The ActMAP – FeedMAP Framework
A Basis for in-vehicle ADAS Application Improvement

Bernd Thomas, Jan Löwenau, Sinisa Durekovic, Hans-Ulrich Otto

***Abstract*— Up to date digital maps are a demanding requirement especially in the context of digital map based ADAS applications. This paper presents first results and applications from the FeedMAP project and how they can be used for increasing driving safety by integrating map deviation detection and incremental update technology into ADAS frameworks using the ADAS Horizon concept.**

I. Introduction

The ActMAP framework [1] provides concepts and methods for wireless distribution of incremental map updates for in-vehicle navigation and Advanced Driver Assistance Systems (ADAS) applications with the general goal to achieve highest up-to-dateness of an in-vehicle map database. Although this incremental map updating framework helps to shorten the time span between map updates significantly the basic assumption is that map deviations are detected by the map suppliers. This obviously has a disadvantage, since constantly checking wide areas of a road network is a time consuming and cost intensive process for update supplies. As a consequence road network changes in remote areas or dynamic events (e.g. road construction sites) are not detected at all or only with a very high latency.

The basic idea of the FeedMAP project [7] is to use the end customer's vehicle equipped with either a navigation system or ADAS application for the automatic detection of map deviations. Consequently a closed loop of map deviation detection and incremental map updating provides a even higher degree of map up-to-dateness for in-vehicle map databases. Thus coupling the ActMAP and FeedMAP framework is conceptually a reasonable step for the following reasons:

1) Faster availability of map updates due to automatic, permanent, and global area-wide monitoring of map errors and real world road changes.

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2) Minimizing maintenance (data acquisition) costs for update suppliers.

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4) Increasing the quality of maps in general and specifically by reliable update information given from public authorities (e.g. on road status and constructions by Swedish Road Administration) and other trustworthy LBC providers.

5) Better quality of service for the end customer due to increased up-to-dateness of maps and additional services like dynamic content updates.

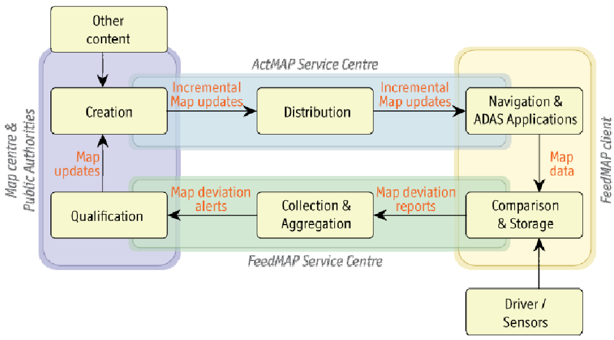

Figure 1 ActMAP - FeedMAP loop

Considering the core functionalities of the ActMAP and the FeedMAP system (Figure 1) the main roles of each system is clearly characterized as Update Distributor (Map Centre and ActMAP Service Centre) and Update Detector (FeedMAP client and FeedMAP Service Centre). Whereas update suppliers like map centres or content providers in general take over the role of an update evaluator/provider. Hence they have to decide if FeedMAP updates derivable from FeedMAP deviation alerts meet a special quality criteria, such that they can be propagated via the ActMAP services to in-vehicle applications.

II. Deviation Detection

The FeedMAP-ActMAP loop starts when the difference between ground truth and content of the digital map is detected. Difference may be in absence of real-world entity in the digital map, presence of digital map entity that does not exists in reality or in difference between a value of entity attribute stored in the digital map and actual real-world value of the attribute.

In the FeedMAP framework, those differences are called Map Deviations and they are described in XML-formatted data structures referred to as a Map Deviation Report

(MDR). These Map Deviations are detected by FeedMAP Clients (FMC). A FeedMAP Client generally fits into two categories: 1) Car probes are FeedMAP clients equipped with sensors and algorithms that are used in deviation detection. 2) Public Authorities (PA) are FeedMAP clients that generate MDRs. However, since PA initiates or at least keeps official records about many attributes contained in the digital map, they are the reference source for that information.

Map deviation detection algorithms implemented in car probes can be generally grouped into three categories: autonomous, manual, and joint detection.

A. *Autonomous deviation detection*

Autonomous detection does not involve any conscious driver action; source of the data that indicates the deviation is only provided by different car sensors. An example of the Autonomous detection is detection of missing links. To detect roads that are not in the digital map, system can monitor behaviour of the map-matching module of the navigation system. When map matching is unsuccessful, despite of good quality of sensor data such as GPS, one can conclude that vehicle is travelling along 'uncharted' street and Map Deviation Report can be generated.

B. *Manual deviation detection*

Manual deviation detection algorithms rely only on driver interventions. Detection of Scenic Routes or changes in Point-of-Interest attributes (telephone number, opening hours, etc.) are typical examples. In general, all manual detection algorithms can be automated by use of hardware sensors and by applying complex software algorithms, but in most cases such approach is not feasible.

C. *Joint deviation detection*

Joint detection algorithms are those algorithms where the system detects the deviation, but some driver confirmation is necessary. This confirmation can be explicit (when the system asks the driver for confirmation), or implicit (when driver action confirms the assumption of system).

D. *Investigated Deviation Types*

For some deviation types, different deviation detection methods can be developed. Systems can rely on more or less sophisticated hardware sensors and or more or less complex software algorithms in deviation detection. Wrong Legal Speed Limit can be explicitly reported by the driver, deducted from monitoring drivers behaviour (as described in section IV.B), or image-recognition camera-based sensor can do the same automatically. Of course, more advanced sensors and more advanced algorithms will reduce the need for drivers' involvement in deviation detection. Since today's 'Driver Workplace' is already fairly complex, one should avoid manual detections and joint detections with explicit confirmations because they increase the drivers' workload.

III. Deviation Report Analysis

It is the task of the FeedMAP Service Centre (FMSC) to receive MDRs, to analyse them and to decide if and when a Map Deviation Alert (MDA) is to be generated and sent to the Map Centre (MC). Within The FeedMAP project, Tele Atlas is implementing a FMSC, that will receive and analyze MDRs from NAVIGON's FeedMAPSensor, as described later in this document. The FMSC comprises the following modules: *Deviation Meta-Database*, *CodeBase*, *Cluster-Database*, *MSC-Database*, *FMC-Database*.

The *Deviation Meta-Database* is the place where configuration data for verification and processing for each deviation type is stored. The *CodeBase* is a repository of algorithms. Here it is specified what algorithm is to be used to check the quality of the MDR and to analyze clusters of particular deviation type. The *Cluster-Database* is used as a temporary store for the MDRs. In that database, MDRs will be grouped into clusters. Each Cluster is a collection of MDRs that describes same real-world deviation types. Each MDR belongs to exactly one cluster. The *MSC-Database* stores information about different map centers where to send the final MDAs to. The *FMC-Database* is the place where relevant data about FeedMAP Clients is stored.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<MapDeviationTransferRequest
        xmlns:adtlt="http://www.location.com/adtlt"
        xmlns:gml="http://www.opengis.net/gml"
        xmlns="http://www.feedmap.com"
        version="1.2.1">
 <MapDeviationReport
            vendor="TELE ATLAS"
            release="GERMANY-2007Q1"
            lastUpdate="2007-07-20T00:42:42.000+00:00">
  <DeviationType>WRONG_ONEWAY</DeviationType>
  <TimeStamp>2007-08-02T00:57:00.000+00:00</TimeStamp>
  <SensorList>
     <GPS>
      <HDOP>12.5</HDOP>
     </GPS>
     <Odometer>true</Odometer>
     <Gyro>true</Gyro>
  </SensorList>
  <ClientID>42</ClientID>
  <DeviationLocation locationQuality="0.1">
   <gml:LineString>
     <gml:coordinates decimal="." cs="," ts=" ">
            9.1566292,45.4839422 9.1567121,45.4840502
            9.1567666,45.4841599 9.1567997,45.4842592
            9.1567941,45.484399 9.1567668,45.4844842
     </gml:coordinates>
   </gml:LineString>
  </DeviationLocation>
 </MapDeviationReport>
</MapDeviationTransferRequest>
```


Figure 2 Example MDR

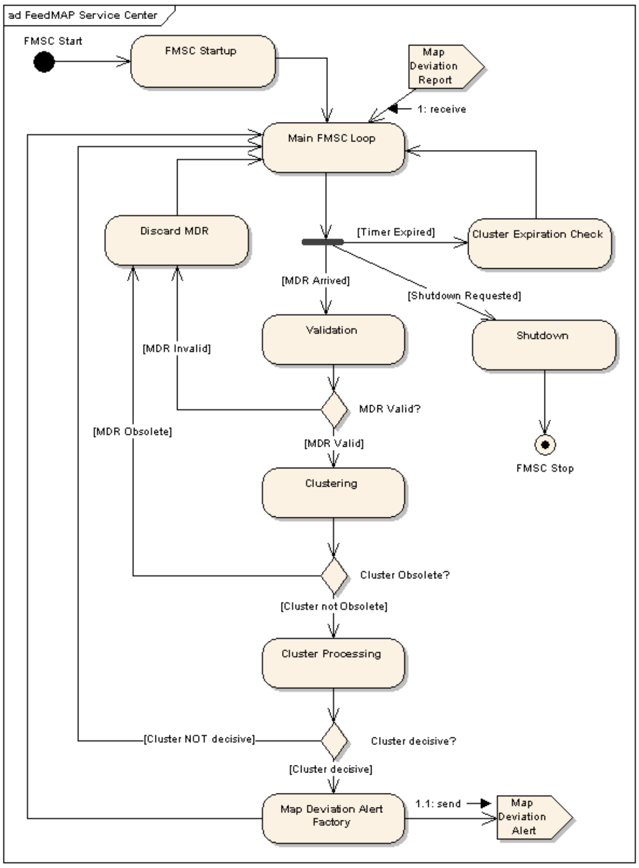

Figure 3 FMSC analysis process

Figure 3 illustrates the general processing steps of the FMSC. In the main FMSC loop, the system will wait for one of three events: *Shutdown request*, *Timer expiration*, or *Arrival of new MDR*.

If a shutdown is requested, the shutdown procedure will clean used resources. If the timer has expired, the system will check all the clusters in the *Cluster Expiration Check* procedure. Old clusters that did not produce MDAs in predefined time, as well as old obsolete clusters will be deleted. When a new MDR has arrived, it will be processed in up to four steps: 1) Validation will check if the MDR is "good enough" to be processed. Validation includes checking of syntax and up-to-dateness of the report, completeness as well as internal consistency of the data included in the report.

2) Clustering will assign the MDR to an existing or new cluster. The clustering process itself is uses Data Mining procedures. Which clustering algorithm is applied depends on the actual deviation type and location referencing method stated in the Map Deviation Reports. For instance, clustering of link-wide deviation such as Legal Speed Limit can be based on simple metrics that defines zero distance between deviation reports that refer to the same link ID and infinite distance if link identifiers are not identical.

3) Cluster Processing will analyze updated cluster(s). Analysis will be focused on two aspects of cluster data: the cluster 'Location Centroid', representative location of the deviation, and on 'Data Centroid', which is the most probable corrected value of the deviation. Both Location Centroid and Data Centroid are calculated from Map Deviation Reports taking into account reported data quality as well as confidence to the user that reported the deviation. For instance, for scalar values Data Centroid can be calculated as weighted average of MDR data that belongs to the particular cluster. In addition, quality of the Location Centroid as well as quality of Data Centroid must be estimated. Exact methods of quality estimation again depend on the deviation types; for instance, standard deviation of MDR data values from Data Centroid can be used as measure of Data Centroid quality.

4) A Cluster becomes 'decisive' if there are enough MDRs in it, and if the quality of its Location Centroid indicates that the location of the deviation is known with enough accuracy. In addition, it may be requested that the quality of Data Centroids are above predefined thresholds. The MDA Factory generates out of 'decisive' clusters Map Deviation Alerts. After Cluster Expiration Check or MDR Processing, the system will go back into Main FMSC Loop.

IV. APPLICATIONS AND FEEDMAP-ADAS TEST SCENARIOS

Within the FeedMAP project different implementations of the FeedMAP Clients, Service Centres and applications are developed. In this paper we focus on ADAS [5] related applications and ADAS development platforms based on the concept of the ADAS Horizon. The ADAS Horizon comprises a solution for providing digital map information about the most probable path the vehicle will take to the vehicles CAN-bus. This concept was developed in the EU research project MAPS & ADAS [3][4][6]. The ADAS Horizon is an extract of the digital map around the current vehicle position. For each street segment a probability of driving through this segment is assigned. The Most Probable Path is a connected set of segments, starting with the one where the vehicle is located and following the segments with the highest probability.

A. *Adaptive Speed Recommendation and FeedMAP*

The BMW application "Adaptive Speed Recommendation" (ASR) is a typical example of ADAS applications whose usability strongly depends on the correctness of the map data. The Adaptive Speed Recommendation Info function provides additional, detailed information on the stretch of road the driver is currently covering. To provide this helpful support, a traffic sign graphics in the instrument cluster – head up display and navigation display - in the cockpit informs the driver of the speed limit at his current location. Adaptive Speed Recommendation is extended with Map Deviation Detection, Reporting and Dynamic Map Update capabilities and it is now active part of the ActMAP-FeedMAP chain.

To calculate recommended speed at each moment, the Most Probable path of the Electronic Horizon[3][4][6] is analyzed; the following road characteristics are taken into account: Curves, Legal Speed Limits, Crossings, and Roundabouts.

As such, ASR system combines curve Information, Speed Limit Information and Crossing Information ADAS functions in one application. It will warn the user of the need to slow down before the vehicle reaches the point where speed must be reduced. For instance, the ASR may display the information about speed limit 50-300 meters ahead of the actual Speed Limit traffic sign. The exact distance depends on several factors such as current vehicle speed, vehicle braking acceleration (deceleration), driver reaction time, etc. Of course, if the system calculates that the present speed does not violate current or future legal speed limit, no information will be shown.

Special care is taken to properly calculate the maximum allowed speed on the curves. Current curve radius data from the vector map database is not always precise enough. In addition, speed in the curve will depend of many other factors as well: number of lanes, width of the road, overall road surface condition etc. While the algorithm will calculate the allowed curve speed based on the available curve radius, all other relevant road attributes from the vector map database will be used to increase or decrease the estimate.

Since the quality of ASR results heavily on quality of Digital Map Data, it is obvious that this application will benefit from up-to-date map content provided by FeedMAP loop. The Opposite is true as well: Adaptive Speed Recommendation system plays a critical role in implementations of many car-speed related map deviations. Simplest example is the FeedMAP algorithm for detection of issues with Legal Speed Limit data in the Digital Map.

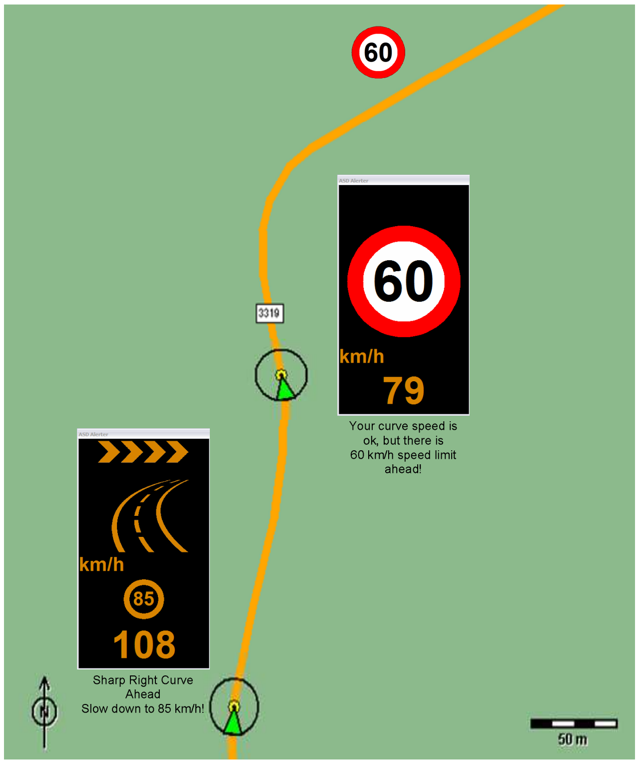

Figure 4 ASR

B. ASR and Detection of Incorrect Legal Speed Limits

To detect wrong Legal Speed Limits, the system monitors the speed recommended by the ASR system and actual driven speed. Let’s assume that a driver drives faster than the ASR recommendation on a particular road segment. In that situation, ASR issues a warning, but this warning is ignored by the driver and he/she does not slow down. Since Legal Speed Limit is part of ASR calculation, one can conclude that actual Legal Speed Limit is higher than the one stored in the digital map: driver ignored ASR speed warning because he knows that the actual speed limit is different from the speed limit stored in the database and used by the system.

A more complex case is if, along a single segment, a driver is significantly slower than the legal speed limit. First of all, the output from ACC radar can be checked to find out if a slow vehicle is present in the front. If this is the case, no conclusion can be reached. If, however, no cars are in front, the driver may simply follow the ASR recommended speed that tells him there is a crossing or sharp curve ahead. Again, digital-map legal speed limit may be correct. When ASR calculates that a driver could be faster, and if there are no cars in front, the most probable reason why the driver is driving slowly is because he saw the actual legal speed limit sign. Under this assumption, the FeedMAP client using ASR will generate a Map Deviation Report about probable wrong Legal Speed Limit.

C. *Updating the ADAS Horizon*

NAVIGON extended within the FeedMAP project their ADAS Horizon Provider solution (MapSensor) with FeedMAP client functionality. This application (FeedMAPSensor) is evaluated in a joint test-site with Volvo Technology (VTEC), and Tele Atlas. The FeedMAPSensor is installed on a VTEC truck, which is equipped with sensors connected to the truck's CAN bus. Such sensors comprise an image lane detection unit, ACC radar, and slope unit. The sensors' information are used to assist the deviation detection algorithms in autonomous detection mode.

The FeedMAPSensor also extends the ADAS horizon and the information on the most probable path by detected deviations (Figure 5). Additionally the FeedMAPSensor is capable of receiving incremental map updates from an ActMAP service centre (Figure 1). Information of the incremental map updates are also used to extend the ADAS horizon (Figure 5). Consequently ADAS applications based on the ADAS horizon information provided by the FeedMAPSensor to the vehicle's CAN-bus benefit from the FeedMAP concept. Such update and detection information available on the vehicle's CAN-bus can be used to alert the driver about map changes and/or directly can be used by ADAS systems for improved applications. Hence the overall driving safety is increased, because of up to date information.

The FeedMAPSensor comprises the manual detection of 4 deviation types and automatic detection of 5 deviation types. For manual deviation detection a GUI is used that allows the user by "point, click, and select" operations on the map to report: Road Works, Point of Interest, Speed Limit, and Traffic Sign deviations. Although manual deviations detection is of some importance for cases where automatic detection is very complex, the main focus of the FeedMAP project is clearly on the automatic detection of deviations, since this reduces workload and minimizes the risk of disturbing the driver.

FeedMAPSensor automatically detects wrong road geometry, missing road, speed limit, slope and lane info deviations. The detection of wrong road and missing road deviations are solely based on GPS sensor data. The speed limit deviation detection can be performed in two different modes, either automatic or manual. Automatic detection is based on speed information given by the GPS receiver and additional (optional) radar information about the speed of vehicles in front of the truck.

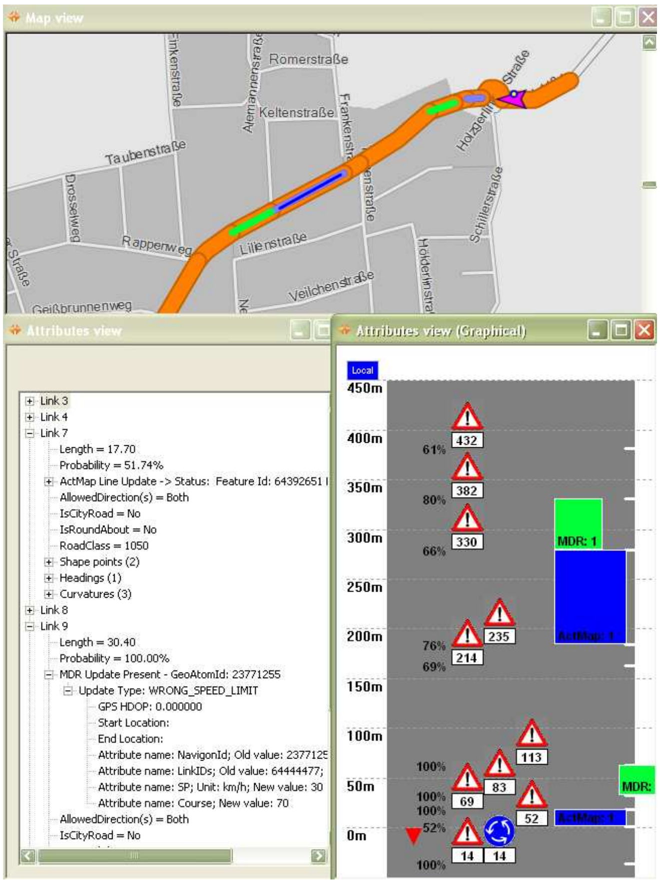

Figure 5 ActMAP Updates (blue), MDR (green), Horizon (orange), attribute and graphical view of ADAS Horizon (left and right)

Since the measured speed information solely based on the GPS information might lead to false assumptions on possible speed limit changes, due to possible congestions or illegal speeding by the driver, the radar information is used to improve the speed limit detection heuristic. The vehicle's speed is compared with speed limit attributes attached to the map and based on different computational models the radar information read from the CAN-bus is taken into consideration for estimating a new speed limit.

The detection of Missing Roads is also supported and requires a close interaction with map matching components of the core system. Information about the new road's geometry is collected and reported to the FeedMAP Service Centre. Figure 6 shows an example of detected missing roads (in green). Missing road and wrong geometry detection is mainly based on thresholds for the distance between map matched position and GPS position, number of succeeding "spurious" position samples, and maximal distance between sample points.

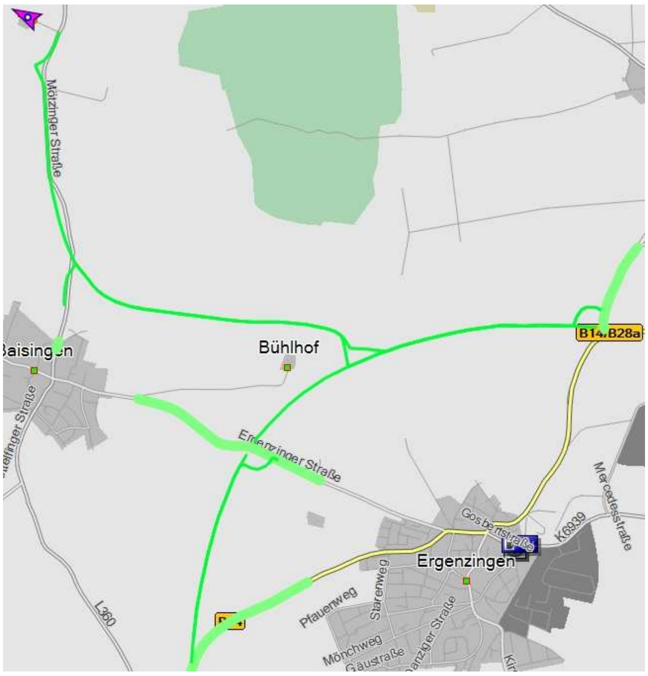

Figure 6 Detected deviations "missing road" (geometry of road in green)

Wrong and Missing Slope information is detected by the use of a slope assessment unit based on the truck's power train control units. This sensor information is compared to slope information when special ADAS maps are used and reported respectively.

For detecting Lane Information deviations a image processing unit by VTEC is used. The vision system provides real time information on the numbers of lanes and lane markers to the truck's CAN-bus. It is capable of detecting the lane width, lane marking types, and information on the neighbour lanes. This data provided by the sensor system plus radar information is used to build a lane model. The detected lane information (markings, number of lanes) is compared to existing ADAS map attributes. In case some lane information is not present for comparison in the digital map (no ADAS attributes) the sensor data is also used to report a MDR containing missing lane information to the FeedMAP Service Centre.

V. CONCLUSION

During first field tests some critical issues have been identified, which are briefly described in the following.

A great variance in positioning information given by different GPS receivers was observed. A variance of up to 30m was detected while estimating the position at the same time and same location with 5 different GPS receivers. This has a direct impact on the reported deviation quality, robustness of algorithms used by the FMSC.

The detection in parallel of different deviation types might lead to contradictory MDRs, e.g. for same deviation spots wrong geometry and missing roads have been reported. One explanation can be found in the standard software components which are tailored for navigation tasks and only adapted for deviation detection tasks (e.g. map matcher component). The use of standard map matchers provide only partially good results for detecting deviations, since their general goal is to match the vehicles position on street segments taking into consideration additional map attribute information (e.g. direction of traffic flow). Hence the use of additional modified map matchers seem reasonable. The tested approaches based on certain threshold (e.g. distance between map matched and GPS position) are good indicators for existing deviations, but it also became apparent that detected deviations like for example a missing road requires complex and sophisticated processing algorithms on the FMSC side.

Concluding it can be stated that the automatic detection of map deviations and the combination with incremental map updating techniques are building one reasonable basis for in-vehicle ADAS applications to improve the up-to-dateness and quality of digital maps and finally the safety and comfort of driving.

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