Ghosthunter III – Detection of Wrong-Way Drivers

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SUMMARY

Wrong-way driver detection is one of many safety-of-life application areas where precise and integrity-checked position determination is essential. The project “Ghosthunter” deals with this application. Part I and part II of this project are already finished, Part III is just starting. In the first "Ghosthunter" project, a corresponding investigation based on GNSS and digital road maps was carried out. The aim was to define conditions under which it is possible with to reliably detect wrong-way drivers on highway ramps. The detection should be carried out the most cost-effective hardware possible. A detection algorithm to automatically detecting and warning of wrong-way drivers was developed. Since digital road map data are one input variable for the algorithm, especially for the map-matching, an evaluation of the digital road maps available on the market was carried out at the beginning of the project. Based on the results, a demonstrator system was further planned to test the quality of the wrong-way driver detection for individual and cooperative warnings based on different scenarios. This demonstrator system was developed in the Ghosthunter II project. Here, the main focus was on porting and optimizing the existing algorithms for wrong-way driver detection on a commercially available, application-oriented and freely programmable target platform. An Android system on a Xiaomi Mi 8 was selected as the target platform.

Firmly connected with the concept of wrong-way driver detection was also the development and realization of a server system. On the one hand, it is about emulating cooperative warnings such as Car2Infrastructure and evaluating them in this context. On the other hand, it enables the storage of raw sensor data, so that later implemented improvements of the system can be explicitly played through in a simulator and quantified evaluated.

In addition to the aforementioned porting of the detection system from the previous project, an iterative optimization of the algorithms and digital road map data are also taking place. For example, the latest lane-accurate digital road maps (HD –Maps – High definition – Maps) were analyzed and a map-matching algorithm based on them was developed.

Based on the two previous projects, further investigations and adaptations of the software with regard to integrity, also for later operation, are now starting in a further project.

The goals of this project Ghosthunter III can be summarized as follows:

1. integration of Open Street Map (OSM) as the map base of the app, developed as a demonstrator in Ghosthunter II and adaptation of the map-matching algorithms to it.

2. Investigation and implementation of a positioning method including the protection level calculation
3. development of a holistic integrity model including models to guarantee, but also improve, the integrity of the overall system.
4. creation of a certification scheme as well as execution of the prototypical certification with the result of a validation of the procedure carried out by a concrete test and certification with the corresponding prototypical test, inspection and / or audit reports.
5. search of a potential operator of the system.

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1. INTRODUCTION

Wrong-way drivers pose a major risk of serious accidents on highways. Every year, there are about 1700 wrong-way drivers on German highways alone. These are responsible for about 80 accidents and 11 deaths (ADAC 2021). Wrong way driving can be divided into two groups. On the one hand, there is accidental wrong way driving (irritation due to road works, orientation according to navigation system, etc.) and on the other hand, there is intentional wrong way driving (suicidal intentions, avoiding traffic jams, etc.). So far, numerous actions have been discussed to prevent these wrong-way driving accidents. Firstly, highway ramps are to be equipped with additional signs or light signals so that road users can more easily recognize a possible wrong-way approach (Vaswani et al. 1973). Another possibility that has been discussed is the installation of lane claws at the off ramps. This slashes the tires of wrong-way vehicles to prevent them from continuing their drive. With the help of induction loops or cameras, wrong-way drivers can at least be detected, making it possible to warn other road users at an early stage by using acoustic or visual signals (Babic et al. 2010, Beckmann et al. 2016). What all these concepts have in common, however, is that an area-wide installation infrastructure is required and is very expensive, even without considering the operating costs. Another approach is to integrate the detection technology directly into the vehicles (Nissan 2010, Toyota 2011). One approach is to develop systems based on cameras that recognize traffic signs and thus determine the direction of travel. Another approach is based on the use of GNSS position measurements (Hard 2015). These GNSS-based solutions have several advantages. No structural changes to highway ramps are required, making the overall system cost-effective and globally available. In addition, a fast and wide distribution can be easily achieved, since GNSS receivers are now widely used due to their application in navigation (navigation devices, smartphones and cars). In addition, with an appropriately designed system, both wrong-way drivers and other road users can be warned (Frankl et al. 2016).
Based on this approach, the Ghosthunter I project aimed to conduct investigations and defined prerequisites to determine whether it is possible with current technology to reliably detect wrong-way drivers on highway ramps and to warn the wrong-way drivers themselves as well as other road users in the surrounding area.
Based on the positive results, a follow-up project (Ghosthunter II) was started. In this project, a detection system for the extension of current navigation systems was developed and implemented so that wrong way drivers on freeways and their ramps can be reliably detected and the wrong way drivers themselves as well as the road users in the vicinity can be warned.

In the current project (Ghosthunter III), the last remaining issues are now to be eliminated and the development completed. This includes: The integration of Open Street Map (OSM) as the map basis of the app and adaptation of the map matching algorithms to this, with the aim of being able to distribute the app free of charge, additionally, an investigation of different positioning methods and the implementation of one of these including the protection level will be calculated through. The development of a holistic integrity model to guarantee, but also to improve, the integrity of the overall system will also be part of the project. Finally, the creation of a certification scheme as well as the execution of the prototypical certification with the result of a validation of the executed procedure through a concrete test and certification with the corresponding prototypical test, inspection and/or audit reports is realized. The search for a future operator of the system will finalize the project.

2. PRELIMINARY WORK (GHOSTHUNTER I)

2.1. System Design and Requirements Analysis

The aim of the Ghosthunter I project was to develop a real-time capable system for the detection of wrong-way drivers. To realize this goal, current technologies was combined. Three different information inputs provided the base for the system: GNSS measurements for absolute positioning, independent auxiliary sensors such as inertial sensors and odometers, and digital road map data with appropriate map-matching algorithms to link position and digital road map data. Three modules were developed to process these data during Ghosthunter I. The map-matching module, the wrong-way driver detection module, which allows the detection of wrong-way drivers from the position, navigation and time (PNT) data, and the warning module, which transmits a warning to the driver directly and to endangered road users in the vicinity.
The realization of the overall system was focused on robustness, maximum detection probability and minimum false alarm probability. The minimization of the false alarm rate is of particular significance since this is particularly important for the acceptance of the system by road users or potential service providers. If the false alarm rate is too high, the road user would no longer trust the system and ignore the warnings. A false alarm probability of $1 \cdot 10^{-8}$ and a missed detection rate of 0.05 were defined as the target values. With these target values, a false alarm rate of less than 1 wrong-way driver per day can be realized for Germany (Beckmann et al. 2016, Frankl et al. 2016).

2.2. Quality Assessment of Digital Road Map Data

In the course of the project, a valid, reliable and comprehensive quality assessment of digital road maps of four different digital road map data providers was performed. Two commercial map providers (HERE Global B.V. (abbreviated to HERE) and TomTom N.V. (abbreviated to TomTom)), an open source project (OpenStreetMap (abbreviated to OSM)) and the German official topographic-cartographic information system (ATKIS-Basis-DLM) were investigated. On the one hand, the geometric accuracy (absolute and relative) of the map data, and on the other hand, the completeness of the attributes was investigated. Table 1 gives an overview of the achieved accuracies as well as the existing attributes (Wang et al. 2017a):

Table 1: Comparison of absolute and relative position accuracy between HERE, TomTom, OSM and ATKIS-Basis-DLM (Wang et al. 2016)

		HERE	TomTom	OSM	ATKIS
Abs. positional accuracy		2.02 m	2.00 m	1.95 m	1.80 m
Rel. positional accuracy	Orientation change	4.1°	5.1°	4.2°	4.8°
	Curvature difference	$5.3\ \text{km}^{-1}$	$7.9\ \text{km}^{-1}$	$5.5\ \text{km}^{-1}$	$8.7\ \text{km}^{-1}$
Number of traffic-related digital road map attributes		10	8	4	3

In summary, it can be concluded that the difference of the accuracy values for the four datasets is small. In the case of attribute completeness, on the other hand, the products of commercial map manufacturers may have had a higher degree. This also includes the attribute of the driving direction, which is essential for the detection of wrong-way drivers. It should be noted, however, that this study represents the situation in 2016. OSM data in particular is subject to constant improvement. For example, the completeness of the attributes has improved significantly, so that they are much more suitable at the time of this publication.

2.3. Map-Matching

Map matching algorithms are used to determine, on which road segment the GNSS-receiver is actually, based on a digital road map and a GNSS derived trajectory. Due to different error influences contributing to the GNSS uncertainty and the digital road map accuracy, this is not directly possible. This allocation can then be done e.g. on the basis of geometric or topological criteria.

In the course of this project an algorithm based on a weighting function was developed and implemented. This algorithm determines a score for each possible candidate and finally selects the one with the highest score as the map matching result. This score is based on three criteria: heading, proximity and connectivity. The calculation of these three criteria is presented below (Wang et al. 2017b).

The heading criterion scores the angle between the direction angle of the last line increment of the vehicle trajectory to the direction angle of the road segment. The rating is based on the following function (Velaga 2009, Quddus et al. 2007):

$$f(\Delta\varphi) = cos\,(\Delta\varphi). \tag{1}$$

It follows from this that the higher the angular difference $\Delta\varphi$, the lower the probability of a correct matching, which in turn results in a lower rating. The angular difference is defined as the angle between the two 2D vectors v_P and v_M. Here, v_P is the direction angle of the last line increment of the vehicle trajectory and v_M that of the road segment to be evaluated (Quddus & Washington 2015, Wang et al. 2017b):

$$\Delta\varphi = \begin{cases} \arccos\frac{v_P \cdot v_M}{|v_P| \cdot |v_M|}, & 0° \leq \Delta\varphi \leq 90° \\ 180° - \arccos\frac{v_P \cdot v_M}{|v_P| \cdot |v_M|}, & 0° < \Delta\varphi \leq 180° \end{cases}. \tag{2}$$

The distance criterion rates the road segment on the basis of the nearest distance between the vehicle position and the road segment. This distance is determined directly from the coordinates of the vehicle position and the coordinates of the start and end nodes of the road segment:

$$D = \frac{x_{P,j}(y_{M,S,k} - y_{M,E,k}) - y_{P,j}(x_{M,S,k} - x_{M,E,k}) + (x_{M,S,k}y_{M,E,k} - x_{M,E,k}y_{M,S,k})}{\sqrt{(x_{M,S,k} - x_{M,E,k})^2 + (y_{M,S,k} - y_{M,E,k})^2}}, \tag{3}$$

here $(x_{P,j}, y_{P,j})$ are the measured coordinates of the vehicle position at epoch j, and $(x_{M,S,k}, y_{M,S,k})$ and $(x_{M,E,k}, y_{M,E,k})$ are the coordinates of the start and end nodes of the road segment, respectively (Quddus 2006).
The third and last criterion evaluates the connectivity between the road segment (Velaga 2009):

$$X = \begin{cases} 1, & \text{with connectivity} \\ 0, & \text{without connectivity} \end{cases}. \tag{4}$$

All segments with a direct topological connection have a score of 1. Segments that are either geometrically not connected or whose attribution contradicts this are considered as not connected and thus receive a score of 0.
Based on these three criteria, a TWS (Total Weighting Score) value is then calculated for each segment. This is done using the following function (Quddus & Washington 2015):

$$TWS = \frac{1}{3}H + \frac{1}{3}\left(\frac{\sqrt{2}b - D}{\sqrt{2}b}\right) + \frac{1}{3}X, \tag{5}$$

where H, D and X are the scores of the heading, proximity and connectivity criteria determined from the equations (1), (3) and (4). The variable b is equal to half of the size of the search area and is used to normalize the distance criterion. The segment with the highest TWS value is then the result of the map matching (Velaga 2009, Blazquez 2012).

2.4. Wrong-Way Driver Detection

The allowed direction of travel can be determined directly and unambiguously from the geometry and the attribute of the road element. The geometry, more precisely the start and end point of the edge, determines the direction of the road. However, this does not have to correspond to the permitted direction of travel. This property is stored in the attribute. The decision whether the road user is a wrong-way driver or not is based on the comparison of the angle $\Delta_{\varphi_M \varphi_P}$ between the trajectory of the vehicle $\varphi_{P,j}$ and the road edge $\varphi_{M,k}$. The two angles are determined as follows (Wang et al. 2017b):

$$\varphi_{M,k} = \arctan\frac{y_{M,E,k} - y_{M,S,k}}{x_{M,E,k} - x_{M,S,k}} \tag{6}$$

$$\varphi_{P,j} = \arctan\frac{y_{P,j} - y_{P,j-1}}{x_{P,j} - x_{P,j-1}} \tag{7}$$

where $(x_{P,j-1}, y_{P,j-1})$ and $(x_{P,j}, y_{P,j})$ are the coordinates of a measured vehicle position at epoch j and j-1 respectively, the points $(x_{M,S,k}, y_{M,S,k})$ and $(x_{M,E,k}, y_{M,E,k})$ are the starting point and the endpoint of a road link k, respectively. In these equations, in contrast to equation 2, the arctangent (implemented as four-quadrant inverse tangent) must be used inclusive of a square intercept, since the arccosine is uniquely defined only for the range from 0° to 180°.
If this difference is higher than a specified threshold, a wrong-way driver alarm is issued. This threshold was set to 20°, based on empirical studies (Wang et al. 2017b).

3. DEMONSTRATOR (GHOSTHUNTER II)

3.1. Overview

The goal of the Ghosthunter II was to develop a demonstrator that shows the usability of the system for the mass market. The demonstrator should on the one hand detect the wrong-way driver himself and on the other hand to be able to identify him as well as endangered road users in its environment.
To realize this, it was decided to develop a system based on an Android app and a cloud-based control center to distribute the warning. The basic design of the demonstrator is shown in Figure 1.

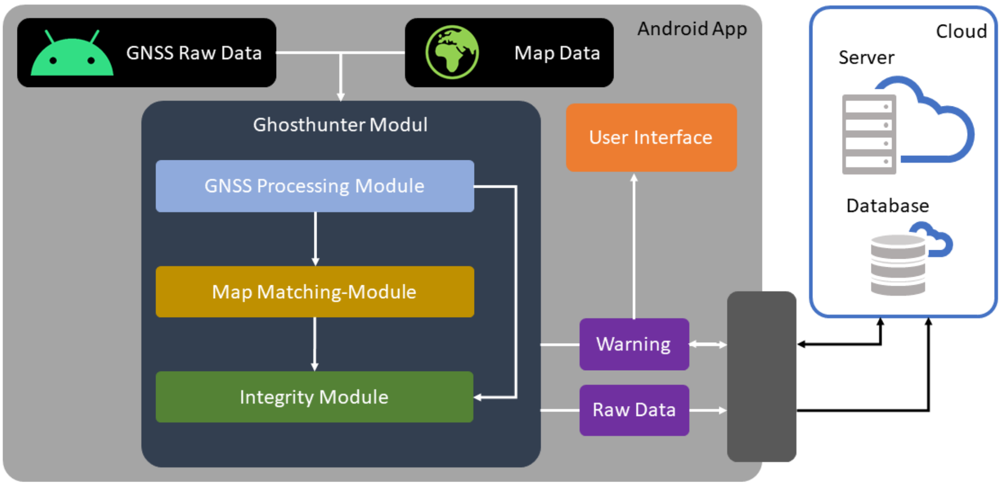

Figure 1: Overview of the structure of the Ghosthunter app

The data base for deciding whether the vehicle is identified as a wrong-way driver or not are the current GNSS positions and the digital road map. This information is processed in the Ghosthunter module. The Ghosthunter module consists of three sub-modules: GNSS processing, map matching and integrity. The output of the Ghosthunter module is a decision whether a warning has to be issued to the user or not. If so, this is then forwarded via the smartphone's mobile internet to the cloud server, which then distributes it to the other road users. The app users who are located on the same road segment then receive a message in the display of their smartphone in case of a wrong-way driver alert.

3.2. Digital Road Map Data

The digital road map represents the data base on which the wrong-way driver decision is based. Within the scope of the project, digital road map data from two different manufacturers was used. On the one hand standard definition (SD) digital road map data of the company TomTom (V2018) and on the other hand high-definition (HD) digital road map data of the company 3D Mapping Solutions GmbH (abbreviated to 3D Mapping) was used. The two data sets therefore differ in terms of accuracy, information content and representation. As in the previous project, these digital road map data were analyzed in terms of geometric accuracy and completeness of the attributes. Table 2 provides an overview of this:

Table 2: Comparison of absolute and relative position accuracy between TomTom and 3D Mapping

		TomTom	3D Mapping
Abs. positional accuracy		2.02 m	0.11 m
Rel. positional accuracy	Orientation change	4.5°	0.1°
	Curvature difference	$7.0\ \text{km}^{-1}$	$0.3\ \text{km}^{-1}$
Number of traffic-related map attributes		10	12

As in Table 2, the absolute accuracy of the TomTom digital road map data did not change significantly compared to Table 1. The orientation change has been improved slightly, these improvements being mainly limited to the freeway exits. The digital road map data of 3D Mapping are thus compare significantly more accurate. It is better both in terms of accuracy (more than a factor of 10) and in terms of attribution. However, it should be noted that both digital road maps were not available for the same area and could therefore change.

3.3. Map-Matching and Wrong-Way Driver Detection

Due to the different way of representing the road geometry, the map matching algorithms from the previous project had to be adapted. The basic properties of the algorithm were not changed. It is still a weight-based algorithm with the criteria heading, proximity and connectivity. Due to the individual representation of each lane in the HD map, the topological relationship between individual edges is no longer directly included and can therefore no longer be used to evaluate connectivity. Therefore, the algorithm was adapted to generate connectivity indirectly from the available information in real time. This evaluation is based on the geometric position of the edges as well as the information about the lane markings (Luz et al. 2020).
For the detection of wrong-way drivers, the approach from the previous project was further developed to reduce the false alarm rate. For this purpose, a significance test was added to the algorithm presented in section 2.4. This test determines whether the direction of travel of the road user differs significantly from the permitted direction of travel (Luz et al. 2021).
In the previous project, it was only possible to detect a wrong-way driver in case of a constructional separation of the carriageways. In order to be able to detect a wrong-way driver earlier, another algorithm was developed and implemented. In countries with right-hand traffic

(and vice versa in countries with left-hand traffic), vehicles are driven to the right of the center line in the positive direction of travel. A significance test is therefore used to check whether the vehicle is located significantly away from the center line, so that a reliable statement can be made about the position of the vehicle. Subsequently, it is checked whether the vehicle is located to the left or to the right of the center (Luz et al. 2021).

3.4. Cloud Infrastructure

Another part of the demonstrator is the cloud infrastructure. This has two functions. First, it is used to evaluate the concept of cooperative warning. The cloud server functions as a central node. Each installation of the app logs on to the server and can then send a wrong-way driver message to it. The server then distributes this to the other installations, which in turn check whether it is a warning in the vicinity. This structure ensures the privacy of the individual users, since the server does not know the position of the individual users, with the exception of the wrong-way drivers. In its other function, the server enables the recording of trajectories, in the form of GNSS raw data and stores them in a database. These can be used to recreate situations in post-processing, and thus allow the execution of simulations, evaluations and the debugging of the app. In a final version of the app, this part will be removed.

3.5. Integrity (False Error Rate)

To evaluate the integrity of the overall system, the algorithms were evaluated with different data sets. These were based on real trajectories on the one hand and on simulated data on the other hand. These data sets consist of a GNSS trajectory and the corresponding true map matching results.
To generate real trajectory data, test drives were performed on the A81 near Stuttgart and the A99 near Munich. And the true map matching results for each GNSS position were determined manually. However, since a large amount of data is needed for the evaluation, but this procedure is time-consuming, additional data were generated by a simulation tool. For this purpose, a nominal trajectory is generated first. This contains all the road segments on which the vehicle is simulated to be traveling. The respective trajectory positions are then determined on the base of the maximum permissible speed. In a final step, an error, consisting of a systematic error $\boldsymbol{\Delta_k}$ and a random error $\boldsymbol{\varepsilon_k}$**,** is added to these positions. A point with a simulated error $\boldsymbol{P_s}$ is then obtained after applying the equation 8 to a nominal trajectory point $\boldsymbol{P_n}$**.**

$$\boldsymbol{P_s} = \boldsymbol{\mathcal{N}}\left(\boldsymbol{P_n} + \delta_k \begin{pmatrix} cos\, \phi_k \\ sin\, \phi_k \end{pmatrix}, \boldsymbol{\Sigma_{wn,k}}\right). \tag{8}$$

Here δ_k describes the size and ϕ_k the direction of the systematic error, $\boldsymbol{\Sigma_{wn,k}}$ the covariance matrix of the random error, which follows the multidimensional normal distribution $\boldsymbol{\mathcal{N}}$. Figure 2 shows the behavior of this model graphically.

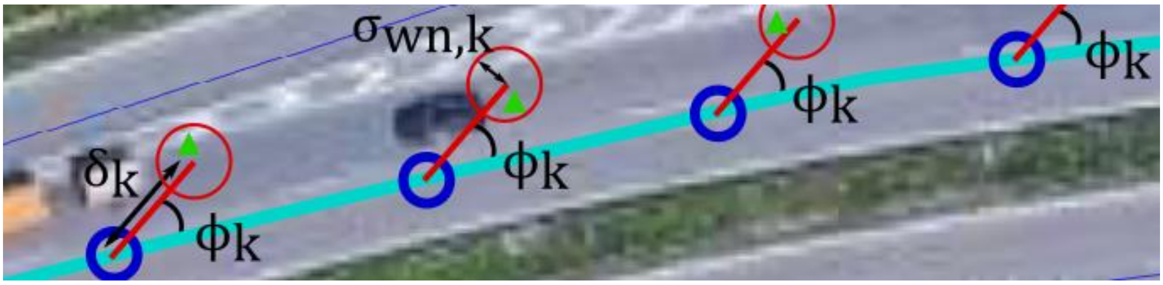

Figure 2: Shifted target position with systematic and random error parameters

In this way, a direct comparison of different position errors is also possible, since the trajectories generated in this way do not differ in the driving maneuver, but only in their added error (Luz et al. 2021).

3.6. Evaluation of Wrong-Way Driver Detection

In the following, the numerical results of the wrong-way driver detection (section 2.4 and 0) are presented. These are divided into the results obtained with real trajectories and those determined on the basis of simulated data.

Real trajectories
Since road traffic regulations had to followed, in real situations, these data sets do not contain any wrong-way driver maneuvers. However, the false alarm probability can still be evaluated with these. Additionally, by comparing the numerical results, with those from the simulation, it can be checked how well the simulation represents reality. The confusion matrix of the results (20,000 GNSS positions) is shown in Table 3.

Table 3: Confusion matrix of wrong-way driver detection with real trajectories

		Actual condition	
		H_0	H_1
Predicted condition	H_0	99.982 %	-
	H_1	0.018 %	-

Simulated Trajectories
In order to be able to evaluate the sensitivity of the wrong-way driver detection, the simulated data sets ($2 \cdot 10^6$ positions) contain wrong-way driver maneuver. The numerical results of the algorithm are shown in Table 4,
Table 5 and Table 6. In the Ghosthunter app, the algorithm based on the 3D mapping digital road map data is only used if the GNSS position accuracy Δ_Q is less than 2 m. To allow a better comparability between the two algorithms, the results of the algorithm based on the TomTom digital road map data were therefore also calculated for this accuracy range (
Table 5).

Table 4: Confusion matrix of wrong-way driver detection with simulated trajectories (TomTom $\Delta_Q > 2\ m$)

		Actual condition	
		H_0	H_1
Predicted condition	H_0	99.974 %	5.36 %
	H_1	0.026 %	94.64 %

Table 5: Confusion matrix of wrong-way driver detection with simulated trajectories (TomTom $\Delta_Q < 2\ m$)

		Actual condition	
		H_0	H_1
Predicted condition	H_0	99.99 %	2.11 %
	H_1	$8 \cdot 10^{-3}$ %	97.89 %

Table 6: Confusion matrix of wrong-way driver detection with simulated trajectories (3D Mapping $\Delta_Q < 2\ m$)

		Actual condition	
		H_0	H_1
Predicted condition	H_0	99.99 %	1.68 %
	H_1	$7 \cdot 10^{-4}$ %	98.32 %

A comparison of the false alarm probability of the real data with that of the simulation shows that they are within similar ranges. The false alarm probability of the real data is between that of Table 4 and

Table 5, which suggests that the GNSS accuracy of the real data is also between them. The achieved false alarm probability of $7 \cdot 10^{-4}$ % and $8 \cdot 10^{-3}$ % is already on a high level, but up to now it does not reach the targeted value of $1 \cdot 10^{-8}$. The authors expect, that an integration of an integrity model for the GNSS position, which will be part of Ghosthunter III, will be improve these values. The achieved false alarm probability is therefore assumed to be too pessimistic and would be lower in real terms. The achieved sensitivity of 94.64% and 98.32% shows that a false driver can be detected by the system in most cases and reaches the target value of 95%.

4. FUTURE WORK (GHOSTHUNTER III)

4.1. Positioning

In the Ghosthunter III project, a positioning module that provides the required accuracy has to be developed based on the results of the previous projects. In the previous investigations, the focus was on precision differential GNSS and on the Android internal positioning solution. These investigations will now be extended to PPP, GNSS/IMU fusion based on a new set of integrity metrics. From these investigations, the most suitable positioning method for the application in terms of accuracy, integrity and realiability shall then be selected and implemented. This module will then be further optimized in terms of integrity and position estimation on a smartphone. The integrity metric that will be developed is supposed to provide a statement about the reliability of this positioning solution.

4.2. OSM Map Data and Map-Matching

As mentioned in chapter 3.1, a basic element of the Ghosthunter app is the used digital road map. The existing app uses a digital road map that is not freely available as a base digital road map, for which license costs are then required in the future, too. In order to provide large-scale distribution, a freely available digital road map should be used, as a base for the application. Therefore, the app will be adapted so that OSM digital road map can be used as a base. As a result, the map-matching algorithms developed in the previous project have to be adapted.
Since the OSM digital road map data is open-source, neither accuracy nor correctness is guaranteed. Therefore, a one-time quality review, of the entire highway network is required. The result of this investigation is a data set for which the accuracy and correctness can be guaranteed. For digital road map parts where the expected quality cannot be guaranteed the integrity is ensured by given this information to the user and, additionally giving the opportunity of a reworking of the OSM data. As already touched upon in Section 2, only a small number of attributes were available when using OSM digital road maps in the past. This was mainly due to a lack of completeness of the attributes, which is why they were not included. However, initial investigations have already shown that this situation has improved significantly, so that nothing prevents from the use of OSM.

4.3. Integrity

An important aim of the development is to improve and ensure the integrity of the overall system. First, the three integrities of position, digital road maps and map matching will be analyzed individually. The respective integrity features will be derived, analyzed and evaluated. In the area of position integrity, filters for monitoring the integrity features (e.g. carrier phase residuals) will be developed. In the area of map matching, methods and algorithms are developed to automatically check and evaluate the integrity of the OSM digital road map base. In the case of map matching integrity, the results from the previous project will be taken into account and the algorithms developed, will be adapted to the OSM digital road map data and further enhanced. In addition, algorithms will be developed to detect changed lane alignments, e.g. due to road works. Subsequently, a holistic integrity model will be developed, which combines the individual integrities to an overall model, with which a guarantee as well as an increase of the overall integrity will be achieved.

4.4. Certification

The certification of the Ghosthunter app is one of the main goals of the Ghosthunter III project. The suitability of the developed app for the purpose of wrong-way driver warning, as well as the compliance with the defined requirements, has to be verified within a prototypical certification. In order to carry out a certification in this area, the creation of a certification scheme is necessary in advance. This is divided into several parts. The first goal is to define the certification label statements, which document the result of the performed certification on the certification label, as they define the goal of the certification. The next step is to define the measurement evaluation process itself. It defines the measurement quantities, the result of the

measurement process and the required quality measures (e.g. minimum and maximum values, required accuracy). Next, a measurement uncertainty analysis is performed to identify sources of error that may influence the measurement process. To do this, the influencing factors are first determined, their magnitude estimated, and a criticality analysis performed. Those for which is not possible to be neglected will be examined in more detail using variance-covariance propagation. One result of the measurement uncertainty analysis may be, for example, that certain measurements are only feasible under certain conditions. The next objective is to create a standard operating procedure (SOP). The SOP is based on the measurement methodology determined in the previous steps and the results of the measurement uncertainty analysis, and implements them accordingly. To maintain a consistent test procedure, the test steps must be exactly reproducible each time they are repeated. Therefore, the SOP includes step-by-step instructions describing how to perform a test operation, in a way that is similar to the test procedures provides in standards. When performing the tests, the application of the respective SOP ensures safety, efficiency and traceability. An SOP is divided into four chapters: measurement basics, prerequisites for the measurements, procedures and interpretation of results. The next step is the development of the detailed test plan as a concrete implementation of the Standard Operating Procedure for the performance of the measurements by the laboratory. At the end, the test plan as well as the SOP are validated by independent product specialists, verified and released after independent review, as well as the audit and/or inspection plan, which, depending on the results of the analysis, are to be prepared in addition to the test plan according to the specifications in the SOP. By documenting the results obtained in the test plan and specifying the concrete test objects, the test report is generated. In the last step, the test sign statements, which were defined at the beginning, are described in detail, and deposited with the contents of the measurement methodology. In certification processes, this documentation is made available on the website of the certification authority and will show third parties which procedures are used to determine the statements on the test label and what the concrete meaning of the statements are.
After this work, and since this is a research project, it will be possible to perform the prototypical certification according to the previously developed certification scheme. Prototypical here means that all activities are carried like a typical certification process but as a research project and can be used as validation. A formal certification is not issued. In this case, the developed tests are carried out and evaluated by the laboratory of test engineers, as well as a possible inspection of the documentation and/or an audit.
The results of the laboratory tests, or of the inspection or the audit are checked by a specialist certifier in the technical review as well as formal aspects in the formal review.
Finally, the certification body decides whether to grant the certificate (DIN EN ISO/IEC 2017, DIN EN 2020, ETSI 2020).

5. CONCLUSION AND OUTLOOK

The goal of the first project (Ghosthunter I) was to determine whether it is possible to reliably detect wrong-way drivers on highway ramps and to warn the wrong-way drivers themselves as well as other road users in the surrounding area.

For this purpose, first the basic system design was specified and then the target variables that the system has to meet in terms of robustness, maximum detection probability and minimum probability of false alarms were defined. Part of this system is a digital road map and a map-matching algorithm adapted to it. Furthermore, a map-matching algorithm and a wrong-way driver detection algorithm were developed and implemented. Thus, a basic test system was available. Based on promising tests with this system, the follow-up project Ghosthunter II was started. In this project, the developments from Ghoshunter I were adapted and further developed for use in current navigation systems. On the one hand, the use of HD digital road maps was investigated, and algorithms adapted to these digital road maps were developed and evaluated. Furthermore, a demonstrator in the form of an Android app and a cloud infrastructure were developed in order to test and further improve the close-to-reality use of the algorithms including a cooperative warning. It was also possible through the demonstrator to test the current system with regard to the target values set in the previous project. However, these could not be fully achieved at this stage of development. Achieving these is a goal in the Ghosthunter III project. Furthermore, the app will be continued to develop in such a way that it can be offered free of charge without licensing problems. This includes both the digital road map used and the algorithms. In addition, its functionality is to be validated by means of a prototype certification so that it can finally be handed over to a partner who will take care of the system's operation in the future.

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