not required for production systems because a camera position and car geometry are known. However in case of prototypes a simple calibration method based on a sound of hitting of reflectors by a wheel may be used right on a road. In order to use it a car has to move slowly outside of a lane and lane marker model position at the moment when a driver hears a bumping sound is a start of a “red zone”. An “orange zone” can be constructed as a 50% of a “red zone” width. Figure 8 shows an example of zones constructed with this approach.

3. Results

The described approach for lane departure detecting was been implemented as a prototype of a Lane Departure Warning system in a Python programming language with the OpenCV image processing library. The implemented prototype uses a web-camera mounted on a windshield and a connected to a laptop as a main and single data source and uses a laptop display as an output. The Figure 9 demonstrates three possible outputs related to a position of a car on a road. The left image shows a situation when a car has passed a lane border and the LDW system displays two red marks. The middle image represents a situation when a car is close to a border and the LDW system displays a warning with an orange single sign.

Figure 9 – Example of an output

It is hard to represent result of this work with a set of static 2d images as the main idea is to make a real time system. The best way to see results is to watch YouTube video:

http://www.youtube.com/watch?v=c29F3JTfU70

However Figure 10 shows some test results based on processing of recorded video.

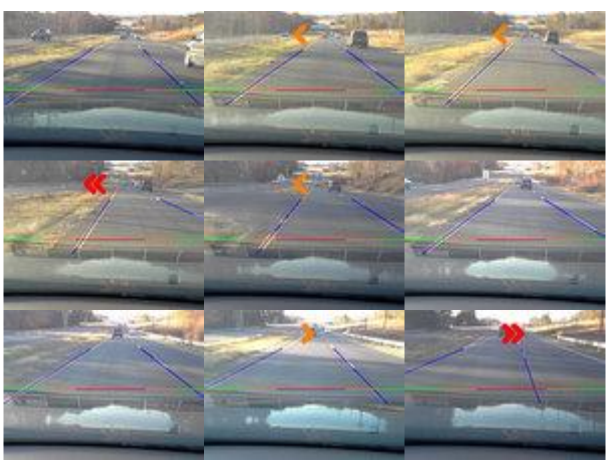

Figure 10 – Recorded video

The Figure 11 shows results of on-road test where the developed prototype displayed warnings when the car moved outside of the lane. It is easy to see that the system displays correct warnings correctly which correspond to the actual car position.

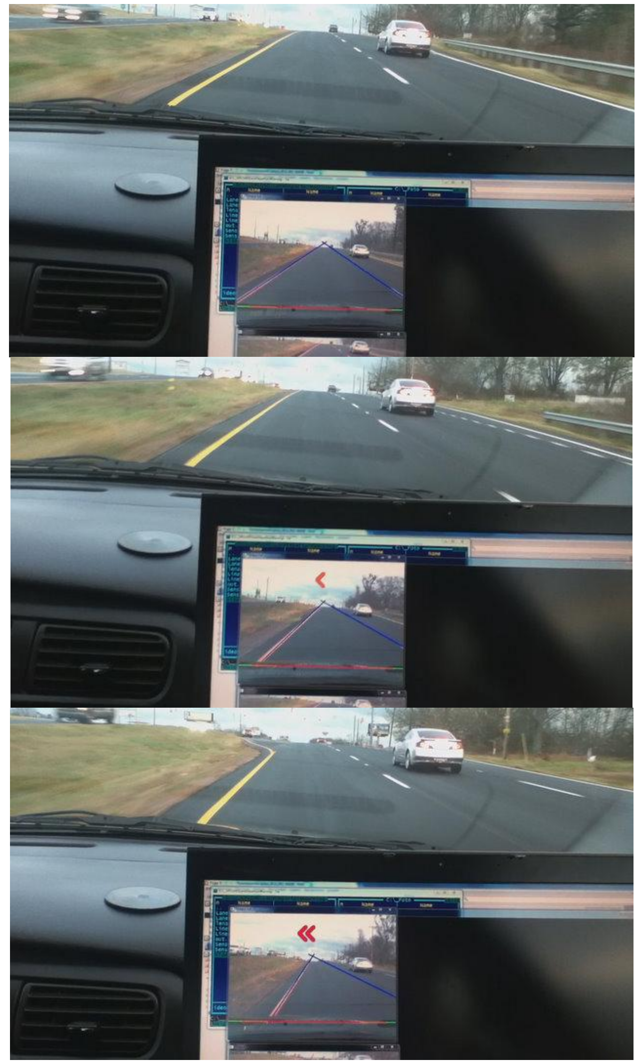

Figure 11 – On-road test

4. Conclusion

In this work the prototype of a Lane Departure Warning system was implemented by processing a video stream from a web-camera mounted on a windshield. Testing of the developed system on recorded videos and on road shows that it can reliably detect lane markers and reconstruct lane geometry. It is possible to notice that a lane change maneuver is not supported in this prototype due to a limited amount of input data related to a driver behavior. However a prototype could change a lane correctly it is primary goal is to prevent an undesirable lane change but not to allow it.

It is also possible to notice that a camera orientation is very important for correct lane marker detection as well as a camera type. Used web-camera did not allow manual selection of the exposition parameters, as results a system performance at a dark time was poor because the camera did not provide frames fast enough and an assumption about small lateral motion was invalid. Another problem with an automatic exposure is a rapid change in average frame brightness which makes it harder to maintain a lane marker color model.

However tests show quite good results it is easy to see that it is a hard problem to make a robust system at any possible lightning and weather conditions especially on roads with old lane markers which are partly erased.

5. References

[1] Sukhan Lee, Woong Kwon, Jae-Won Lee: “A vision based lane departure warning system“, Intelligent Robots and Systems, 1999, pp. 160-165 vol.1

[2] Joon Woong Lee: “A Machine Vision System for Lane-Departure Detection", Computer Vision and Image Understanding, April 2002, pp. 52-78 vol. 86 issue 1

[3] Suzuki K., Jansson H.: “An analysis of driver's steering behaviour during auditory or haptic warnings for the designing of lane departure warning system” JSAE Review, Volume 24, Number 1, January 2003 , pp. 65-70 vol. 6

[4] Jung, C.R., Kelber, C.R.: “A lane departure warning system based on a linear-parabolic lane model”, Intelligent Vehicles Symposium, 2004 IEEE, 14-17 June 2004, pp. 891-895

[5] Jung, C.R.; Kelber, C.R.; “A lane departure warning system using lateral offset with uncalibrated camera“, Intelligent Transportation Systems, 2005. Proceedings. 2005 IEEE, 13-15 Sept. 2005, pp. 102-107