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The road surveying system of the federal highway research institute – a performance evaluation of road segmentation algorithms

R. Streiter and G. Wanielik

Chemnitz University of Technology, Professorship of Communications Engineering , Reichenhainer Str. 70, 09126 Chemnitz, Germany

Correspondence to: R. Streiter (robin.streiter@etit.tu-chemnitz.de)

Abstract. The construction of highways and federal roadways is subject to many restrictions and designing rules. The focus is on safety, comfort and smooth driving. Unfortunately, the planning information for roadways and their real constitution, course and their number of lanes and lane widths is often unsure or not available. Due to digital map databases of roads raised much interest during the last years and became one major cornerstone of innovative Advanced Driving Assistance Systems (ADASs), the demand for accurate and detailed road information increases considerably. Within this project a measurement system for collecting high accurate road data was developed. This paper gives an overview about the sensor configuration within the measurement vehicle, introduces the implemented algorithms and shows some applications implemented in the post processing platform. The aim is to recover the origin parametric description of the roadway and the performance of the measurement system is being evaluated against several original road construction information.

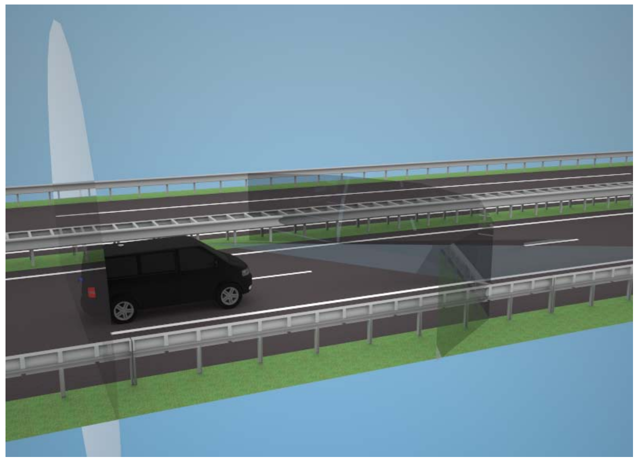

Fig. 1. The measurement vehicle is based on a Volkswagen Multivan witch was prepared to incorporate all sensors (5 cameras in front, lane mark detection system, high accurate positioning module with inertial measurement unit and a laserscanner).

1 Introduction

The structure of federal roads and highways is subject to many construction rules that ensure safe and comfortable driving even at high velocities. To verify and monitor the state and the course of roads the highway research institute commissioned a multisensory equipped measurement vehicle including Cameras, lane mark detection system, laser scanner and high precision positioning components with inertial measurement unit in order to observe the state of roads. The aim of that work is to give an overview and a performance evaluation of the implemented algorithms that recover the parameters of the roads from the raw data collected by the measurement system. Several segmentation approaches were evaluated – Unscented Kalman Filter, Hough Transformation and (RANdom SAmple consensus) RANSAC. For several roads original planning information was available as ground truth that leads to an absolute performance evaluation of all approaches. The concept and all technical details about the measurement system are introduced in Streiter et al. (2012). This paper is focused on the software algorithms that were implemented in order to recover the original parameters that can describe the characteristics of the road parametrically.

2 Measurement system

The whole system is divided into two separate units. There is the actual measurement vehicle equipped with a multisensor

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platform where all data is recorded and there is a postprocessing unit where all data is visualized and mapped to existing road meta-information. That platform offers many opportunities to evaluate different data fusion algorithms. Within that work the road segmentation algorithms are introduced. The course of a road will be estimated by a parametrical description of its road elements. To ensure a continuous curvature profile of a roadway, prescribed road elements are used for the planning and dimensioning of a road. Here, the elements straight line, clothoid and circular arc are used for designing federal roads and highways. These elements are joined in that order with the function of the clothoid to fit the curvature of the circular arc to the straight line with respect to the curvature continuity.

3 Segmentation algorithms

There are several profiles of the road which parameters can be determined along the runlength of a given segment. The descripting parameters for each profile of a road segment are shown in Table 1.

Most challenging task is to determine the transition points between the segments. In order to do this, several approaches were implemented. On the one hand there are consecutive algorithms, where the position measurements are given consecutively. An Unscented Kalman Filter was used here to estimate the parameters of a road segment, including all measurements arrived up to the last time step. When the generated segment violates a given error threshold, all arrived measurements are discarded and the last estimated segment is accepted. All following measurements are assigned to the new segment. These approaches have the disadvantage that available knowledge about the future is ignored and the transmission points are recognized too late. That makes the algorithm find more small segments in a given sequence than it is actually containing. The currently used algorithm will process all position measurements from the whole sequence. Number and describing parameters of the containing segments are estimated by a RANSAC Xu und Lu (2012) approach that – thanks to the given future knowledge is able to optimize the transmission points in both directions. Due to the algorithm is implemented in a post processing application there is no need for an online solution.

3.1 Unscented Kalman filtering

The main condition for estimating the curvature profile of a road segment is the continuous curvature along the whole path. That requirement is satisfied by matching the path trough a set of clothoids. A fundamental introduction into clothoid mathematics is given in Wilde (2009) and Shimizu et al. (2006). The special cases straight line and arc are also special cases of clothoids with $c_0 = 0$ and $\mathrm{dc} = 0$ for straight lines and $c_0 = \mathrm{const}$ and $\mathrm{dc} = 0$ for circle arcs. In road designing rules these two elements are connected by clothoids with a given $c_0 = \mathrm{const}$ and $\mathrm{dc} = \mathrm{const}$. That means, that the whole path can be described through a set of consecutive clothoids. The task is, to consecutively put the position measurements to the filter and let it decide weather to set up a new clothoid or to assign it to the current one.

3.1.1 Measurement model

The measurement model input are position measurements x_n in Universal Transverse Mercator (UTM) coordinate system[1] $x_{\mathrm{meas}}, y_{\mathrm{meas}}$. In order to transform the position measurements of the positioning module into parameters, the following measurement model is used. The state vector $\boldsymbol{X}$ consists of the clothoid parameters g_0, c_0 and dc. The task of the measurement model is to transform the measurements into the model, which parameters should be determined. As shown in Fig. 3 the corresponding point s on the clothoid to the point x_n must be calculated. The given clothoid in the image is generated from the UKF which proposes several values for $\boldsymbol{X}$. The distance between x_n and s is a measure for the fittnes of the proposed clothoid. That approach leads to promising results, but the curvature transition between the estimated clothoids is not continuous and the real transition points are not being recognized correctly.

To meet the continuous curvature condition the curvature at the end of the last clothoid must be equal to the curvature of the beginning of the new clothoid. One approach is to extend the measurement model to a set of two clothoids with a state vector containing the parameters of both clothoids. There are many approaches like in Schwartz (2003) that stated, data fusion algorithms are not able to estimate a set of parameters fitting the clothoid. It was shown that, due to the strong nonlinearity of the filtering problem the UKF is not able to converge, too. Therefore, the condition is implemented as shown in Gackstatter et al. (2010). The idea is to estimate two consecutive clothoids and then to fit the transition curvatures as proposed. That approach has the advantage to estimate clothoid elements, that are fitting well the given path. The disadvantage is, that it cannot detect the transition points between the original elements, correctly. That means a given path of several known consecutive elements is estimated to have more short elements than less long elements because they are fitting the given trajectory much better, due to more degrees of freedom. In order to find the correct number of elements requires an algorithm that gets all position measurements at once. The most common approach is to optimize the required parameters for a set of given measurements with the help of an optimizer (i.e. nelder-mead). Unfortunately, due to the unknown number of elements these approaches do also not deliver sufficient results. The approach introduced in the next section however, can handle all the requirements.

[1]Global coordinate system with plane cartesian projection.

Fig. 2. A cornerstone of the measurement system is the postprocessing application, where the road profiles are calculated. The image shows a screenshot of the camera images, where the laserscans are transformed to. A well-known RANdom SAmple consensus (RANSAC) implementation delivers the slope of the road from every laserscan. All slope measurements of a given road segment together are the input for the estimation algorithm which delivers a parametric description of the entire course of the segment.

Table 1. Profiles of the road, which parameters are estimated along the runlength of the given set of measurements (segment).

profile	description
curvature	The curvature profile contains the elements straight line, circle arcs and clothoids, the curvature values are calculated from the positioning module and are plotted over the length of the segment
height	Contains the elements straight line and circle arcs, the height values are derived from the height information of the positioning module and are plotted over the length of the segment
width	The width profile contains straight lines, the width values are calculated from the lane mark detection system and are plotted over the length of the segment
slope	The slope profile contains straight lines, the slope values are calculated from the laserscans and are plotted over the length of the segment

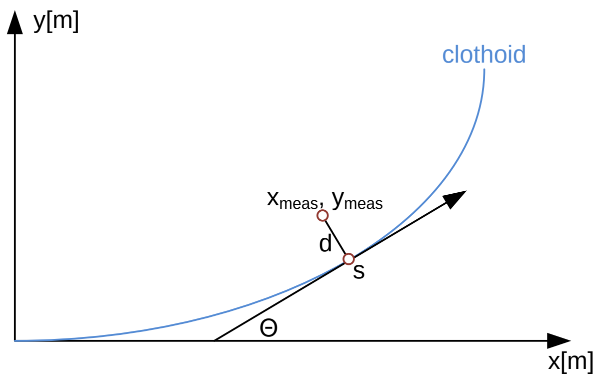

Fig. 3. The image depicts the measurement model of the Unscented Kalman Filter. The point $x_{\text{meas}}, y_{\text{meas}}$ is the position of the measurement in local clothoid coordinates, s is the corresponding base point of the measurement on the clothoid and θ is the gradient of the clothoid in s.

3.2 Hough transform

The Hough transform is a feature extraction technique used in image analysis, computer vision, and digital image processing. The purpose of the technique is to find imperfect instances of objects within a certain class of shapes by a voting procedure. This voting procedure is carried out in a parameter space, from which object candidates are obtained as local maxima in a so-called accumulator space that is explicitly constructed by the algorithm for computing the Hough transform. An illustrating application of the Hough transform is shown in Fardi und Wanielik (2004) where it is used for road border detection in infrared images. The idea behind the Hough transform was, to not directly estimate the parameters of the clothoids but to calculate the curvature in every point of the measurement set and then estimate the transition points from the resulting curvature graph. For that approach the Hough transform is implemented as edge-detection in images. Figures 4 and 5 show the results of the Hough implementation. The upper images show the transformed curvature measurements of a segment from the A72 and the L288. These images are the basis for the Hough Transformation. The lower images show the Hough image. Every segment in the Hough image can now be parametrically described as part of a linear function (How the clothoids are obtained from the linear segments is described in Sect. 3.3.

Due to the resulting elements in the Hough image are ambiguous that approach is also not suitable for a fully automated evaluation of several road sections.

3.3 RANSAC implementation

In RANSAC, the goal is to determine a set of inliers from an input data set of points. Inliers are data points consistent with the best model. Inliers and their corresponding model can be estimated optimally by repeatedly drawing samples from the input data set. A fundamental introduction was given in Fischler und Bolles (1981) and some common examples are proposed in Xu und Lu (2012). In order to find the dedicated segments in the given data sets of different road profiles, different models were implemented, that fit the data points. In

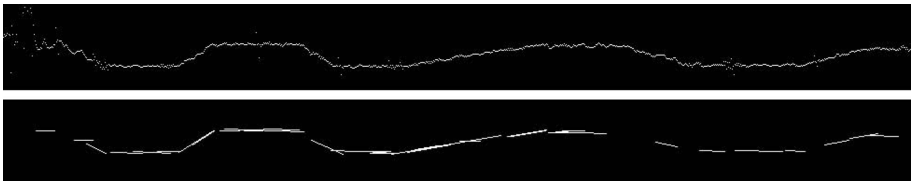

Fig. 4. The upper image shows the transformed curvature measurements of a segment from the A72. That image is the basis for the Hough Transformation. The lower image shows the image after the Hough Transformation. Every part of the image can now be parametrically described as part of a linear function.

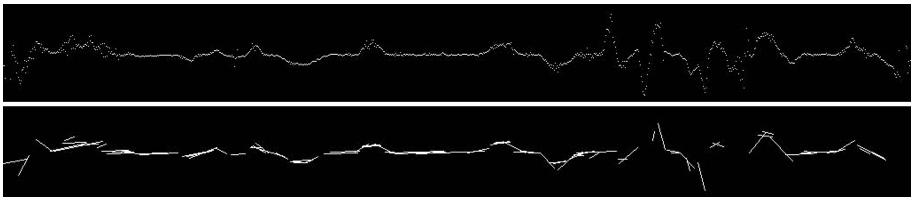

Fig. 5. The upper image shows the transformed curvature measurements of a segment from the L288. That image is the basis for the Hough Transformation. The lower image shows the image after the Hough Transformation. Every part of the image can now be parametrically described as part of a linear function.

the case of the curvature profile it is a quadratic fit model. In the case of the height profile it is a circle fit model and in the case of the slope and width profile a simple linear fit model is implemented. The following lines show the application of the RANSAC implementation on the curvature profile. Due to the strong nonlinearity of the operation $c = \frac{1}{r}$ in every point the calculation of the curvature of a given set of position measurements will always cause a very noisy plot of the curvature along the run length of the segment. This transformation is shown in the upper plot of Fig. 4. Obviously, that result makes it hard for any segmentation algorithm to determine the containing elements. Due to the noisy graph of the calculated curvature profile, the alternate approach is to obtain the curvature profile from the heading information of the positioning module. An example of the heading measurements is shown in Fig. 6. It is composed of different polynomials of 2nd order where the the curvature information can be derived from. The implemented RANSAC algorithm is able to find these polynomials in the following manner. Randomly heading measurements are drawn from the whole set of measurements until the best fitting polynomial (it is always the largest element in the group) is found. All measurements belonging to the element are deleted from the measurement list and the algorithm starts from the beginning until all measurements are erased. Figure 7 shows an overlay of Fig. 6 with the result of the RANSAC algorithm, where the 2nd order polynomials $h_n(x) = A_n x^2 + B_n x + C_n$ are plotted. The derivates of these polynomials are linear functions $c_n(x)$ where each is representing a clothoid with the following parameters. c_0 is the function value of $c_n(s)$ where s is the length on the segment in the beginning of the current element and dc is the gradient of $c_n(x)$. Figure 8 shows $c_0(x)$ to $c_{28}(x)$ of the given example.

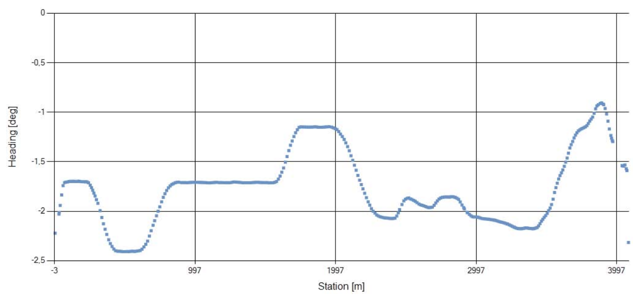

Fig. 6. The diagram shows the heading measurements of the positioning module. In contrast to the calculated curvature profiles, the heading information is a direct output of the positioning module and has a high quality of accuracy.

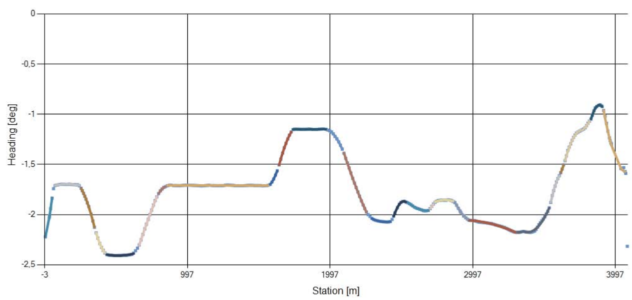

Fig. 7. The overlay to Fig. 6 shows the 2nd order polynomials as a result of the RANSAC algorithm.

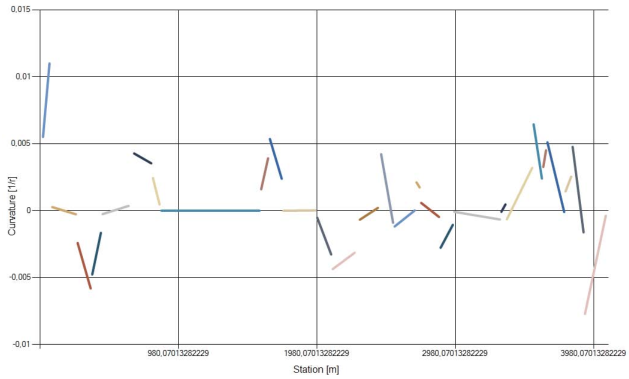

Fig. 8. The derivatives of the polynomials shown in Fig. 7 are shown in that diagram. The resulting graph is unambiguous and does – after some simple connection heuristic is applied – directly represent the curvature profile of the given road segment.

4 Conclusions

After an heuristic postprocessing of the generated plots of the RANSAC implementation (Application of some designing rules for roads), the results can directly (without any human revision) be included into the road database. The road segmentation algorithms and the road representation models will be applied in future research for robust relative positioning. Proposed road segments and the knowledge from the complex road models will be used to estimate the course of roads for several seconds and integrate that knowledge to new lane mark detection algorithms and for position smoothing of low cost GNSS receivers.

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