Abstract

We propose a lane keeping assistance system which warns the driver on unintended lane departures. Based on an existing robust video-based lane detection algorithm we compare different methods to detect lane departure. A number of assumptions on driver behaviour in certain situations have been integrated to distinguish between intended and unintended lane departures. We integrated our lane keeping assistant in an experimental car and performed systematic experiments in real traffic situations.

1 Introduction

The safety of driving cars could be significantly increased by using driver assistance systems which interpret traffic situations autonomously and support the driver [1]. An important component of such a system is the evaluation of image sequences recorded with cameras mounted in a moving vehicle. These image sequences provide information about the vehicle’s environment which has to be analysed in order to support the driver in real traffic situations. A systematic overview on the development of image sequence analysis systems for road vehicles is given in [2].

Especially, the driver’s task of keeping the lane should be monitored by a driver assistance system. In modern cars the access to relevant parameters like velocity, blinker and braking state are available without additional costs. Furthermore, video-based lane detection systems have shown to provide the necessary information about the lane geometry [3, 4]. Therefore, a lane keeping assistant is within reach.

The main causes that a driver is getting off the road are inattentiveness and fatigue. These inner states of the driver can be concluded by measuring the driver’s activity. There are in principal two different ways to do this: to measure the performance of the lane keeping task itself or to measure variables which are directly influenced by the driver, e.g. steering angle.

A well known indicator of lane keeping performance is to calculate the time to line crossing (TLC), i.e. the predicted time when the car tire will cross the lane boundary assuming a constant motion of the car.

Based on the TLC, Renner and Mehring [5] detect the driver fatigue by an analysis of the lateral vehicle position, the steering angle, and the velocity. The work of Kreucher et al. [6] computes the TLC by a time dependent function of the lateral distance to the lane border. Batavia et al. [7] show a memory-based method of calculating the TLC. A prior trained array of frequency distribution of future lateral vehicle positions related to the current position and the velocity serves as a basis to the TLC calculation.

LeBlanc et al. [8] and Kovacs et al. [9] faced the problem of active intervening by different decelerations of the front wheels and thus correcting the driving direction when the car tends to leave the road. The system introduced by Onken [10] also provides a time to collision (TTC) with preceding vehicles.

Driver influenced variables are e.g. steering activity, braking and gas pedal operation as well as setting the blinker. Such parameters can be indicators to detect driver fatigue. Fairclough [11] compared three fatigue indicators: psychophysiology measures like electroencephalograms (EEG), primarily driver influenced variables like steering angle and velocity and a subjective evaluation of the own fatigue state. Siegmund et al. [12] found a strong correlation between the steering wheel movement, control measures like EEG, and a subjective evaluation of the driver state by video recording of the driver in action. They suggest the steering wheel as a potential indicator of fatigue. Richardson et al. [13] explored the impact of fatigue to the driving performance over long driving time periods. The fatigue was determined by EEG measures.

This contribution presents a video-based lane keeping system which combines the evaluation of different lane departure detection algorithms, the blinker and braking state
as well as the steering activity. The system generates an acoustic signal when the driver tends to leave the road.

2 Situation Analysis

In the beginning it was important to clearly determine when a warning should be issued. We defined nine basic situations. On the one hand, there are three possible forms of the lane: “straight”, “left bend”, and “right bend”. Each of them can be combined with “keeping the lane”, “leaving the lane to the left”, and “leaving the lane to the right” on the other hand.

In the situation “keeping the lane”, clearly, no warning should be given, regardless of the form of the lane. In the cases “leaving the lane”, warnings should be issued only when the lane is left unintentionally. It is necessary to monitor the behaviour of the driver to detect intentional lane leavings. Situations with intentional leaving are

- lane changes,
- corner cuts,
- evasive manoeuvres in emergency cases.

Warnings in these situations are regarded as false warnings (false positive). To achieve a high user acceptance of the system, no false positives are allowed. Important states of the car which allow to monitor the driver intentions are

- blinker state (off, left, right),
- braking,
- steering angle.

These informations can be easily obtained from a car network, e.g. a CAN-bus.

To describe the position of the car relative to the lane, we use a clothoid model. It uses the following parameters:

- lane width \( b \),
- horizontal lane curvature \( c_{h0} \),
- lateral offset \( y_0 \) of the car to the lane centre,
- gear angle \( \phi_1 \) of the car relative to the tangent on the lane.

These parameters are obtained by using a robust lane detection system described in [4].

The lane model presented in [4] was simplified to analyse lateral offset, orientation and motion of the vehicle. We neglected, e.g., the vertical curvature of the road. To describe the vehicle position with respect to the own lane we used a planar coordinate system which coincides with the road surface. The lateral offset \( y \) is measured from the center of the lane, and the distance \( l \) from the car is measured along the tangent to the current lane borders.

In this coordinate system, the lane borders can be approximated by clothoides which are described by the equation

\[
y(l) = \pm \frac{b}{2} + \frac{1}{2} c_{h0} l^2 + \frac{1}{6} c_{h1} l^3,
\]

where \( c_{h1} \) is the change rate of the horizontal curvature. The plus and minus sign is used for the right and left lane border, respectively.

Since the curvature change rate \( (c_{h1}) \) was close to zero, the last term was ignored, hence leaving an easier to handle second order equation:

\[
y(l) = \frac{b}{2} + \frac{1}{2} c_{h0} l^2 \quad (2)
\]

3 Detection of Lane Departure

3.1 The Car’s Current Position

The easiest way to detect the departure of the lane is to check the car’s current position (CCP) in the lane. The position is estimated by the lane detection algorithm. The lateral offset \( y_0 \) denotes the distance between the center of the lane and the center of the car. Since the gear angle is small, the car is approximately parallel to the lane. With the given car width \( b \), the position of the front wheels relative to the lane borders can be computed by the equation

\[
\Delta y = \begin{cases} 
\frac{b}{2} - \left( y_0 + \frac{b}{2} \right) & \text{if } y_0 + \frac{b}{2} < 0 \\
\frac{b}{2} + \left( y_0 - \frac{b}{2} \right) & \text{if } y_0 - \frac{b}{2} > 0 
\end{cases}.
\]

The current lane width \( b \) is also estimated by the lane detection algorithm. The upper and lower line of Eq. 3 correspond to the position of the right and left wheel relative to the right and left lane border, respectively.

The car is inside a lane when both front wheels of the car are still inside the lane. This is the case when \( \Delta y > 0 \) in both cases. No warnings are necessary here. As soon as one wheel crosses the lane border on its side, the car leaves the lane (Fig. 1). Then, \( \Delta y < 0 \) on the corresponding side of the lane. Weather a warning is necessary or not depends on the driver’s intention (see Section 5).

With this approach, only lane departures can be detected when they actually happen, but this can be too late for a warning. This problem can be avoided by assuming a virtual lane width which is slightly smaller (e.g. 30cm on motorways) than the actual one. So the driver will be warned earlier. Surely, drivers who use the full lane width would not accept the system, since some unexpected warnings will occur.
3.2 Time to Lane Crossing

To detect a possible lane departure early, we considered a Time to Lane Crossing (TLC) approach. According to an assumed model of the car’s motion during the next seconds, the time is estimated when the car will leave the lane.

Two different motion models are considered. The first model assumes that the car keeps its current direction (Fig. 2). The direction angle $\theta$ relative to the lane is given by summing gear angle $\phi_1$ and sideslip angle $\beta$ which is the angle between the vehicle’s longitudinal axis and its direction. The sideslip angle can be computed from the steering angle. The assumed motion is then described by the equation

$$y(l) = y_0 + \theta l.$$  \hspace{1cm} (4)

The second model assumes that the driver will almost keep the current steering angle during the next seconds. Thus, the car will move on a curve which should fit to the current lane curvature (Fig. 3). The car motion curve is modeled similar to the lane border clothoide model. It is approximated by the equation

$$y(l) = y_0 + \theta l + \frac{1}{2} c_r l^2$$  \hspace{1cm} (5)

where $c_r$ is the curvature of the curve of the car and can be computed from the current steering angle.

In both cases, the equation describes the motion of the car center. The wheel motion is described obviously by regarding the car size:

$$y_{L/R}(l) = y(l) \pm \frac{b_c}{2}.$$  \hspace{1cm} (6)

The intersection of the motion curve with the corresponding lane border curve (Eq. 2) gives the presumed distance of the lane crossing. The TLC is computed with the velocity of the car. If this time exceeds a certain threshold, no warnings are necessary.

4 Monitoring of the Car Driver’s Behaviour

We have to distinguish between two cases of lane departures, intended and unintended departures. By monitoring certain actions of the driver, assumptions about his intention can be taken. Obviously, setting the blinker announces a following lane change. Lane departures after setting the blinker are almost surely intended.

Breaking will occur often in emergency cases together with evasive manoeuvres. It is usually safe to assume that a driver is conscious and watching the traffic when he brakes. Therefore, warnings are suppressed in these cases.
Another activity of the driver is steering. His steering activity can be monitored by analysing the Fourier transform of the steering angle (Fig. 4). The power spectrum of the steering angle over time leads to a useful measurement of the steering activity.

The steering activity measure was used in two different ways. We introduced two thresholds for low and high activity. Under low steering activity conditions, e.g. on long straight roads, it is assumed that the driver might get inattentive easily. Thus, warnings are given earlier by using a virtual lane with reduced width (10 to 30 cm smaller) instead of the actual lane. High steering activity indicates actions of an attentive driver, e.g. in evasive manoeuvres. Warnings in these cases might disturb the driver and are therefore suppressed.

5 Intended Leaving

To avoid false warnings during intended lane departures, additional information is necessary. We considered the following intended departures:

- lane changes which are announced by the driver using the blinker,
- emergency manoeuvres with brake and high steering activity,
- leaving the lane partly for a short time when cutting a curve.

Additionally, we considered an overall activity criterion. Before changing a lane drivers are obliged to set the blinker to the according direction. So, if the blinker is set while departing the lane, warnings are suppressed. If the driver brakes he already reacts to some situation and is most likely aware of the situation. Additional warnings would be disturbing in such cases and are therefore suppressed. The same argument holds if there is a high steering activity.

Drivers who cut corners surely will not accept a system that warns in such situations. Using the TLC approach to detect lane departures, it is possible to estimate not only the exit point but also the reentry point of the car into the lane (see Fig. 2). This information can be used to detect the situation “cutting the curve” and thus avoid an unnecessary warning. Cutting the curve is assumed when the predicted track of the car reenters the lane within the maximum lookahead of the lane tracker.

6 Experimental Results

The situation–dependent lane keeping system has been integrated into our driver assistance system [4]. The system works on gray level images taken by a single camera fixed at the front window of the vehicle. It runs on a 450 MHz standard PC with a Pentium II processor with Windows NT. No special hardware components have been used. The system has been integrated into an experimental vehicle which is equipped with a CAN bus and an additional analogue module to measure the internal states of the car.

If the lane keeping assistant detects an unintended lane departure, an acoustic warning is emitted using the speakers
of a stereo car radio. The signal sounds similar to a tire rolling over some nail markings in the road. We used balance control to signal the direction in which the vehicle will leave in order to stimulate a safety enhancing driver action [14].

Experiments have been performed online in the car by different drivers on motorways and ordinary roads. Journeys of the authors between Karlsruhe and Dresden (ca. 550 km) as well as to our project partner in Hildesheim (350 to 450 km) have been extensively used for experiments. During these experiments, a data base of about 10 Gigabyte of image sequences has been taken in a variety of scenes with different environmental conditions which were used for a detailed analysis of warning situations.

The system was tested by some drivers. Different situations have been analysed using situation diagrams (Fig. 5 and 6). Important criteria to evaluate the system performance were the drivers’ comments to the system behaviour.

Using the CCP method, the system warns only when the car actually leaves the lane (see Fig. 5). All drivers accepted these warnings. No false warnings are given, except when cutting a curve.

The TLC method was developed to recognize cuttings of curves by comparing the estimated track of the car with the current lane. The prediction of the car’s position is very sensible to the assumed motion model. A lot of false warnings occurred. More sophisticated motion models are necessary to achieve a more reliable prediction of the car’s position.

A higher robustness can be achieved by monitoring the driver activity. Driver activity such as braking, setting the blinker, and high steering activity leads to a suppression of warnings.

As well, earlier warnings can be issued when the steering activity is lower than normal, so that the reaction time can be increased. But the adjustment of the parameters for the steering activity has to be very accurate to achieve a well operating system. Also, these parameters are driver dependent.

The time requirements of the warning algorithm can be neglected compared to the amount of time necessary for the lane recognition module, which runs in about 10 ms per image.

7 Conclusion

We proposed a prototype lane keeping assistant module for an integrated driver assistance system which handles a variety of situations to decide whether warnings are necessary or not. Different warning algorithms have been combined to achieve a more robust assistance function.

Modelling cutting a curve as an intended lane departure without a warning does not include that it is safe to cut the curve. More information about the environment, e.g. other traffic participants and lane border consistence, will be necessary to distinguish safe and unsafe situations.
Investigating user acceptance of the warning signal is still necessary. An important task to increase the overall acceptance is to evaluate the actual driving history to adapt the reactions of the system to the more global behaviour of a driver.

8 Acknowledgements
We thank W. Oertel for helpful comments on a draft version of this contribution. This work has been supported by Robert Bosch GmbH, Hildesheim.

References


