Road border detection and tracking in non cooperative areas with a laser radar system.

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Abstract

In automotive applications, especially for driver support systems or autonomous transportation systems, the precise knowledge of the road border in front of the vehicle is fundamental. The basic idea presented in this paper is to detect and track the road border in the difficult case of non cooperative areas (no white lines, etc.) with a laser radar system. A two step approach has been developed: algorithms for the detection of the road border in a single scan based on statistical approaches, and tracking algorithms to estimate the road border from the generated detections. The presented results show that the solution works in several different road scenarios. For the development and verification of the road border signal processing, a specially equipped electro mobile is used.

1 Introduction

This paper treats an important problem concerning the reliability of driver assistance systems. Such systems often need information not only about obstacles in front of the car but also about the road edge, in order to distinguish dangerous obstacles on the street from unimportant ones beside the street. The precise knowledge of the road edges can be useful in other applications: for example, in autonomous transportation system applications and driver assistant systems, for warnings in case that the car crosses the road border.

A lot of work has already been done to detect the lane and road borders. Several approaches use vision based sensors, especially CCD-cameras (e. g. [1] , [2]). In case of daylight, good weather conditions and white border lines, this approach reaches reasonable results. But in non cooperative areas and during the night or in bad weather conditions, the white lines are not always visible, so this approach fails. We show the capability of the laser scanner in this difficult case of non cooperative areas.

A scanning laser system is used for this work. A laser scanner is nearly independent on the measuring time (night or day) and it is a high resolution measuring system: it is able to detect white lines as well as deliver detections on roads without boundaries (guardrails, etc.). The used laser radar is a LMS 221 from SICK AG. The high frequence scanning system is based on a mechanical rotating mirror and delivers 180 degrees measurements. The maximal horizontal angle resolution is 0.25 degrees, and the maximal scanning frequency is 75 Hz. In our application the system runs with 0.5 degrees horizontal angle resolution, 38.5 Hz and with a scanning angle of 100 degrees. For all of the 200 measurement points, the scanner delivers a range and a reflectivity value. The maximum measurement distance is 80 meters at a resolution of 10 cm. The scanner is mounted in front of the test vehicle in such a way that the measuring plane cuts the ground plane at a fixed distance. In

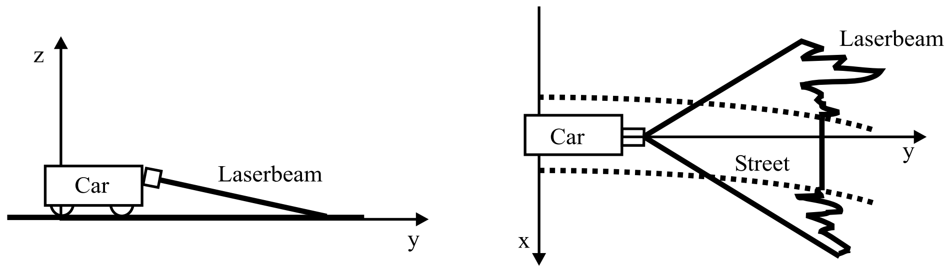

Figure 1: Embedding of the laser scanner

this way the measurements are independent on the road boundaries as, for example, guardrails [3]. Figure 1 shows the embedding of the sensor. The scanner is connected to a PC via a high speed serial link. The PC is able to collect all range and reflectivity values in real time.

2 Detection algorithm

The aim of the detection algorithm is to extract the road edges from the raw data. For every scan the LMS delivers 200 range and reflectivity values with their according angles. In general, both values can be used to detect the road border. The detection algorithm for the reflectivity values is based on statistical approaches and is under development, at the moment, as well as the data fusion algorithm combining the reflectivity and range data. Typical reflection values are shown on the left side of figure 2.

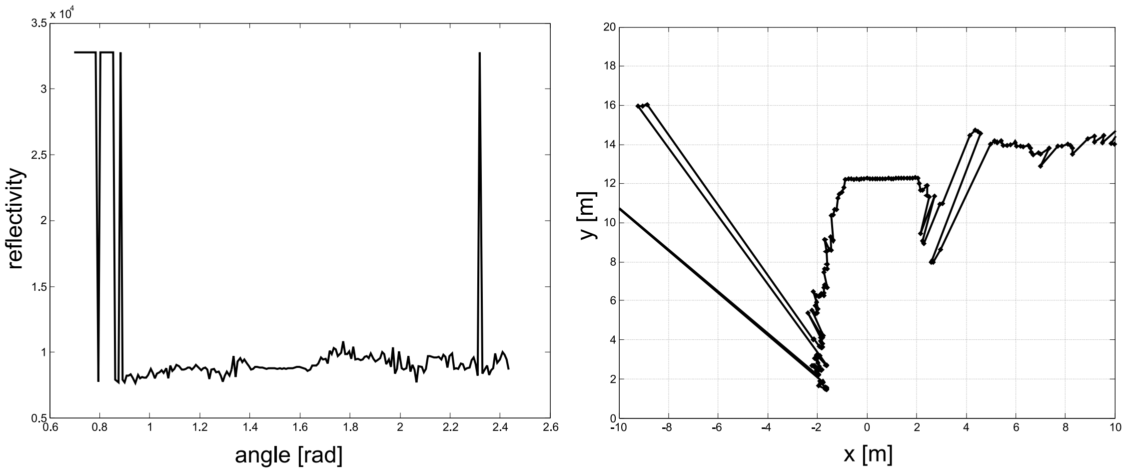

Figure 2: Examples for typical scans

Using the range values for detection, the street appears as part of a straight line. On the right side of figure 2 a typical scan, transformed into a cartesian coordinate system, is shown. This part of the detection algorithm is introduced in more detail below.

Every planar surface in the measured environment turns out as a peace of a straight line in the scan. For this reason the road appears as a planar surface but, in general, more than one planar area exist in a scan. The presented approach follows the idea, first to estimate these straight lines and then to define a segment on them which represents the road together with the edges of the road.

So the detection algorithm can be divided in two parts: the first part estimates one or more possible lines, the second part defines the segments.

Straight line estimation
A straight line in the cartesian coordinate system can be described by the equation

$$y = ax + b, \tag{1}$$

with the unknown parameters a and b. These both parameters have to be set for every line. The slope a will be estimated first for the whole scan (see figure 3) and will be calculated only using the values

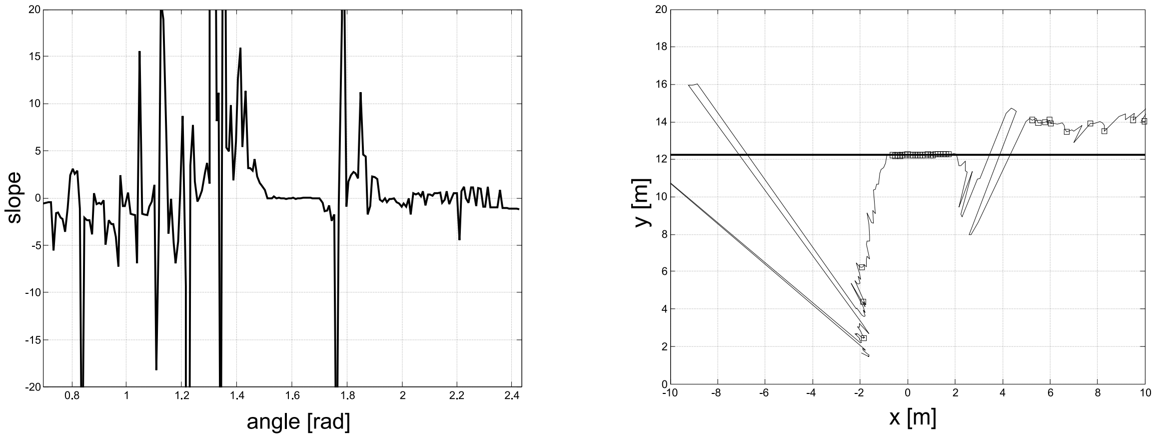

Figure 3: Slope and estimated straight line

corresponding to the maxima of the histogram. Statistical analysis shows that only these values belong to the street, as the areas beside the street are noisy and will contribute to the rest part of the histogram. By calculating and interpreting the histogram over the derivated values, one or more parameters a can be found. The possible parameters a are collected and the according parameters b have to be estimated. This is again done by analyzing the statistical conditions. As output of this algorithm, a collection of parameter pairs representing straight lines can be denoted as

$$P = \{(a_1, b_1), (a_2, b_2), \; ... \; (a_n, b_n)\}. \tag{2}$$

Segment definition

With the help of the pairs in (2) a segment for every possible road can be defined. The approach is based on the fact, that just the measured points belonging to the street are close to the estimated line. An example, with only one estimated line, is shown in the right part of figure 3. The algorithm calculates the variance of local parts of the scan. This method is able to detect the road edge precisely. The result of the edge definition is a list of point in the x-y coordinate system, labeled as right or left border.

3 Estimation model

A model based estimation system is used to track the road border. The model includes a number of state values and a measurement function. This is expressed in the two basic state equations

$$\begin{aligned} \mathbf{x}(k+1) &= A(k)\mathbf{x}(k) + \mathbf{w}(k) \quad (3) \\ \mathbf{y}(k) &= C(k)\mathbf{x}(k) + \mathbf{v}(k), \quad (4) \end{aligned}$$

where $\mathbf{w}(k)$ describes the error of the model and $\mathbf{v}(k)$ describes the measurement error. The discrete Kalman filter algorithm, as described for example in [4], first predicts the state vector and the uncertainty in the state. Then measurements can be associated to the state, transformed in the measurement space. With the help of the uncertainty of the measurement and the uncertainty of the state, the Kalman filter computes the optimal weight for the new measurements. Finally the updated state and its uncertainty is computed.

As shown above, the detection algorithm delivers a list of points in cartesian coordinates. Under the assumption that the pitch of the car is zero, the y values in this list are normally more or less at a fixed level (figure 1). With this model, an estimation of the road border at a fixed distance in front of the car is reached. The state vector is therefore composed of the x_{vc} values

$$\mathbf{x}(k) = \begin{bmatrix} x_{vc} \\ x'_{vc} \\ x''_{vc} \end{bmatrix} \tag{5}$$

with

$$x'_{vc} = \frac{d\, x_{vc}}{d\, s}, \qquad x''_{vc} = \frac{d\, x'_{vc}}{d\, s}. \tag{6}$$

Besides the measured value x_{vc}, the state space contains the slope and the variation of the slope. In (6) Δs is the distance, covered by the mobile during the time interval T assuming that the tangential movement is a good approximation for our electro-mobile. The state transition matrix $A(k)$ is defined as

$$A(k) = \begin{bmatrix} 1 & v_{veh}T & \frac{1}{2}(v_{veh}T)^2 \\ 0 & 1 & v_{veh}T \\ 0 & 0 & 1 \end{bmatrix}. \tag{7}$$

The measurement matrix C transforms the state space into the measurement space and is defined as

$$C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, \tag{8}$$

the measurement vector is a scalar

$$\mathbf{y}(k) = [x_{vc}(k)]. \tag{9}$$

The system can be modeled as a linear system because the relevant range values from the laser scanner are assumed to be fixed. Under this assumption, the covariance of the measurement noise becomes

$$R = (y \sin(\sigma_\alpha))^2 \tag{10}$$

where σ_α is the standard deviation of the measured angle.

Two Kalman filters are initialized for both, left and right road border. The state, at the starting point $\mathbf{x}(k_0)$ of the filter, is calculated from the first measurements which are set as starting value for the filter. Figure 4 shows an example for this estimation algorithm. On the y axis the time is shown, the x axis shows the measurements and the fused state as lines.

3.1 Gating and data association

The gating function preselects measurements which probability, that this measurements belong to the estimated track, is high. In this approach, the gating is obtained using the transformed uncertainty description P, as explained in [5] and [6]. As the detection algorithm delivers few false alarms close to the true road border, a simple standard data association can be used. So the used algorithm is the Nearest Neighbor Standard filter (see also [7]). The two methods are stable in this estimation environment and they are comparatively less complex. Using also the reflectivity detections, it is possible to combine both information in the data association algorithm.

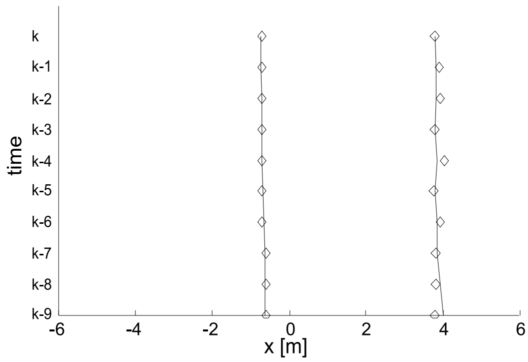

Figure 4: Tracking results

4 Conclusions

The presented approach for detection and tracking of the road border is working well in very different areas. Test have been made in unstructured areas. In these areas the algorithm is stable as under normal conditions. The Kalman filter approach reduces the noise of the measurements and the filter is working also, when, in several scans the detection algorithm was not able to deliver information. Depending on the sensitivity of the laser scanner, the road border can be detected at further distances and in low reflecting situations.

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