DARMSTADT
UNIVERSITY OF
TECHNOLOGY

PAL '99©

PROGRESS IN AUTOMOBILE LIGHTING

Department of Lighting Technology

September 28/29, 1999

FOUNTAIN AT MATHILDENHÖHE, DARMSTADT

PCNA Ex. 1027
U.S. Patent No. 9,955,551

628.9
SCHMI
99

Volume 6

Dept. of Lighting Technology, Darmstadt University

dedicated to

Mr. Reinhard Röpke

628.9
SCHMI
99

PAL '99©

28 / 29 September, 1999

Proceedings of the Conference

99
01891

Lichttechnik Darmstadt

Published by

Prof. Dr.-Ing. H.-J. Schmidt-Clausen
Darmstadt University of Technology

Eigentum der
AUDI AG
D-85045 Ingolstadt

Herbert Utz Verlag · Wissenschaft

München 1999

ISBN 3-89675-920-5

PAL '99: 2 Volumes, Vol. 5 & Vol. 6; not to be sold separately

Die Deutsche Bibliothek – CIP-Einheitsaufnahme
Progress in automobile lighting / Darmstadt, University of Technology, Department of Lighting Technology. Publ. by. H.-J. Schmidt-Clausen. – München : Utz, Wiss.
Vol. 6. PAL '99 : 28./29. September, 1999 ; proceedings of the conference / Lichttechnik Darmstadt. - 1999
ISBN 3-89675-920-5

Das Werk ist urheberrechtlich geschützt. Die dadurch begründeten Rechte, insbesondere die der Übersetzung, des Nachdrucks, der Entnahme von Abbildungen, der Funksendung, der Wiedergabe auf photomechanischem oder ähnlichem Wege und der Speicherung in Datenverarbeitungsanlagen bleiben, auch bei nur auszugsweiser Verwertung, vorbehalten.

Die Wiedergabe von Gebrauchsnamen, Handelsnamen, Warenbezeichnungen usw. in diesem Werk berechtigt auch ohne besondere Kennzeichnung nicht zu der Annahme, daß solche Namen in Sinne der Warenzeichen- und Markenschutz-Gesetzgebung als frei zu betrachten wären und daher von jedermann benutzt werden dürften.

Copyright © 1999 Herbert Utz Verlag GmbH

Druck: drucken + binden gmbh, München

Herbert Utz Verlag GmbH, München
Tel.: 089-277791-00
Fax: 089-277791-01
utz@utzverlag.com
www.utzverlag.com

Evaluation of the applicability of digital maps for the reconstruction of the real street shape

Alejandro Vukotich

Darmstadt University of Technology and Audi AG

Abstract

This paper focuses on the applicability of digital road maps, as they are used in commercial navigation systems, for the reconstruction of the street geometry. It points out a procedure to predict the accuracy of calculated curve radii depending on the quality of database. To obtain a satisfying approximation of the real street shape, appropriated interpolation and spline methods are used. Finally, an algorithm for radii calculation is demonstrated.

1 Introduction

With the advances and proliferation of navigation systems, the efforts of the automotive industry in making use of the employed geographical databases for different comfort and security applications, such as "Advanced Frontlighting System" (AFS) and "Automatic Cruise Control" (ACC), has grown in meaning and importance. Both systems can be improved with regard to functionality and robustness by evaluating the geometrical description of the forthcoming lane.

This paper demonstrates a procedure for a quantitative evaluation of the suitability of digital databases for the geometrical description of roads. The investigation efforts reported in this paper do not focus on the navigation system as a whole but on the underlying digital road map.

In chapter 2 the basics of digital road maps are presented, chapter 3 demonstrates a method to evaluate and compare existing databases. An example of evaluation is given in chapter 4, where different methods of

interpolation and an algorithm for radius calculation are demonstrated based on a selected test track.

2 Basics

2.1 Navigation System

Satellite navigation systems are characterised by low positioning accuracy (100 meters), limited availability, and integrity owing to masking effects. For exactness, these deficiencies have to be compensated for by complementary sensor data, such as velocity and yaw rate [8]. Therefore, once the actual position of the car is determined through the "Global Positioning System" (GPS), it can be matched to the database by using additional sensors, and so, the adequate route from point A to B can be calculated on basis of the digital map.

The use of the determined route for AFS and ACC goes along with high demands concerning availability and accuracy of the predicted lane, which leads to severe requirements on the vehicle positioning and the map matching algorithms, and clearly differ from the original purpose of navigation systems. After matching the actual position to the map, the shape of the street is to be derived by evaluating the corresponding extract of the database. For this procedure, it is a prerequisite that the digital road map is as accurate and updated as possible.

2.2 Digital Road map

The database installed within the car is generated in two steps.

First, the European streets are digitised by two main suppliers according to their rules and methods, which are company dependent. The digital data are then encoded in a standard "Geographic Data File" (GDF) format [2].

The second step comprises the reduction and conversion of the GDF database by the navigation system manufacturer into a system specific format where redundant information concerning navigability is removed.

In commercial digital road maps, streets are represented by polygons, where the spots represent the shapepoints and the interconnecting lines the street vectors. To each of them, additional information concerning specific properties is stored in form of attributes.

To generate the shapepoints and attributes, the database providers make use of two methods.

The first procedure consists of the extraction of information of detailed road maps that are available at public offices. These maps, mainly in the scale of 1:5000, are processed and evaluated with computers. Afterwards, a trained employee sets the shapepoints manually on the road map, and annotates the attributes. In this case, a certain subjectivity remains in the positioning of the shapepoints due to the influence of the human factor.

The second method to digitise a road network is by recording the geographical position delivered by a "Differential Global Positioning System" (DGPS) [6] while driving along the routes. In this case, an accuracy of one to three meters can be achieved, while the shapepoints are recorded in steps of one to two seconds. Usually, only a small number of the recorded shapepoints is stored in the final GDF database.

In both digitising methods no altitude information is collected. In this respect, to guaranty the quality of digitalisation, a subsequent verification of the data generated is done on field.

In order to run through all the stages described above, a year is required until a database can be commercially released. Taking into account that 20 percent of the street geometry changes each year, several problems concerning the information value of the digital map have to be expected. Furthermore, it has to be considered when applying such systems that large areas are only partially or not at all digitised.

The matter about how precise the database does match the real street geometry is analysed in the following steps.

Procedure

The procedure illustrated in this chapter aims at a quantitative evaluation of the accuracy of digital maps concerning their capability to give information about the real street shape. The goal is to get a global value and an evaluation method that can be given to a database manufacturer to test their digital map concerning the applications needs, without having to know the exact algorithms used by the applications. Figure 1 demonstrates the proceeding while the single steps are explained in more detail in chapter 4.

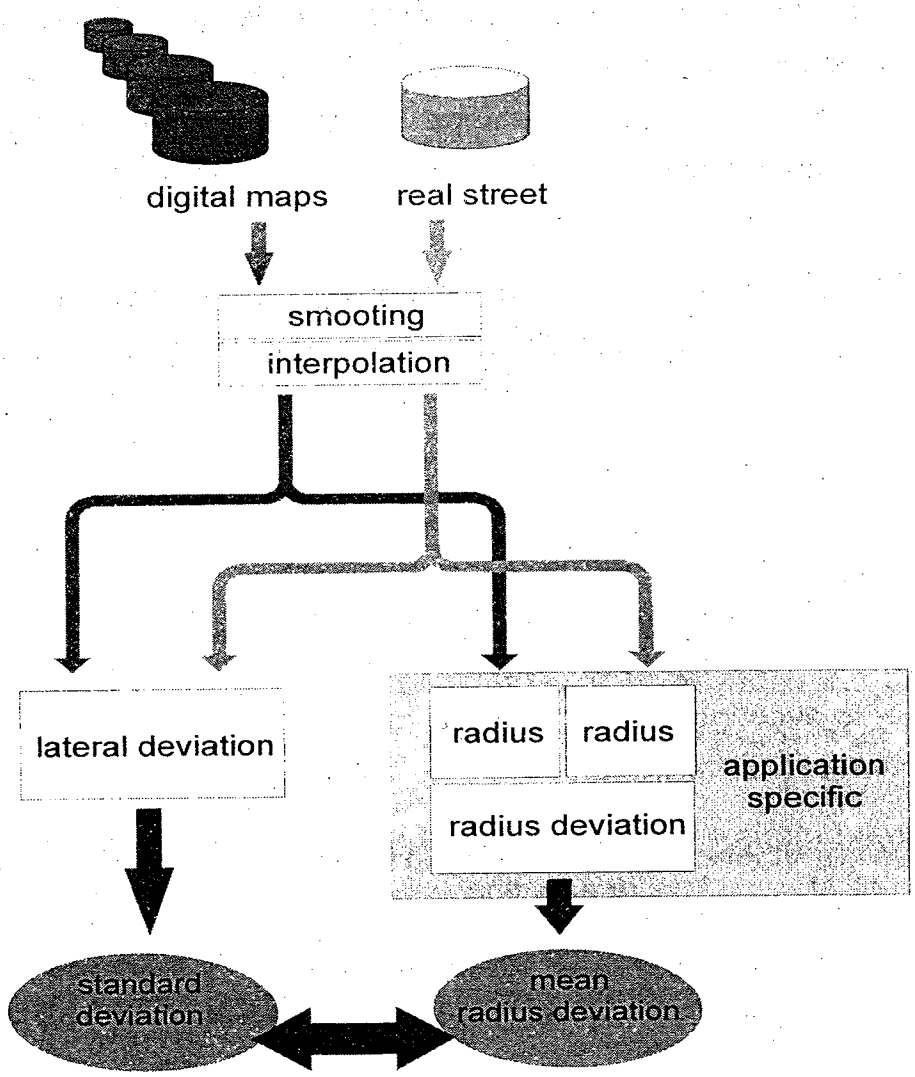

Fig. 1: Block diagram of proceeding.

The standard deviation of the distance between digital map and real street characterises how well the digital data matches the street geometry concerning shape.

The calculated radius of a curve, which is extracted from a digital map by using specific algorithms, can be used as reference for the evaluation of the underlying database. Specially, the mean error of the determined radius represents a value that differs clearly between different databases and algorithms that are applied for the calculation of the curvature.

A description of the functional dependency between the above demonstrated values, allows a deduction of a relatively simple to measure value to a complex one which represents the more appropriate criteria to describe the accuracy of a digital map in connection to a certain algorithm. In this investigation, the standard deviation of the lateral distance to the real street represents the simple, and the mean error of the determined radius stands for the complex value.

By analysing different databases without changing the algorithm for the radius calculation, a comparison between different digital maps can be achieved.

3 Investigation

3.1 Test course

A track of 2.5 kilometres length is used as reference for the following investigations. The country road segment disposes of three left and right curves, in order to avoid possible shape dependent influences on the evaluation and interpretation of the database.

Three digital road maps, named map A, B and C, are used and matched with the actual street shape. The description was taken from corresponding map material that was obtained from survey offices in the scale of 1:5000. Maps A and B correspond to the original GDF databases, while map C represents a possible navigation system specific road map.

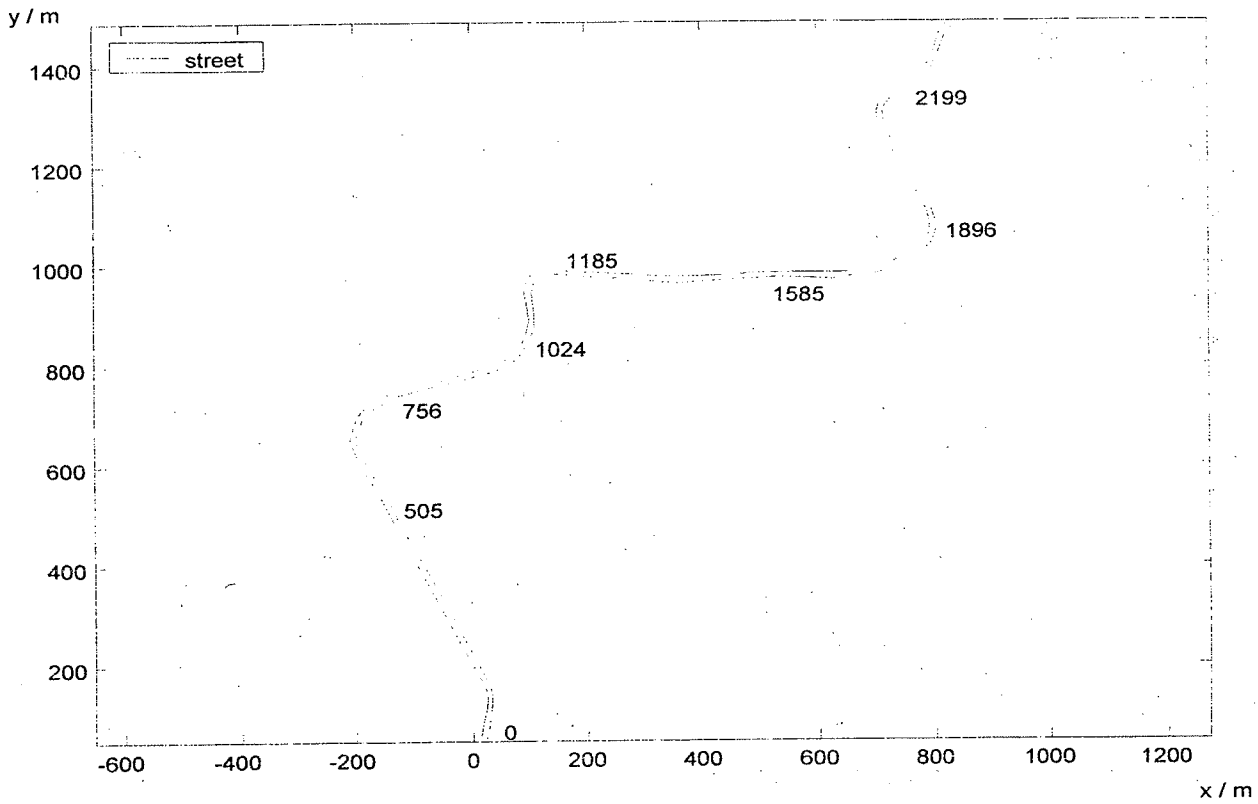

Fig. 2: Representation of the entire test track.

In Figure 2, the reference road segment is shown in its integrity. The track is exposed in a Cartesian system, where the axes are given in meters. The numbers beside the track represent the distance, measured along the course, from the lowest point of the track. The real street is drawn by the left and right delimiting survey points. Figure 3 shows the two curves at a distance of 1024 metres in more detail.

The individual points represent the shapepoints, the connecting lines, the street vectors. To describe a curve with similar lateral deviation values as in straight segments it is necessary to place a higher number of shapepoints. It can be clearly observed, that the density of shapepoints increases in curves.

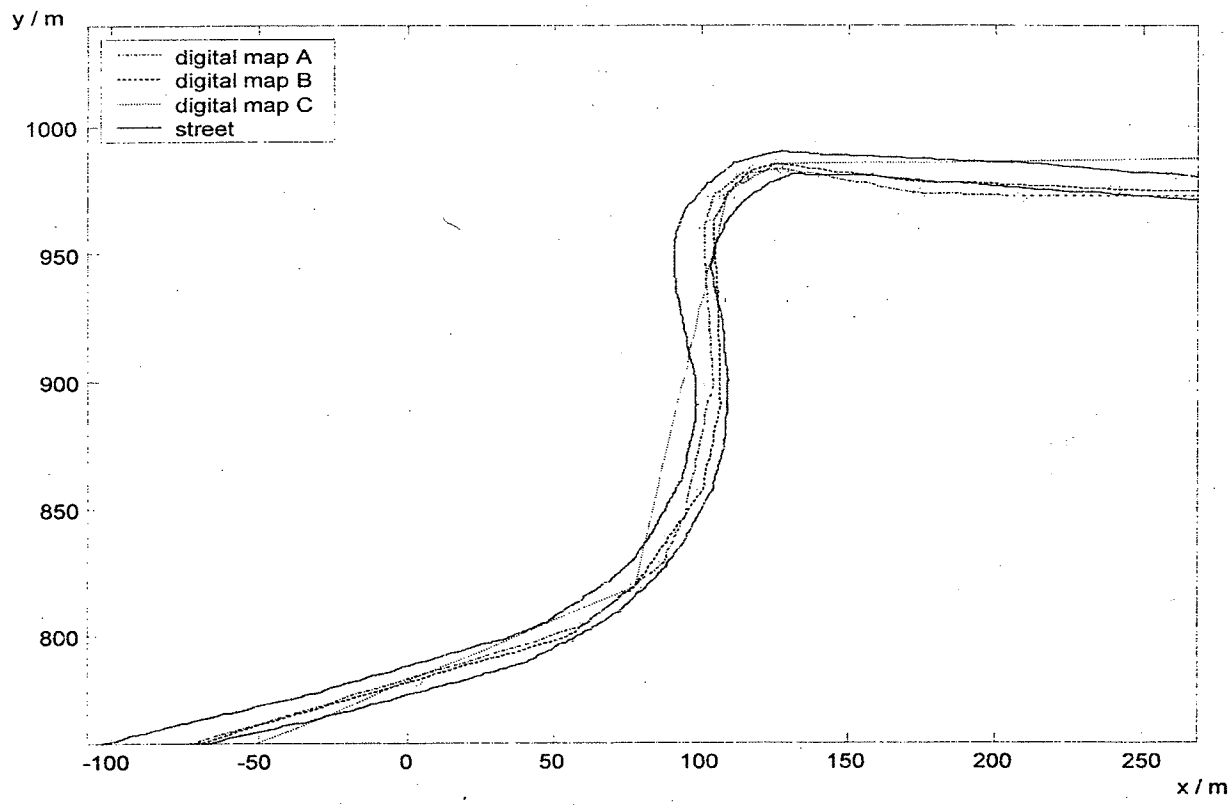

Fig. 3: Detailed representation of curves.

3.2 Interpolation

In order to achieve a good approximation of the real street course, interpolation methods are used to generate additional points between the shapepoints given by the database.

The methods analysed in this context are the *cubic* and *cubic spline interpolation* [7]. The linear interpolation was not considered due to the fact that it gives no further information about the curvature of the street. Figure 4 and 5 show the individual interpolation results based on map A. As reference, the street median was computed and also graphically represented.

The cubic and the cubic spline interpolation fits polynoms of third degree between the base points. Equation 1 shows the fitting function

$$f_k = A_k(x - x_k)^3 + B_k(x - x_k)^2 + C_k(x - x_k) + D_k. \quad (1)$$

Both interpolation methods demand continuity in the first derivation at the transition points (equation 2 and 3), while the cubic spline sets additional limiting conditions on the second derivation (equation 4).

$$f_{k-1}(x_k) = f_k(x_k) \qquad (k = 1,\ldots,n-1). \tag{2}$$

$$f'_{k-1}(x_k) = f'_k(x_k) \qquad (k = 1,\ldots,n-1). \tag{3}$$

$$f''_{k-1}(x_k) = f''_k(x_k) \qquad (k = 1,\ldots,n-1). \tag{4}$$

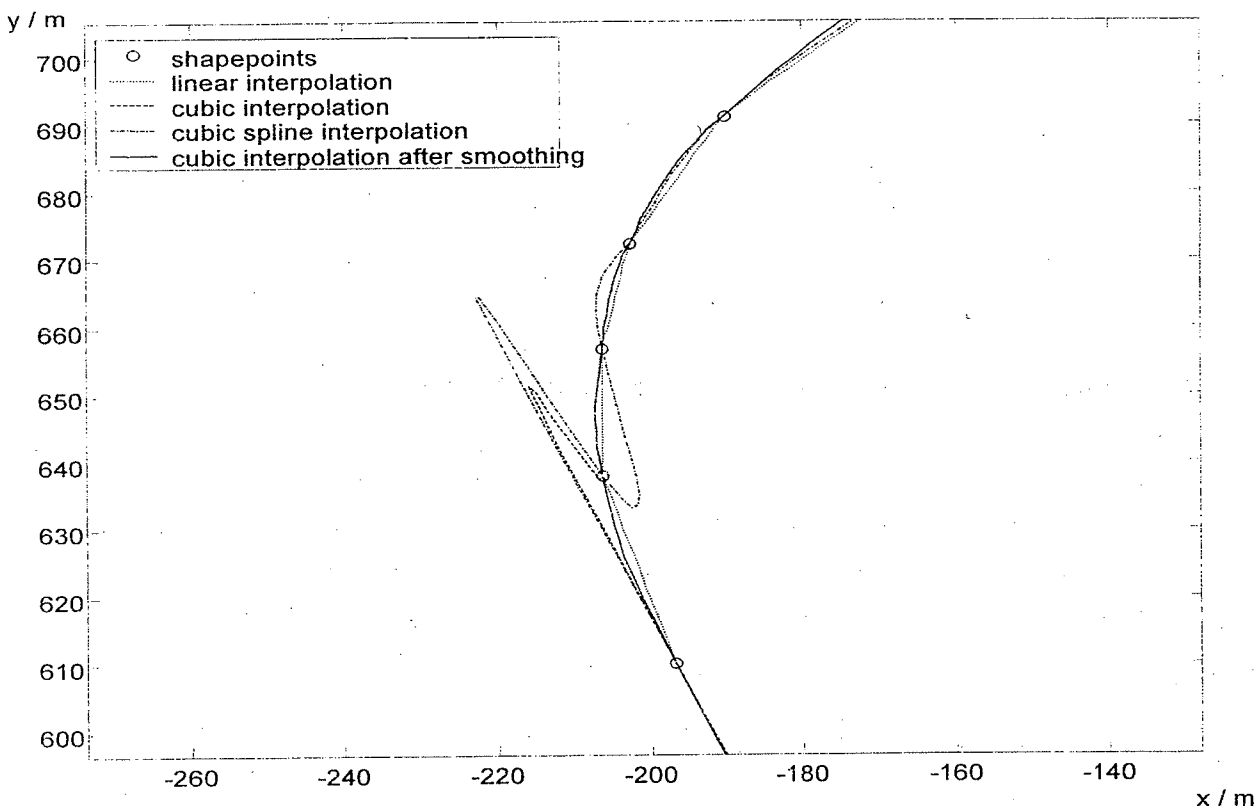

Fig. 4: Interpolation results, demonstrated based on map A.

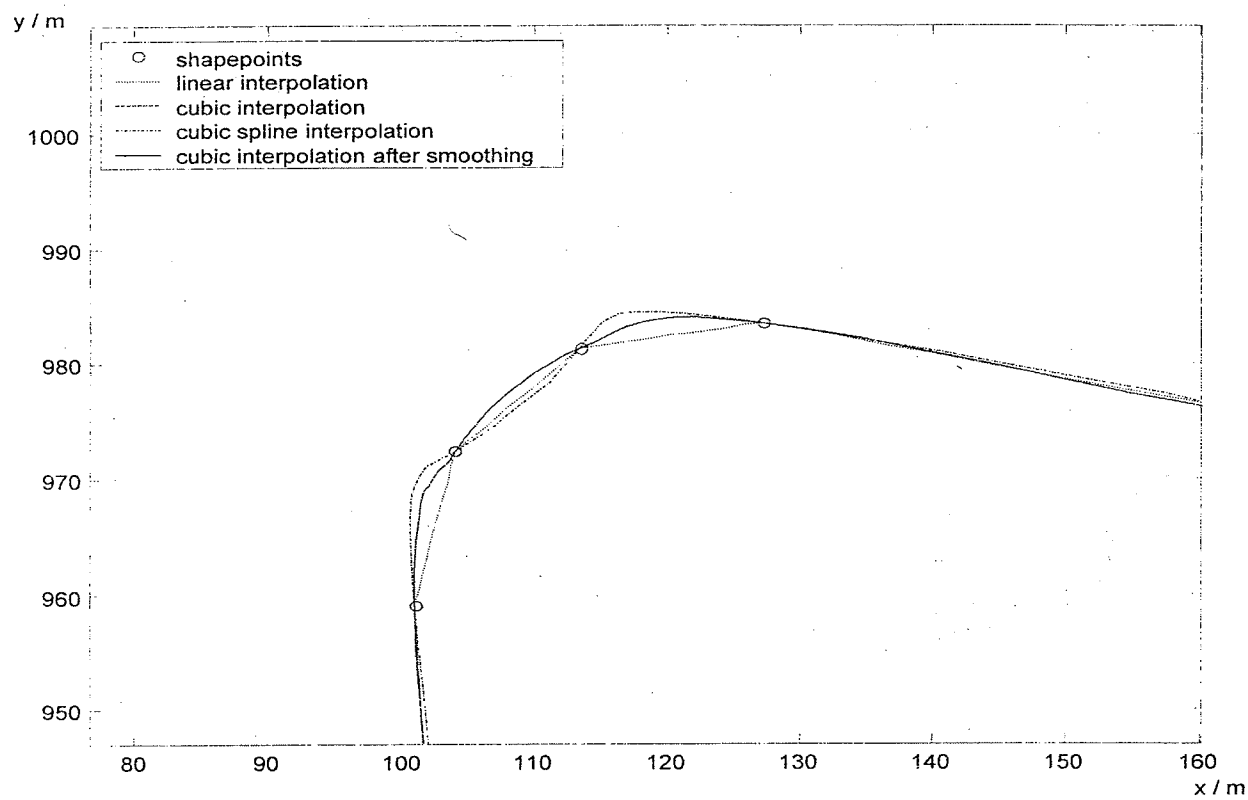

Fig. 5: Interpolation results, demonstrated on basis of map A.

Strong deviations of the expected course can be observed for the cubic and cubic spline interpolation at curve entrances and exits which is explained by the irregular spaced data. Lengths between 20 and more than 450 metres can be found in map A for the corresponding test course.

The overshoots caused by the cubic interpolation are smaller than those produced by the cubic spline interpolation, leading to the conclusion, that the cubic interpolation represents the best match to the real street geometry.

3.3 Smoothing

To improve the interpolation of the data a smoothing of the calculated track has to be achieved. This can be done either by adding shapepoints at suited positions, or by formulating special conditions to be fulfilled by the spline function. For the following analysis, the first method is used.

By subdividing the long street vectors in equally spaced parts, the overshoots can be suppressed. Figure 6 demonstrates the length of each street vector depending of the distance, once for the smoothed and once for the original shapepoints of map A. The solid line in Figure 4 and 5 represents the best match, achieved by smoothing and interpolating the data.

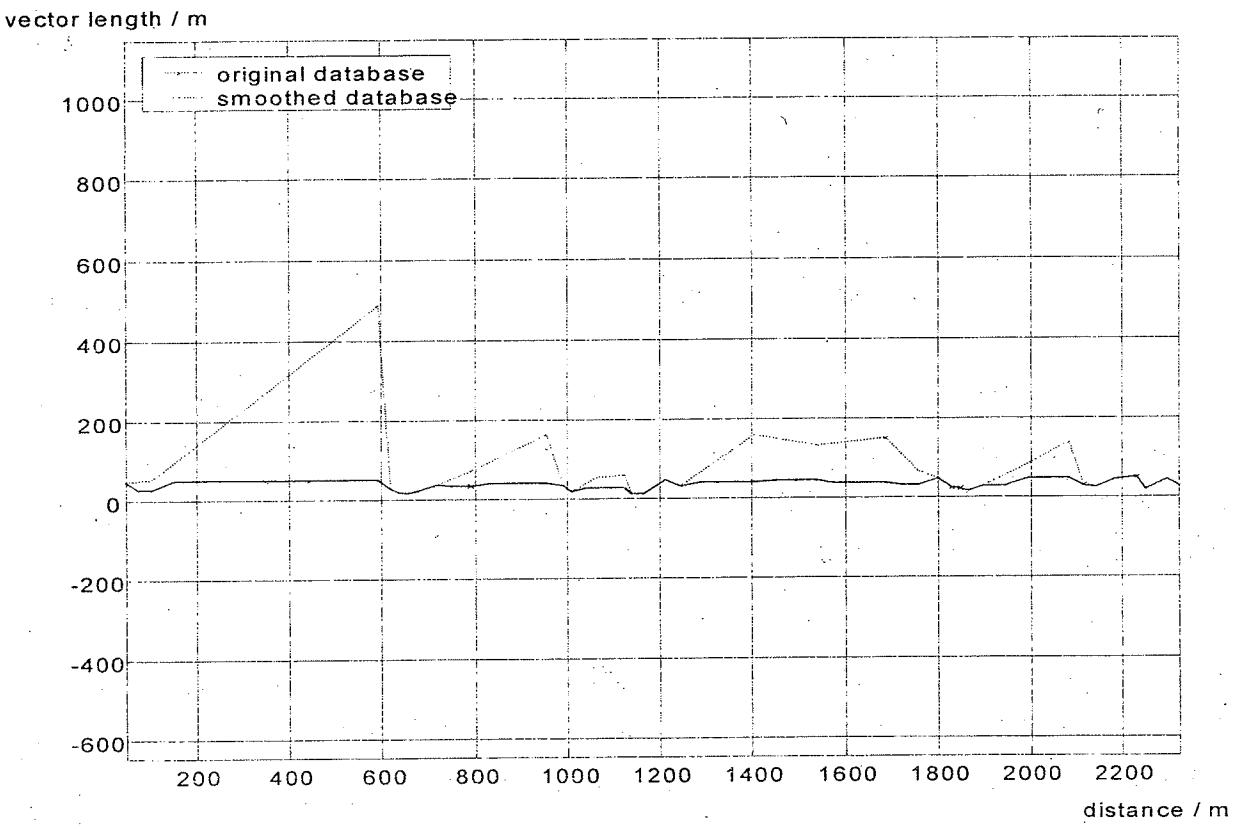

Fig. 6: Vector length of map A before and after the smoothing.

3.4 Lateral deviation

The lateral deviation is defined as the shortest distance between one shapepoint on the digital map and the street median. In Figure 7 the definition is graphically demonstrated.

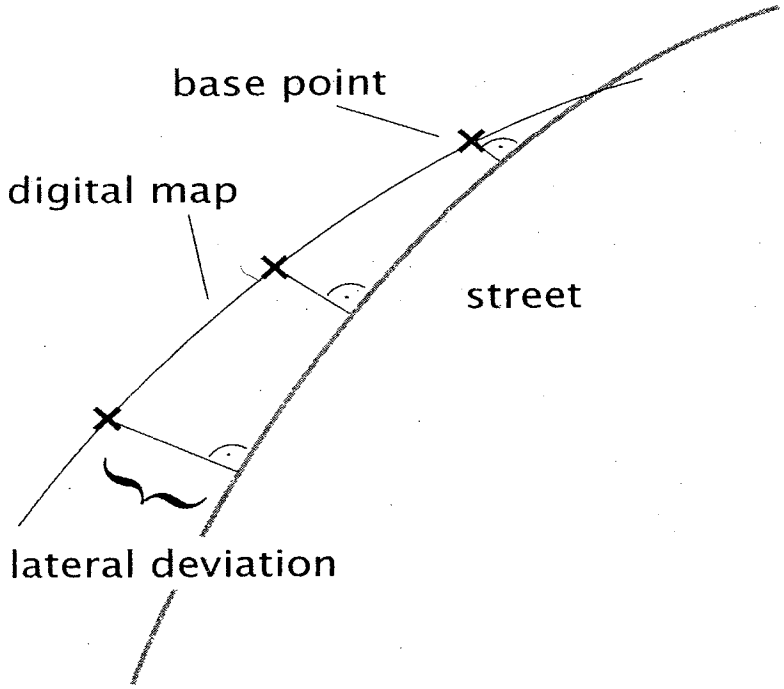

Fig. 7: Definition of the lateral deviation.

In order to achieve a homogeneous ponderation of the lateral deviation over the entire test track, base points are generated on the interpolated map at constant distances to each other. The lateral deviation to the street median is calculated for each of these base points.

In the following the lateral deviation is used as a criterion for the fitting quality of the digital road map to the street. A quantitative comparison between the different maps is made possible by the mean and the standard deviation of the lateral deviation. The probability distribution function of the lateral deviation is represented in Figure 8 for map A.

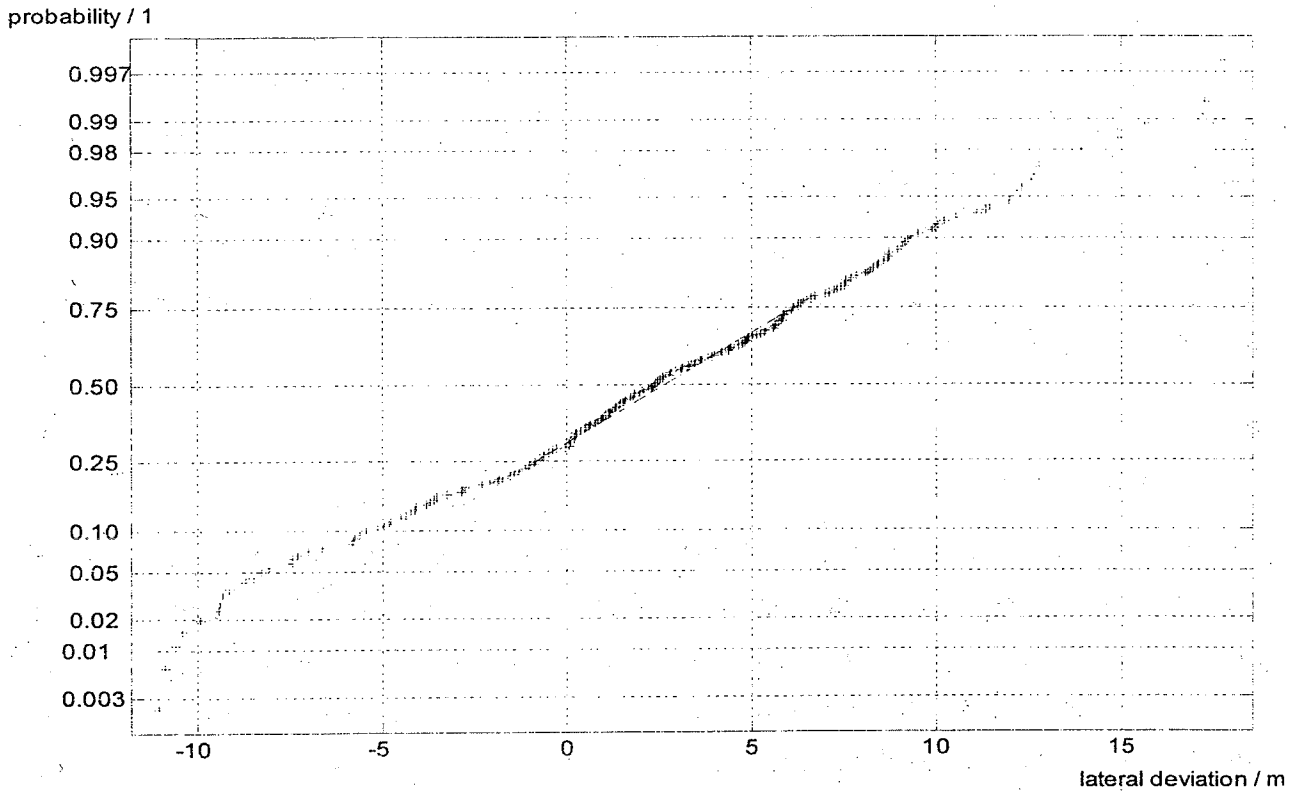

Fig.8: Lateral deviation of map A.

It can easily be recognized that the function above represents a Gaussian distribution. Similar representations result for map B and C. Table 1 summarizes the mean and standard deviation values for the lateral deviation of map A, B and C.

	mean / m	standard deviation / m
map A	2.44	5.76
map B	-1.97	5.23
map C	0.92	10.36

Table 1: Statistical values for the lateral distribution of map A, B and C.

For long test courses it is expected to get mean values of zero. Due to the limited length of the analysed street this effect could not be observed. Future investigations shall demonstrate this context.

A digital map can have a constant offset to the real street without having effect on the quality of shape prediction. The standard deviation gives further particulars about the shape fidelity of the digital map.

For map C the standard deviation determined is almost twice as high as for map A and B. This leads to the presumption that map C delivers the worst description of the forthcoming lane.

3.5 Street geometry – curve radius

According to RAS-L [1] modern streets are composed of three different types of segments. These are straight lines, clothoids and circles. The transition of a straight part into a curve with constant radius is smoothed by clothoids, where the radius changes continuously along the street. In order to reproduce this effect, the selected method of radius calculation retrieves a radius for each shapepoint. Figure 9 demonstrates how the algorithm works.

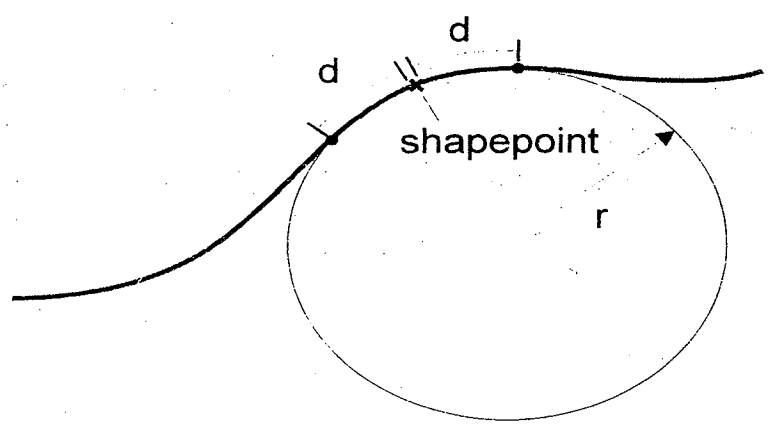

Fig. 9: Algorithm for radius calculation.

For each shapepoint, two virtual points are generated in a defined distance (d) along the polygon. The three points define a circle, the radius (r) of which is

determined and associated to the original shapepoint. Ideally d is to be chosen as small as possible, but with the decreasing of d, the calculated radius becomes more noisy. This occurs due to the measuring and positioning errors during the generation of the digital map. In this investigation a distance of 40 metres was chosen. The direction of the curve has no influence on the evaluation of the radius and therefore was not considered in this investigation.

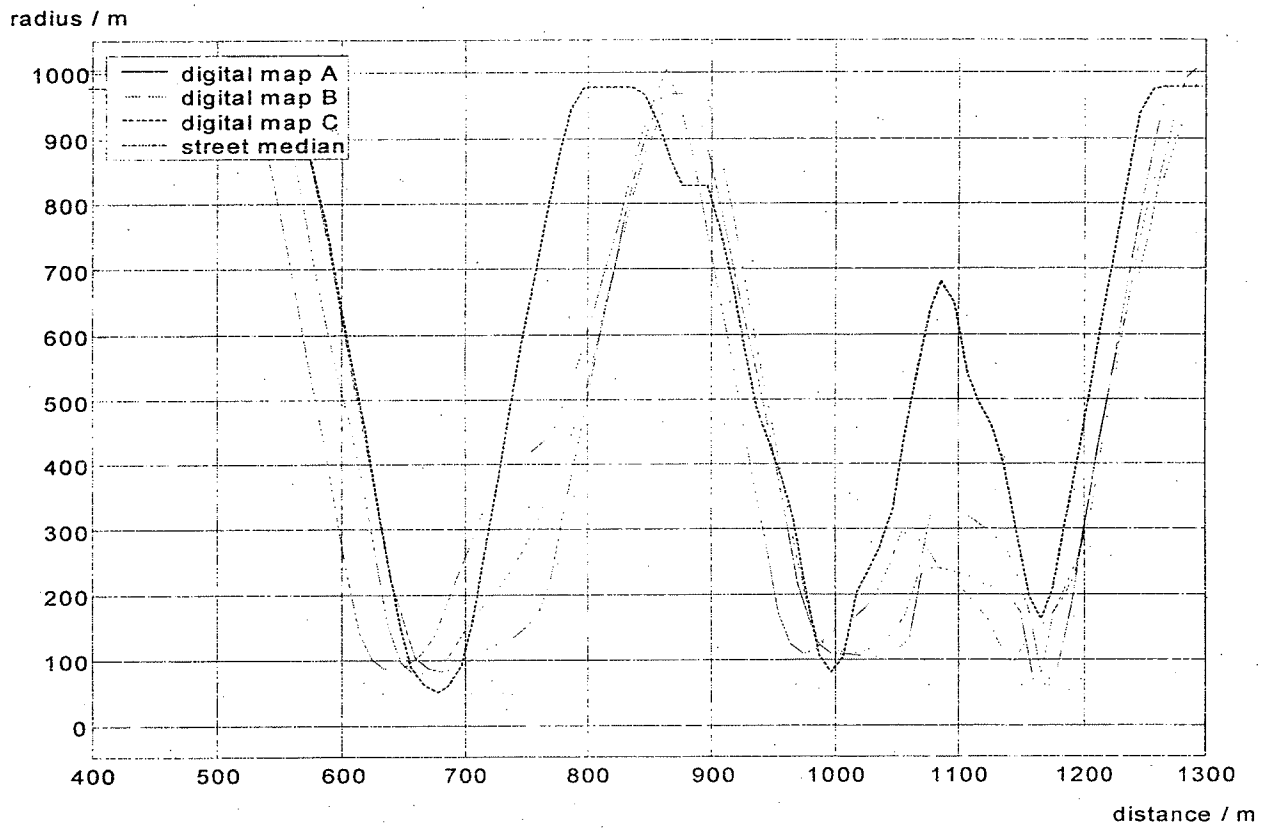

Fig. 10: Calculated radii for maps A, B, C and for the real street shape.

Figure 10 demonstrates the radii generated by the algorithm shown above for each of the digital maps and for the real street. It can be observed, that the minimum of radii are very similar for all maps, while the location of the minimum varies.

Figure 11 shows the difference between the radii calculated for the digital maps A, B and C and the radii for the real test course.

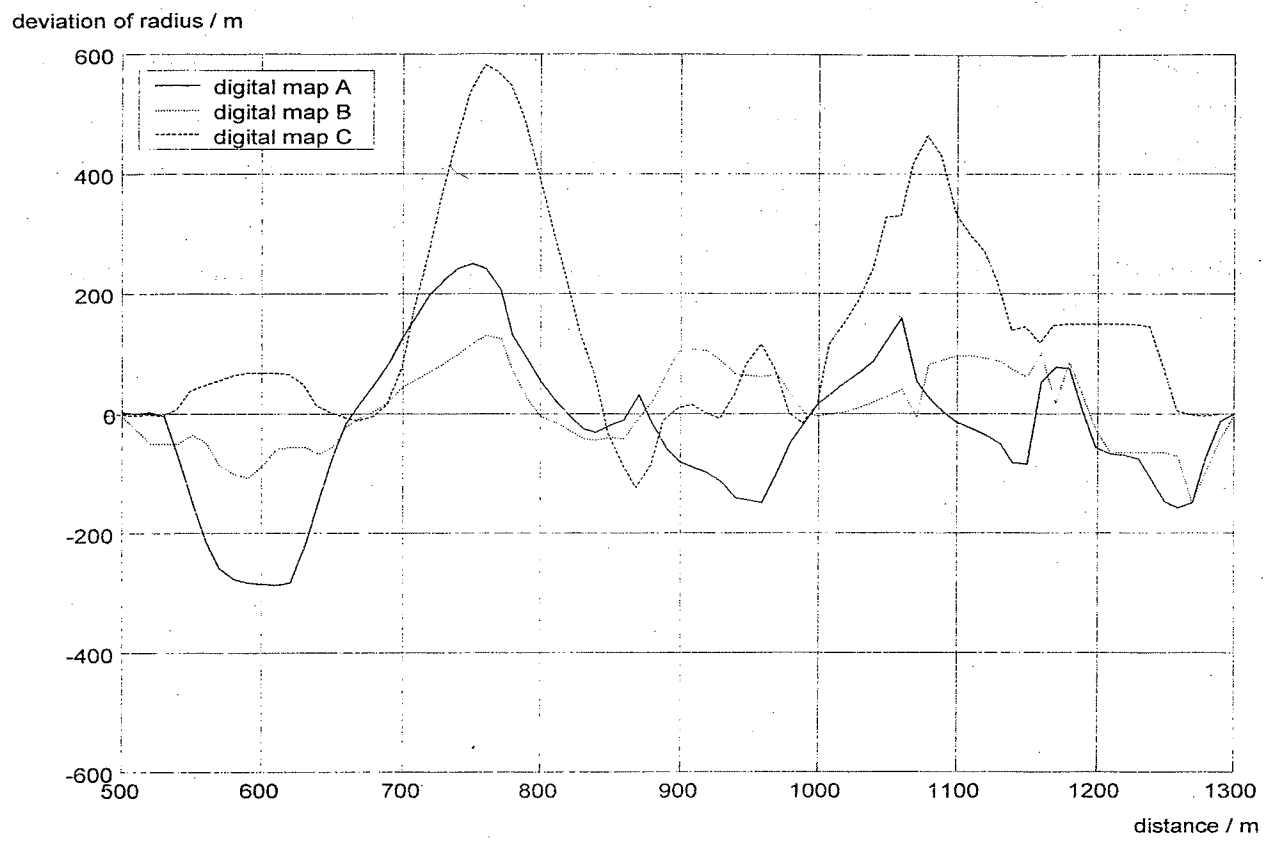

Fig. 11: Calculated deviation of the radii for maps A, B, C from the radii calculated for the real street shape.

In Table 2 the mean value of radii difference is represented for the digital maps.

	mean of radii difference / m
map A	-34.1
map B	-32.3
map C	89.1

Table 2: Mean values of the distribution of the radii difference of map A, B and C.

It can clearly be seen that the radii retrieved by map C is the worst concerning accuracy. The mean deviation of the radii to the target value is more than twice as high as for map A and B.

3.6 Functional dependency

Comparing the results of Table 1 and 2, it can be seen that the standard deviation of the distance between digital map and real street is correlated to the quality radius calculated by the demonstrated method.

This investigation demonstrates that with an increasing of factor 2 of the standard deviation of the lateral deviation, the error in radius determination increases by nearly factor 2.5.

4 Summary and Conclusion

The presented investigation represents an evaluation method, exemplified for a selected test course. For a secure statistical statement, additional tracks must be used and examined.

Further, particular algorithms such as the smoothing can be extended and improved. Other procedures like Bezier curves must be tested concerning their applicability. The influence of different types of streets such as motorway and highway has to be considered.

The error generated in the calculation of the street radius depends on the absolute radius value of the respective curve. This functional dependency has to be analysed in order to get a mean error for different radii.

Nevertheless, a correlation between the lateral deviation and the calculated street radius was found.

Furthermore, the procedure shown in this paper allows a quantitative comparison of different road maps.

Reference

[1] Bundesministerium für Verkehr
Richtlinien für die Anlage von Straßen, Teil: Linienführrung (RAS-L), StB 13/38.50.04/728F95, Bonn, 1995

[2] European Committee for Standardisation
Geographic Data Files, CEN TC 278, 1995

[3] Hamberger, Werner
Verfahren zur Ermittlung und Anwendung von prädiktiven Streckendaten für Assistenzsysteme in der Fahrzeugführung, VDI-Verlag, Düsseldorf, 1999

[4] Hamberger, Werner; Cremers, Rolf; Willumeit, Hans-Peter
Verbesserung der aktiven Fahrzeugsicherheit durch fortschrittliche Navigationssysteme;, 1998. - 14 Abb. : 5 Abb., 14 Lit.

[5] Lehn, J.; Wegmann, H.
Einführung in die Statistik, B. G. Treubner Stuttgart, 1985

[6] Seeber, Günter; Schmitz, Martin
Methodik der GPS- und DGPS-Messung, Institut für Erdmessung, Hannover, 1996

[7] Späth, Helmuth
Spline-Algorithmen zur Konstruktion glatter Kurven und Flächen, R. Oldenbourg Verlag München Wien 1986

[8] Weisser, Hubert; Schulenberg, Peter J.; Bergholz, Ralf
Autonomous Driving on Vehicle Test Tracks: Overview, Motivation, and Concept, IEEE International Conference on Intelligent Vehicles, 1998