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Lane departure warning for mobile devices based on a fuzzy representation of images

Nicolás Madrid *, Petr Hurtik

Institute for Research and Applications of Fuzzy Modeling, University of Ostrava, 30. dubna 22, 701 03 Ostrava, Czech Republic

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Abstract

The use of driver assistance systems is a current trend in the car industry. However, most driver assistance systems require the use of multiple sensors, increasing the cost of their implementation in cars and making them inaccessible to many users. In this paper, we present an "*efficient*" Lane Departure Warning system for mobile devices, which is real-time, accurate and accessible to most users. On the one hand, the accuracy of the system relies on Line Detection based on Hough Transforms, a combination that has proven to be reliable for this goal in many approaches. On the other hand, the reduction of the computational time, to achieve real-time processing, is due mainly to a proposed fuzzy representation of images. Finally, we also present various tests that show that the system proposed runs at up to 20 FPS on a mobile device (with a dual-core CPU at 1.0 GHz) with a resolution of 320 × 240 px.

Keywords: Fuzzy image; Hough Transform; Image processing; Lane detection; Android; Intelligent transportation system; Driver assistant

1. Introduction

The proper detection of lanes is crucial for the development of autonomous cars and driver assistance systems. For instance, the development of *Lane Departure Warning Systems* [13], *Drive Attention Monitoring Systems* [23], and *Lane Tracking Systems* [7,27] depends strongly on the correct determination of the boundaries of a road. Despite most of activating driver tasks requiring the use of multiple sensors, such as laser scanners (LIDARs), differential GPS, stereo-cameras, sonars, omni-directional cameras, gyroscopes etc., in most *Lane Detection Systems*, the only sensor required is a vision camera; one exception is [20], which also requires radar for the detection of trials.

Lane detector systems can be roughly described by focusing mainly on two features: road assumptions and feature extraction. In road assumptions, the system models the structure and geometry of a road by assuming various features in roadways. For instance, it can be assumed that roadways are on a flat plane [7,15,32] or on a manifold [24], that lane marks are white on a dark background [23], that right and left boundaries are parallel [4], etc. In some approaches,

* Corresponding author.
E-mail addresses: nicolas.madrid@osu.cz (N. Madrid), petr.hurtik@osu.cz (P. Hurtik).

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these assumptions are described explicitly, while they are implicit in the underlying methods of other approaches. On the one hand, these assumptions simplify, from a computational point of view, the positioning of the lane boundaries, but on the other hand, they restrict the scope of the systems; for instance, the assumptions used to model highways with several lanes are not valid when modeling an urban road. According to road assumptions, lane detectors can be split in two groups: those focused on *structured roads* that allow and impose strong road assumptions (such as streets or highways where lane marks are usually clearly visible) and those focused on *off roads* that require weak road assumptions [16,20] (such as trails or mountain paths). This paper is framed concerning the former group. The way a lane detector system extracts the features of a lane depends strongly on the road assumptions. To the best of our knowledge, lane detector systems based on structured roads have a common strategy aimed at detecting lane marks. The procedure usually applies in some step a binarization procedure, mainly an edge detector [33,26,15] or an intensity thresholding [30,7]. Subsequently, most systems search for the boundaries of a lane by means of assumed shapes of lane marks (such as straight lines [7,30], parabolas [17], clothoids [24], etc.) by Hough Transforms [32,30,26], Bayesian models [7,17,15,20], Mathematical morphology [31,18] (extracting roads from satellite images) or other methods [13,33,15].

A common drawback among Lane Detector Systems is the hard computational cost and/or hardware designed specifically for such a task. Only a few approaches have focused on a procedure in real-time.[1] The first approach dealing with the real-time challenge was [5] in 1995. Their system was implemented in *PAPRICA*, a massively parallel architecture, and they reached a speed of 17 FPS with a resolution of 128 × 128 (pixels per frame). Subsequently, in 1998, the system was modified to cover the detection of obstacles as well [4], reaching a speed of 10 FPS with the same resolution. Later, in 2011, [27] developed a system that also reached 10 FPS (with a resolution of 200 × 400) via a PC implementation (Intel dual-core E5300, 2.5 GHz). Recently, various approaches have implemented lane detectors on FPGA hardware [21,1,11] with great efficiency. Specifically, in terms of computational time, the system in [11] runs at 25 FPS with a resolution of 256 × 256, the one in [21] runs at 30 FPS with a resolution of 752 × 480, and in the case of [1], the system runs at 40 FPS with a resolution of 752 × 320. Last but not least, [25] shows an implementation on image processing specific hardware (Texas Instruments C6x DSP running at 600 MHz) reaching up to 160 FPS with a resolution of 720 × 480. It is worth mentioning that the specific hardware used in the approaches above is not installed in mobile devices, which should process all the data via a CPU.

Among all possible systems related to lane detection, we focus in this paper on *Lane Departure Warning Systems*. Specifically, we present a reliable system implemented on a CPU that sends, in real-time, a warning to the driver when the car is outside of a lane of the highway. The system has been tested on a Notebook (Intel i7M, 3.1 GHz) and on a mobile device (dual-core 1.0 GHz). In both cases, real-time performance is convincingly reached: 26 FPS on the Notebook and up to 20 FPS on the mobile device, with a resolution of 640 × 480 and 320 × 240, respectively. To the best of our knowledge, the only Lane Detection System implemented on mobile phones in the literature is that of [26],[2] which runs at only 1 FPS. The improvement in the computational cost is achieved mainly because of a novel fuzzy representation of images. The idea is to link a fuzzy set to each pixel to represent the uncertainty associated with the intensity assigned to it by the image. This representation is quite similar to the one given in [14,6] in terms of intervals but with a remarkable difference namely, the storage of the intensity assigned originally by the image. The extraction of such a representation (which can, and must, be called fuzzification) is an extra procedure that is not performed in other *Lane Departure Warning Systems*. Thus, it appears at first sight that our approach would require more computational time than others. However, the reality is different, as computing some operations from the fuzzification is considerably faster. For instance, we show that our gradient operator (included the fuzzification) is obtained more than 2 times faster than Sobel and Prewitt gradients for 3 × 3 windows and 5 times faster for 5 × 5 windows. In addition, the fuzzy representation also allows the statement "*the intensity of a pixel is C*" to be coded in fuzzy terms. This is useful when we search for white pixels in lane marks that are distorted for different reasons.

The structure of the rest of the paper is as follows. To write as self-contained an article as possible, Section 2 presents some basic notions regarding image processing and fuzzy sets. Subsequently, in Section 3, we show how to

[1] For us, real-time is at least an analysis of 10 FPS (i.e., the borders of the roadway are determined in less than 100 ms including preprocessing steps). Thus, papers that do not achieve this level of performance (or do not specify the computational time) have been omitted in the comparison, even if they state that their systems run in real-time.

[2] Perhaps this is the only approach fully comparable with ours, as the target of both approaches is the development of Lane Detector Systems on mobile phones.