Lane Detection on the iPhone

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Abstract. A robust and efficient lane detection system is an essential component of Lane Departure Warning Systems, which are commonly used in many vision-based Driver Assistance Systems (DAS) in intelligent transportation. Various computation platforms have been proposed in the past few years for the implementation of driver assistance systems (e.g., PC, laptop, integrated chips, play station, and so on). In this paper, we propose a new platform for the implementation of lane detection, which is based on a mobile phone (the iPhone). Due to physical limitations of the iPhone w.r.t. memory and computing power, a simple and efficient lane detection algorithm using a Hough transform is developed and implemented on the iPhone, as existing algorithms developed based on the PC platform are not suitable for mobile phone devices (currently). Experiments of the lane detection algorithm are made both on PC and on iPhone.

Keywords: intelligent transportation system, driver assistance, lane detection, iPhone, Hough transform

1 Introduction

Intelligent Transportation Systems (ITS) are developed to improve road safety, reduce transportation times, or save fuel. Basic ITS technologies include traffic signal control systems, security CCTV systems, speed cameras, or automatic number plate recognition. Driver assistance systems (DAS) are advanced technologies, mainly designed for improving traffic safety. Various computing platforms are used for the application of DAS, such as PC, laptop, play station, integrated chips and so on. With the wide spread of mobile phones, many functionalities of DAS are also build into those phones, for example, GPS positioning or a video camera.

Lane detection is a core technology in DAS, as it can help to estimate the geometry of the road ahead, as well as the lateral position of the ego-vehicle on the road. Lane detection is used in intelligent cruise control systems, for lane departure warning, road modeling, and so on. Typically, lane detection is used for localizing lane boundaries in given road images, and has been widely studied on various scenarios [12]. Recently, some commercial lane detection systems appeared, for example, based on embedded chips integrated into the car (e.g. mobileye [1]).

We demonstrate in this paper how to implement computer vision-based lane detection on a mobile phone, making good use of those mobile platforms with cameras. An iPhone [3, 7], a product of Apple Inc, is used in this paper due to its integrated system components. Also, the lane detection method used in this paper covers various lane marks such as solid lines, dashed lines, road shoulders, or dotted lines. Due to the restriction of memory and computing power of an iPhone, we focus on a straight and flat lane model, and use the original Hough transform [4] (for straight lines). The aim of this paper is not to provide a top performance lane detection method, but a promising application situation on a mobile phone with restricted resources while a fairly robust detection result. For a brief review about algorithms for detecting and tracking lanes in general, see [8].

The paper is structured as follows. In Section 2, we give a general introduction to the iPhone, and the difficulties caused by iPhone's restricted resources. In Section 3, we describe the lane detection algorithm as implemented on the iPhone. In Section 4, experimental results from iPhone, and some comparison with PC-based lane detection are provided. Some conclusions are presented in Section 5.

2 IPhone

The iPhone is an evolutionary phone, it features a multi-touch screen, GPS, wifi access, an internal motion sensor, a build-in camera, a Unix-based operating system that operates inside of the phone (but is normally not accessible for a programmer), and more, but what is not needed for our purposes (e.g., a web browser).

Generally, the implementation of computer vision-based lane detection on an iPhone has its difficulties in two aspects: hardware and software. As a mobile phone, iPhone has its limitation on computing power and memory, as well as other peripheral components. The comparison between iPhone and iMac (or, say, a typical PC) in hardware is conducted in Table 1. As indicated in this table, the shortage of physical memory and the slowness of CPU define the two main challenges. Typically, the same application running on an iPhone will be over 100 times slower than on an iMac. Furthermore, programming on an iPhone is another great challenge, as the iPhone is a closed system with limited reference documentation and functions, having no multi-tasking, no virtual memory, and less support in programming library.

	iPhone 3G	iMac
CPU	620 MHz	Intel Core 2 Duo 2.93 GHz
Memory	128 MB	4 GB 1066 MHz SDRAM
Screen Size	3.5-inch	24-inch
Screen Resolution	320×480	1920×1200
Power	3.7 V battery	200 W power

Table 1. A comparison between iPhone and iMac.

For the installation of an iPhone in a car, see the left of Figure 1. We mount the iPhone on the windscreen by an iPhone-specific car mount holder. This allows that the iPhone's camera is not blocked by the holder and also provides a stable mounting. (Of course, there is still the egomotion of the car, such as a changes in tilt and roll angles with respect to the road surface.) The user may place the phone either horizontally or vertically, and may freely move the holder to a different position. The system will automatically detect the placement of the phone using its internal sensor. We also use an USB car charger (to avoid any battery issue).

The geometric model of the camera and lane using the above installation is shown on the right of Fig. 1. Below are the parameters:

- f : focal length
- O: focal center
- H: height of the camera above ground manifold
- θ : tilt angle of the camera

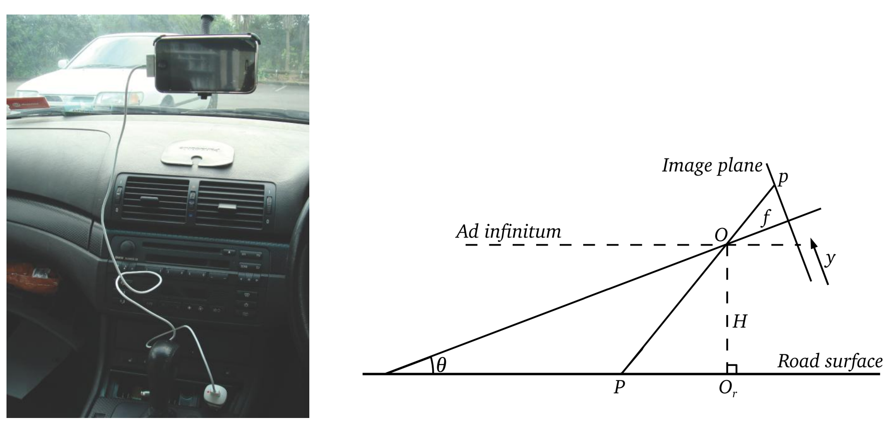

Fig. 1. Left: installation of iPhone on an ordinary car. Right: the geometry of road and camera.

3 Lane detection

With the restriction of the application platform, the developed lane detection algorithm must be simple and efficient. Our lane detection algorithm is based on the assumptions of planar ground manifold and locally straight lane boundaries. For lane detection in general situations, see [8]. The main flow chart of our algorithm is as shown in Fig. 2. After acquiring an image from the iPhone's

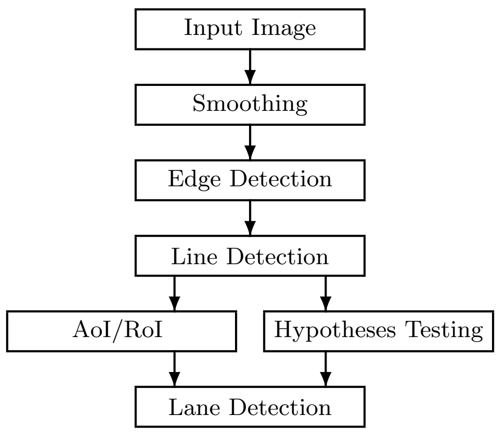

Fig. 2. Flowchart of lane detection.

camera, smoothing is applied in order to remove noise. Then a Canny edge detector is used to obtain a binarized edge map. Furthermore, in order to detect dotted lane marks, some morphologic operations are also adopted. The Hough transform, applied to the edge map, detects lines. As there are many lines besides lane boundaries, a hypotheses testing module has been implemented for these candidate lines using multiple cues. An AoI/RoI will be defined in order to improve the computation efficiency, as the road will only appear in the bottom part of an input image. A real example of lane detection, using this algorithm, is shown in Fig. 3.

3.1 Preprocessing

The preprocessing of the input image includes three steps: smoothing, edge detection and morphologic operations. For the smoothing operation we may choose one of various filters, such as mean, median, or Gaussian. We decided for a 3×3 Gaussian filter. Similarly, the Canny edge detector is selected among other edge operators to generate a binarized edge map. For some kind of lane marks (e.g.,

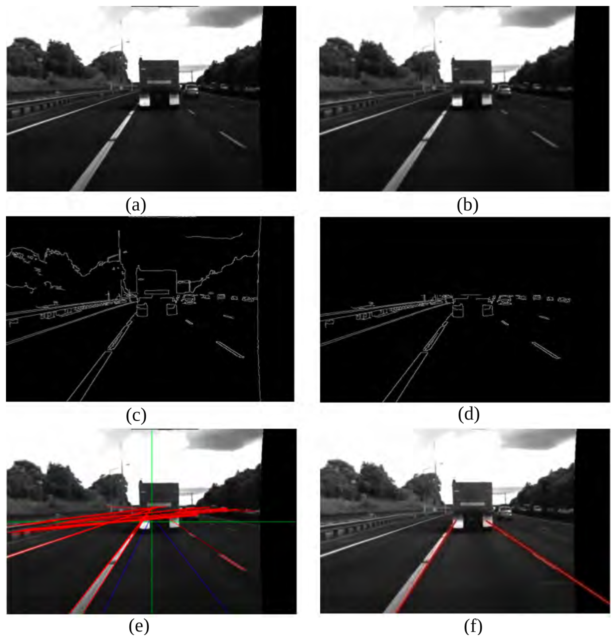

Fig. 3. An example of lane detection with intermediate results. (a) An input image. (b) Smoothing. (c) Edge detection. (d) AoI/RoI . (e) Hough transform. (f) Lane detection result.

dotted lane marks, which are common in New Zealand but not possible in areas having snow in winter), combinations of erosion and dilation (the two basic morphologic operations) are applied on the edge map in order to improve line detection results in the subsequent Hough transform. The effect of the applied morphologic operator is illustrated in Fig. 4.

3.2 Lane detection using a Hough transform

Hough transforms are widely used for detecting lines and circles, and have also been applied in lane detection situation [10]. The selection of a Hough transform as the main processing step for lane detection is due to its robustness to noise and occlusion. This is because each edge point is considered independently of the others in a Hough transform. That means, the removal of some edge points, or the introduction of some more noise will not affect the result of Hough transform very much. With this advantage, broken line patterns used in road marks, or lane marks partially occluded by obstacles (e.g., vehicles) can be easily detected using a Hough transform [10]. Another important reason for selecting a Hough transform compared to other lane detection methods is in its simplicity and computation efficiency, which can be seen from comparisons of time needed for lane detection using a Hough transform or other algorithms, see [8] (discussion in Section 4).

3.3 Hypotheses testing using multiple cues

We assume that the lane width is between 3 to 5 meters and that an ego-vehicle is typically in the middle of the lane. We calculate prioritized lane border lines in the image, then we define for each line an area of interest (AoI) by a width parameter, for example, selected to be one meter.

By allowing different locations of the camera in the car, we define adaptively different areas of interest in images. Because the camera's optic axis is basically parallel to the forward direction, and the road surface is assumed to be planar (i.e., close to the car), the top part of the image is not used in the Hough transform or lane detection.

We apply the following multiple cues to decide whether lines are lane borders or not; candidate lines are found as a result of the Hough transform:

- AoI: A lane border must proceed in the AoI from the bottom towards a middle line of the image.
- Lane width: The difference of a lane's width must be less than a constant (for example, one meter) when measured either at the bottom or the middle of the image.
- Parallel lines: Lane borders should be approximate parallel (taking perspective projection into account).
- Vanishing point: All parallel lines meet at the same point (i.e., the vanishing point). All lane borders should 'nearly intersect' the vanishing point.
- Enlargement of the AoI: If no lane border is found in an AoI, then we enlarge it (to the borders of the image; for example, if there is only a middle line marking in a local road, then the enlarged AoI should allow us to find the road shoulders).

Following the planar-ground and straight-lane assumptions used in this paper, experiments proved that, if there are lane borders detected by the Hough

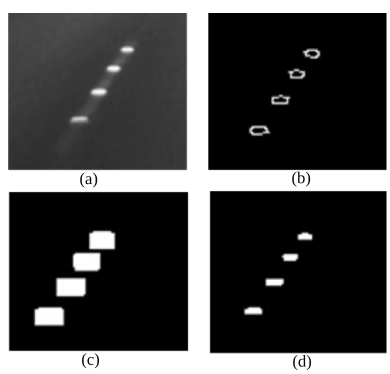

Fig. 4. Morphologic operatorapplied to the edge map of dotted lane marks. (a) An input image of dotted lane marks. (b) Edge detection. (c) Lane marks after repeated dilation. (d) Lane marks after repeated erosion.

transform, then they will be robustly selected within the set of all detected lines according to the above cues, even in some complicated environments (see Fig. 5).

4 Experiment

The Environment Perception and Driver Assistance project (*.enpeda..*), see [5], at The University of Auckland provides calibrated multi-view video cameras in the test vehicle HAKA1 (High Awareness Kinematic Automobile 1). These data have been used for evaluating the lane detection algorithm in this paper, with results as illustrated in Fig. 5. It can be concluded from these experiments that the lane detection algorithm developed in this paper works robust for various lane types if local road planarity and piecewise straightness of lane borders is satisfied (as on highways, or on roads in cities which do not have many hilly areas).

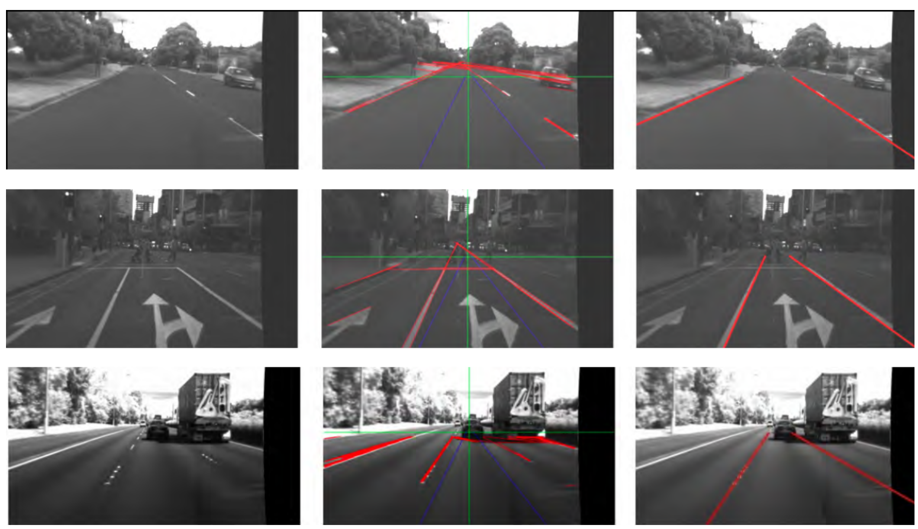

Fig. 5. Experiments of lane detection using recorded sequences. Left: input image. Middle: detected lines using the Hough transform. Right: Final lane detection result.

Compared with another lane detection method [8] developed in the same research group, this lane detection algorithm computes much faster and consumes less memory, and fits well to the mobile platform.

The performance of the lane detection algorithm in the iPhone can reach one frame per second with optimization only in an experimental implementation. Figure 6 shows a lane detection result on the iPhone. Experiments in Auckland showed that the rate of successful lane detection is above 90 percent with clearly detected straight lane borders.

Fig. 6. Experimental results of lane detection on an iPhone at night.

5 Conclusions

In this work, we reported about an implementation of lane detection on the iPhone, which is a promising mobile solution for driver assistance systems. A simple and efficient lane detection method using a Hough transform was developed. We discussed the performance of this lane detection algorithm on a PC and on an iPhone. Experiments show that our scheme is practical, and the next generation of iPhones will allow to implement even more advanced techniques.

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