

## **DYNAMIC EVALUATION OF CLOUD-BASED ACTIVE SAFETY SYSTEMS**

**Gropengießer, Uwe**

**Maier, Christina**

**Kallweit, Dr. Roland**

IAV GmbH

Germany

Paper Number 19-0306

### **ABSTRACT**

The field of driver assistance systems faces new technologies like vehicle-to-x (V2X) communication [1] and cloud services to improve safety on the streets. These upcoming functions carry new possibilities and new challenges as well. Thanks to scaling-up techniques, it is already possible to gather and manage huge amounts of data in the cloud with less time consumption compared to standard systems. This data is suitable to be used for statistics and pattern recognition based functions with time-critical demands.

But beside the development of these functions there is always a need for evaluation to assure correct functionality. Therefore, IAV created a concept to dynamically evaluate cloud-based active safety systems like the wrong-way driver detection function developed by IAV, which is conceived to warn oncoming vehicles on motorways. This goal is achieved with cloud and V2X techniques.

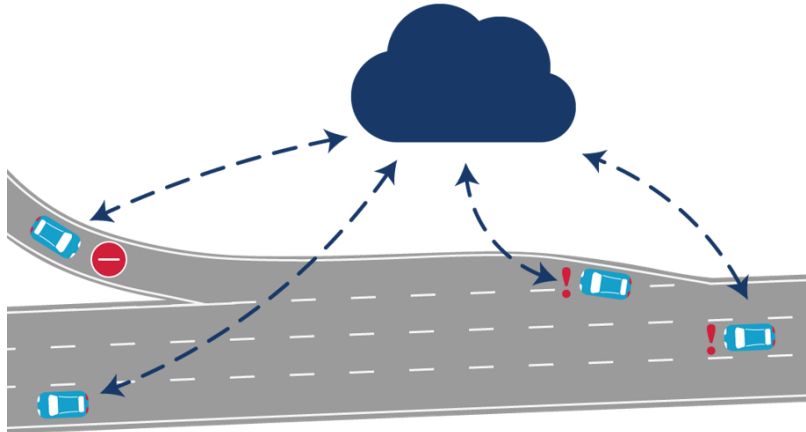
The wrong-way driver warning is a service running on the cloud, which receives V2X messages from vehicles including their positioning data, heading and other information to reference their traces via map matching [2] algorithms. An underlying database compares the data with continuously calculated thresholds to recognize wrong-way drivers and warn others in the surrounding areas via V2X against them. As changing infrastructures like construction sites have an effect on the false-positive rate of the classification, it needs to be dynamically tested if the function is able to react appropriately.

For this reason we propose an approach for an evaluation process based on an integrated self-controlling module. This module notices changes in trajectories which can be caused by changed traffic guidance and adapts the detection parameters. As a result, the following detection should classify the vehicles correctly based on the changed conditions.

The discussed process of the introduced wrong-way driver warning shows an example how a specific cloud-based function can be dynamically evaluated without dependence on the functional logic. Especially functions whose results strongly depend on ever-changing input data need solutions to test their behavior in critical situations. This approach delivers also a possible answer how to implement additional methods to create more flexible and long-term reliable cloud-based active safety systems.

## INTRODUCTION

With the possibilities offered by V2X communication and the opportunity to calculate models in the cloud, the field of predictive safety functions has experienced kind of a revolution. This is also a necessary development to fire progression towards autonomous driving. Therefore, research is driven to V2X and cloud-based functions to evaluate their potentials and limits [3]. There are also functions that dynamically adapt their algorithm parameters to changing inputs. These methods offer advantages and disadvantages, e.g. reacting to intraday situations but also learning algorithms incorrectly. One example of such a function is IAV's wrong-way driver warning which uses different information like vehicle positioning to detect wrong-way drivers on motorway junctions and warn endangered drivers nearby (Figure 1).



**Figure 1. IAV's wrong-way driver warning function.** In this figure you can see a possible scenario for the detection of a wrong-way driver and the need for the warning of the endangered drivers nearby.

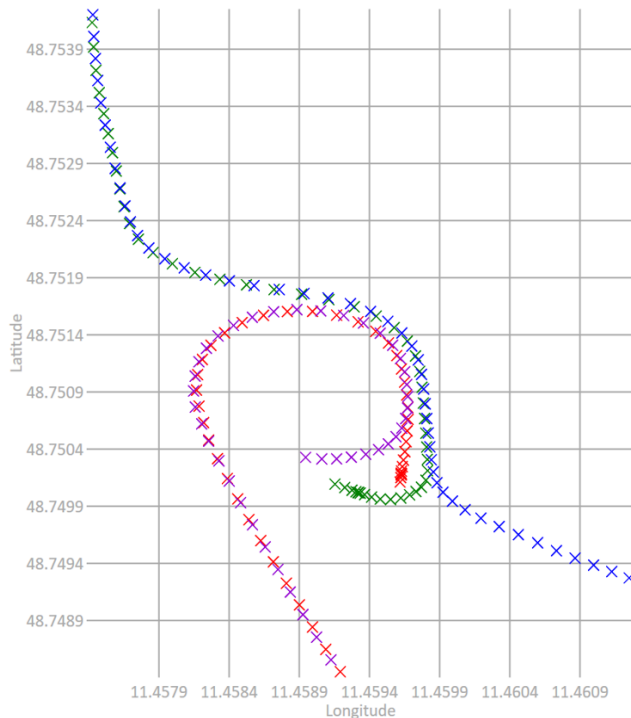
According to given example, we present an algorithm that contains two different modes. The first mode is the training mode. In the first phase, data is collected to evaluate a motorway junction not yet trained by the algorithm. Among other things, the position data of the vehicles will be used to perform a map matching. A threshold value is searched, which indicates how far an object may move away from a map matched position, in order to avoid false-positives.

In the second phase, which is called "live" phase, the system allows to activate the detection of wrong-way driver for a given motorway or exit. In this phase every vehicle that drives this way will be evaluated. Whenever a vehicle exceeds the way specific threshold, the function warns the endangered drivers nearby.

This approach leads to the situation of handling position offsets regarding to e.g. daytime construction sites. Such scenarios can lead to the situation that the algorithm is not able to map match a vehicle or much worse to result in false-positives. In this paper we provide a method to calculate new thresholds while the live phase. The main goal is to avoid false-positives in any situation.

## GPS BASED WRONG-WAY DRIVER DETECTION

Statistically speaking, the most validated incidents of wrong-way driving in Germany are caused by taking wrong entries at motorway junctions [4]. Therefore, we decided to observe the junctions regarding to the ramps and exits of the motorway. From this idea, we started to use the GPS tracking which is basically concentrated on such areas. To have a starting point we use a junction next to Ingolstadt. As you can see in Figure 2 there are four different ways to drive on this junction. Visualized GPS trajectories show their different traceable ways, which will be related to mapped roads.



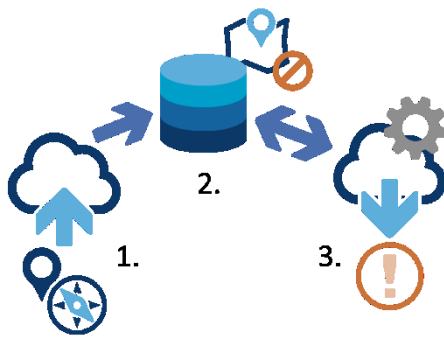
**Figure 2. Measured GPS trajectories over time, based on real vehicle bus signals.** As an example, this image illustrates four different GPS trajectories that describe the four different ways a vehicle can take on a motorway junction in Ingolstadt, Germany. This includes two motorway ramps (blue, green) and two motorway exits (red, purple).

Matching these trajectories on a map is needed to calculate thresholds for our wrong-way driver detection. This leads to the problem of map matching the vehicle to the correct road. The map matching process has to be done carefully, because GPS accuracy may vary and incorrect matches may influence the detection quality in a considerable way. To ensure that there is no false-positive, each motorway junction has a learning phase. Therefore, there is a need of doing different steps. Generally it is necessary to match each vehicle to the regarding road it takes. This is needed for the detection as well as for the warning part. This leads to the problem of map matching algorithms. In particular the algorithm has to handle the accuracy of GPS which has a potentially high variance. This can lead to incorrect matches. Therefore, the algorithm needs to calculate a threshold for each motorway junction and has to update the model in cycles. The thresholds are stored together with the map information like ways and prescribed driving direction in a database within the cloud. As described above, after the phase of learning the algorithm determines a threshold which is suitable for a given motorway junction and this way gets active for detecting wrong-way drivers.

When the live phase is released, the detection algorithm is running and warning endangered drivers (Figure 3). The detection is done by calculating probabilities. This probabilities are dependent on the positions over time, which are matched on the map information. The algorithm makes use of data from the database including the prescribed driving direction and compares them to the real vehicle driving direction, traceably by its GPS trajectory. If the probability is steadily increasing and moving into a danger area, a wrong-way driver will be detected and all endangered drivers nearby, as well as the wrong-way driver itself, will be warned via V2X messages. During the process of detection, the thresholds are still changing based on the input data from vehicles in order to provide flexibility to adapt to changing circumstances.

As mentioned in the introduction, daytime construction sites can lead to changed traffic guidance and sometimes lanes are closed or redirected over opposite lanes. This can result in false-positive detections, therefore

validation checked input data and a solution for handling changing infrastructures is advised. Otherwise the quality, robustness and durability of the function cannot be guaranteed.



**Figure 3. Productive wrong-way driver warning with dynamic adaption of detection parameters.** In this illustration you see the processing steps of learning and warning of the wrong-way driver detection. In the first step the data is collected from the objects and sent to the cloud database. In the next step the data is map matched and compared with entries in the database for the detection algorithm. If a wrong-way driver is detected, the endangered drivers nearby and the wrong-way driver itself will be warned in step three.

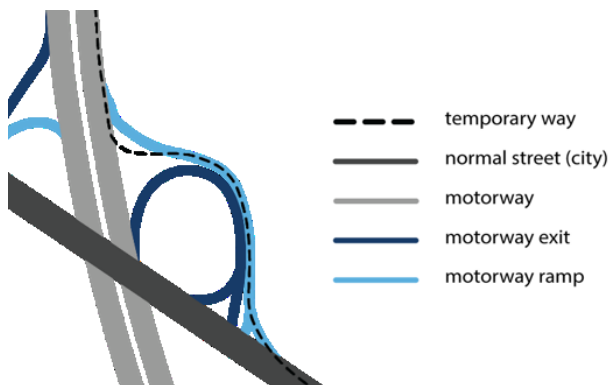
This problem is not appearing exclusively at the described IAV wrong-way driver detection, but is also applicable to several other functions with dynamic behavior. To handle this problem, this paper introduces a solution concept and discusses the challenges and possible adaption to other functions.

### IMPROVING THE APPROACH: DETECTING ALTERNATIVE WAYS AND RATE WAY VALIDITY

The already introduced wrong-way driver detection function uses map matching algorithms to relate the vehicle's trajectory to the map. The role of the used map database is essential, the function uses this as reference for the calculated thresholds as well as during map matching in the detection phase. But this dependency can have bad effects, like obsolete map data or temporary construction sites that is not considered nor recognized by the algorithm. This could lead either to false-positive detections or to no possible map matching, which in turn effects the productivity of the function. This lack of efficiency and reliability is not desirable for a safety function.

For this reason, solution concepts need to be developed to prevent from this effects. A conceivable approach for a self-controlling module could be the following described alternative way detection method.

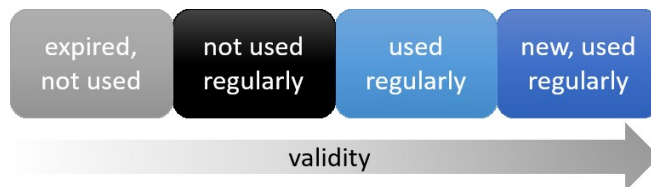
This method takes up the theory that the way information could be extended by an expiration date attribute. This attribute could be used to register the actuality and validity of each section of way from the map. Usually a motorway junction is used several times per day. This means that map matching should happen on each way or section of way regularly. Exceptions from this assumption are closed or redirected lanes using opposite lanes or temporary roads (Figure 4). Respecting this scenarios during detection, an algorithm to indicate possible new ways and register no longer used ways is considered.



**Figure 4. Example A for a temporary road due to construction site.** The alternative way is following the motorway ramp excluding a specific section that leads to the motorway.

To detect such scenarios we need to classify each road within the database. The classification will have four different categories. We assume that the validation of the category increases with the usage of the road over time. Therefore, every way is classified by the categories seen in Figure 5.

If a way is indicated as used regularly, this is marked with the related expiration attribute and updated every time of map matching. Not regularly used ways and expired, not used ways can be detected by specific indicator rules or statistical calculations. During designing this indicators, it is important to consider seasons of the day and the amount of map matches over time. This is important, because overnight traffic volume is lower than during the day.



**Figure 5. Classification scheme based on the validity of used ways.** We provide a categorization of a way with four possible states. Expired means not used for a specific time, not used regularly has not been used for a specific time, used regularly is a normal used way and new, regularly used way is a validated alternative way.

Taking into account that already expired ways could also increase invalidity because of recently mapped trajectories, this ways are still stored in the database. From this point on they can also gain importance and be reactivated. Especially in scenarios of short-term closed or redirected routes this is a potential method to update the database without information loss.

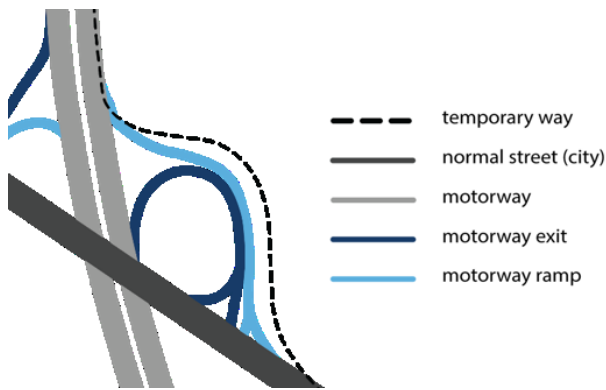
Furthermore alternative ways, which are pretended as temporary roads, can have different characteristics. Basically they can be divided into three different types.

#### **A. Ways that have common sections with already known ways**

By their nature, there are different challenges in detecting sections as a potential new way. Caused by already known points, ways that have sections in common with ways in the database can be detected more precisely in general than completely unknown ways (Figure 4). It must be noted here that this statement is also dependent on how many sections or points are in common with already saved ways from database. In principle, the more points are common, the more certain is a successful and contemporary detection of an alternative branching way. This is based on the fact that already known sections are interpreted as validated and therefore they are weighted as more likely than unknown sections. Sections which are not known are not saved in the database and will be accepted with lower probability of existence. If trajectories are mapped to already known sections of ways and also describe new unknown ways, they are saved as possible alternative way, but not immediately as new and regularly used way. Only if this alternative way can be map matched frequently to appearing trajectories, thresholds are calculated and it will be marked as a new way.

#### **B. Ways that have same start- and/or endpoints in common with already known ways**

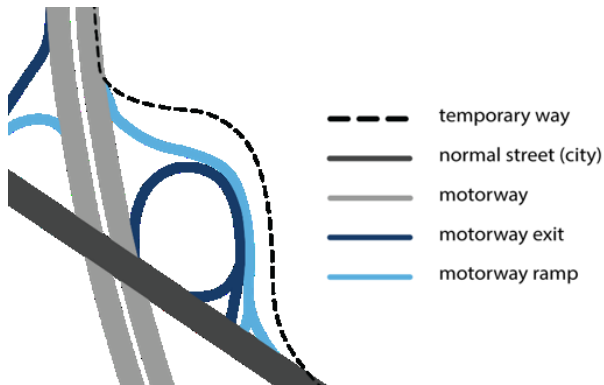
In cases of ways, which only have a common start- or endpoint (Figure 6) it is essential to know the covered way of a vehicle trajectory to get an indication of an alternative way. This means not only tracking motorway junctions but also trajectories before and after a known motorway junction. If the trajectories can be mapped to already known ways that are connected to a motorway junction, every successfully map matched point of the GPS position increases the probability of a plausible alternative way. This requires correct and reliable map matching without jumps in mapped ways, which means that the mapping process must not result in a variety of different possible ways. Otherwise map matching is unsteady and alternative way creation should be waived to prevent from erroneously applied ways and resulting false-positive detections of the wrong-way driver function. This suggested method requires information from additional ways that are connected to motorway junction and also need to be persisted in a database. To provide thresholds for map matching trajectories to additional ways, it is possible to use calculated average values from directly connected ways around, or they will be trained like the motorway junction way. If the alternative way is frequently map matched, the probability of a plausible alternative way increases every time of matching until it can be marked as new, regularly used way.



**Figure 6. Example B for a temporary road due to construction site.** The alternative way is next to the motorway ramp but ends up in the same point as the motorway ramp.

### C. Completely new ways without common sections

Ways that have no point in common with any way from database only can be indicated by collecting trajectory information over a period of time (Figure 7). This also includes trajectories before and after motorway junction to detect where a way branches to another way that is not persisted in database. Indications are increased incidences of no further mapped positions at a specific position on the way. Every point of the unknown trajectory from the vehicle is insecure at the first time, so the probability of a plausible alternative way is low and increasing with every additional map matched trajectory from other vehicles. The required thresholds for map matching to the alternative way can be transferred from other known ways for the first times until they can be calculated individually. If an alternative way is considered, it must be handled with care, because the information about the correct driving direction is not validated by already known sections at this point. Therefore, only frequently occurrence of trajectories from vehicles in a certain time can be assumed as plausible and their driving direction interpreted as the correct driving direction. Every time of successful map matching to the alternative way increases the probability of plausibility, until the level is reached and specified as a new way in database.



**Figure 7. Example C for a temporary road due to construction site.** The alternative way is next to the motorway ramp and has no point in common with it.

The described methods for detecting new ways on basis of already known ways require different additional information and have their limits. To get a first idea, if the described method is an applicable solution approach for the mentioned problem, exemplary tests were carried out.

### EXEMPLARY TESTS

To prove the general functionality of the method, a first test set is used. This set includes an exemplary database with ways and thresholds for a simple motorway ramp (Figure 4). For each type of alternative way (A, B, C) a manually created artificial trajectory is used for testing. Therefore, a test trajectory is created which has no point in common with the motorway ramp (C), one that has the same startpoint and no other common sections (B), and another that has a section in common and a section apart from the motorway ramp (A). It is necessary that the section apart from the motorway ramp is not included in any threshold from the database, to prevent from map matching to existing ways. In this test environment the following mentioned values are assumptions and variably adaptable.

Because of the need for a frequently occurrence of the trajectories, each of the artificial trajectories is taken as basis to create 10 additional trajectories with a randomized deviation for each point respecting a maximum deviation of  $5 \cdot 10^{-6}$  degrees in longitude and latitude. These trajectories serve as a test set to analyze the behavior of the algorithm to detect new ways.

Each point of the trajectory that is map matched to an existing way is rated with a percentage of 5%. This value is added to the general probability of existence of the alternative way. The expiring of ways is not considered in the test environment. Trajectories with GPS points that could not be map matched to existing ways, will be reserved as potential alternative way to compare them with new incoming trajectories. The next time a trajectory can be map matched to the potential alternative way, each GPS point is rated with a percentage of 0.5%, if it happens in less than a minute, the probability of existence assumes to be higher and the percentage is rated with 1%. In this test environment we suppose day time, so usually ways should be taken frequently.

If a potential alternative way is rated with at least a percentage of 90% it is considered as a new, regularly used way. If a way is not used, the percentage decreases every five minutes about 5%. The wrong-way driver detection algorithm only uses validated categories of ways (Figure 5) and no potential alternative ways.

With this parameterization the test environment is operated. For each categorized artificial trajectory every 30 seconds one of the randomized trajectories serves as input for the wrong-way driver detection function. After that, one of the trajectories is inverted to simulate a wrong-way driver and proof, if this is correctly detected. This procedure is repeated for each trajectory, so that for each category and each generated trajectory one inverted trajectory has been processed by the wrong-way driver detection.

## RESULTS

During the tests we discovered that the process of map matching the changed traffic guidance to the already stored ways has to be done consciously. Failures during this steps can lead to bad influences on the detection algorithm, therefore a high specificity is required. In general, trajectories of category B and C could not constantly be detected as new ways caused by the problem of map matching and parametrization. Depending on the different categorized trajectories, the trajectories of type (A) has been detected earlier than for type B or C. This is an expected result, because of the common section to already existing ways in the database. The percentage of 0.5% or 1% for points that cannot be map matched to existing ways has been too low to reach the 90% level in some cases. When new ways have been identified correctly, and the map matching of the points to the new ways succeeded, the inverted trajectories have been detected successfully as wrong-way driver. The same applies to not inverted trajectories, which have been detected as driving in the correct direction.

Generally speaking, the regulation which defines the way when and how strong the changed conditions affect the database has to be defined by the amount and time intervals of their occurrence. Under these conditions we achieved higher quality rates than without the self-controlling module. When the map matching failed, the amount of false positives increases in some cases.

## LIMITATIONS

The described evaluation process is limited to handling changed traffic guidance which is temporary not considered in the map. Depending on the parametrization of map matching the results of the evaluation process vary in both directions. In general this process enables to react automatically to changing street conditions and test the resulting behavior of the detection algorithm. But there are limitations.

Changed infrastructure directly on motorways is not considered. Furthermore, to build up a reliable self-controlling module it is advised and partly necessary to extend the database with connected ways around motorway junction ways, especially for completely new ways, which correspond to a new motorway junction. It is also necessary to respect the fact that motorway junction ways can have various forms, which are not further discussed in this paper, nor tested.

The introduced approach is mainly tailored to IAV's wrong-way driver detection, but also has adaptable aspects. For example, going one step back and gather additional information to indicate changes to react appropriately can also be adapted to other functions. Also the discussed classification scheme of ways is build up dynamically and not determined for a special defined function. The concept behind is extendable and open for changes.

## CONCLUSIONS

The discussed process of the introduced wrong-way driver warning shows an example how a specific cloud-based function can be dynamically evaluated without dependence on the functional logic. Especially functions whose results strongly depend on ever-changing input data need solutions to test their behavior in critical situations. This approach delivers also a possible answer how to implement additional methods to create more flexible and long-term reliable cloud-based active safety systems.

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