

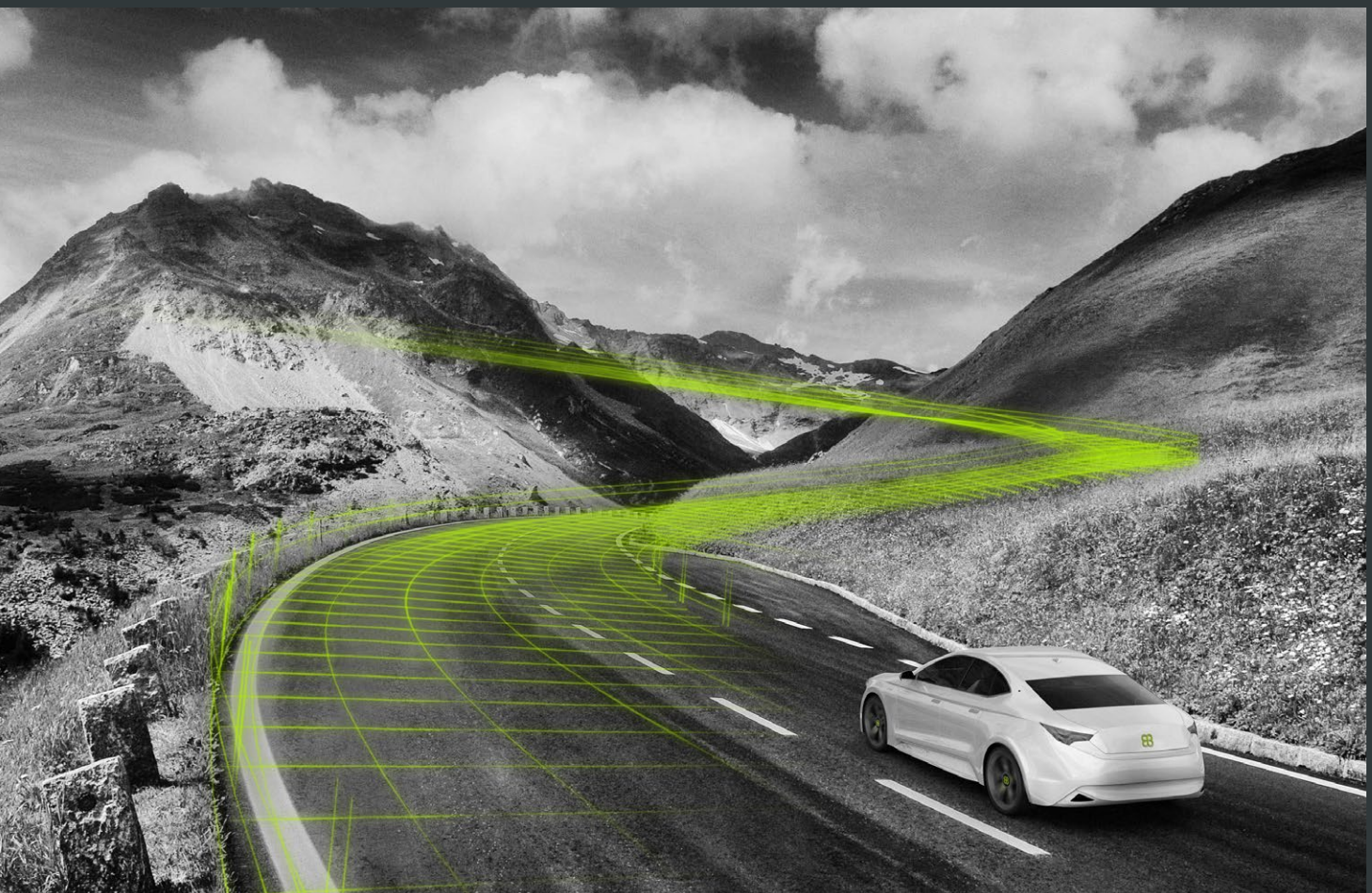


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**ADAS: Contributor as well as beneficiary
of cloud-enriched street map data**



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1. The role of and applications for integrated map and sensor data in automated driving

This paper details the role of and applications for integrated map and sensor data in next-generation driver assistance systems. It discusses the function of highly accurate map data in automated driving and identifies map features. These features include comfort functions, comfort-supporting functions, safety functions and more. Crowd-sensing approaches and cloud communications will play a critical role in ensuring more complete, accurate and timely updates of map data, and will be vital for the development of the new, sensor-enriched “safe” road map.

2. The role of map features for automated driving

Cutting-edge series production cars are already using street map-based features. The new Audi Q7, for example, adjusts speed when using adaptive cruise control (ACC) according to speed signs and legal regulations [1]. Similar systems are being produced by Daimler, BMW and VW. The main information source for these systems is the navigation system, although its output is then cross-checked with output from in-car sensors such as video cameras as signs come into range.

Future cars will have an increasing amount of automated capabilities, and map data will become a significant information supplier [2] [3] for these. The list of features and potential beneficiaries of map data in **table 1** gives an overview of how map features can support the creation of an environment model.

Table 1: List of map features and potential functional beneficiaries

Map Feature	Green Driving	Comfort Functions	Comfort Support	Safety Functions
Slope	✓			
Curvature	✓	✓	✓	
Stop Line	✓	✓		
Crosswalk	✓	✓		
Maximum Speed	✓	✓		
Crossroads	✓	✓		✓
Road Grade		✓		
Road Barriers		✓		
Road Geometry		✓		
Lane Boundaries		✓		
Safe State support		✓		
Superelevation			✓	
Driving tracks				✓
Topologically connections				✓
Tunnel			✓	
Rights of Give Way	✓	✓		✓

The environment model contains the car's state, static as well as dynamic objects around the car, driveable areas, legal constraints, road and lane models and anything else that is necessary to determine automated driving actions. The car's sensor fusion system generates the environment model by capturing the critical data with on-board sensors. This environment model is (optimally) free of jitter, sensor noise, false positives etc. so it provides a good source for data to be published in a crowd sensing database. Also, it can be used to treat data from a crowd sensing database as just another sensor input, so it is the sink for cloud sensing as well. Although almost all data produced by driver assistance can be geo-referenced and therefore contribute, we believe the features given in **table 1** as most relevant.

2.1 Map features for green driving

Key map features for green driving are those that require a change in speed, such as slope, curvature, stop lines, crosswalks, legal maximum speed and crossroads, including rights of give way.

The engine consumes the most energy. The ability to pre-determine the need to decelerate as well as avoid unnecessary acceleration will optimize in-vehicle energy savings. With hybrid systems that are capable of storing and reusing energy, predicting energy flow is key to leveraging their capabilities. Such systems benefit from understanding the vehicle's speed as well as the topography and geometry of the road ahead.

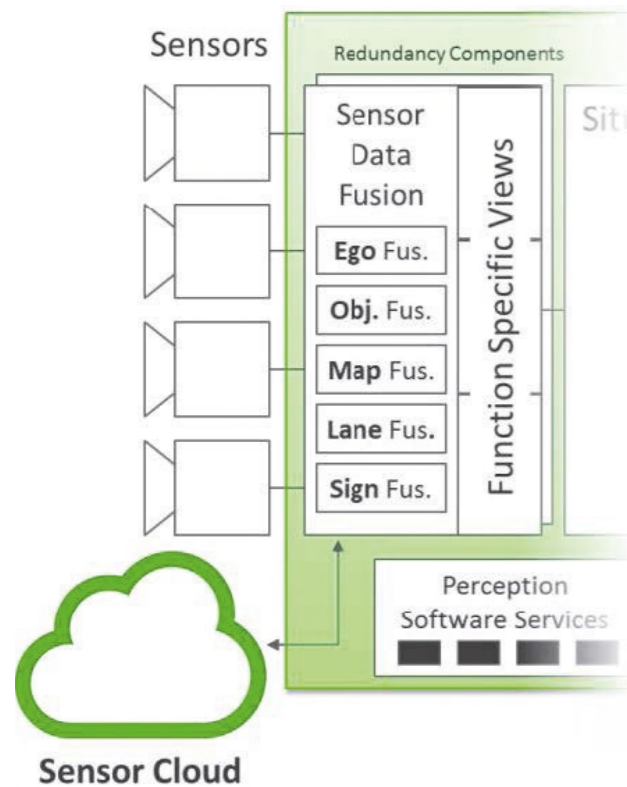


Figure 1: Sensor data fusion is source as well as sink for crowd sensing data

2.2. Comfort functions

The term "comfort functions" refers to all applications that relieve the driver by taking over driving tasks. Comfort functions in today's series production cars are categorized as level 2 IIHS (Insurance Institute for Highway Safety) / NHTSA (National Highway Traffic Safety Administration) classification [4], and include capabilities such as Traffic Jam Assistant or Pre-dictive ACC that rely on features like e.g. curvature, maximum speed limit, road grade and existence of road barriers. Future applications such as a "Highway Pilot" or "Exit2Exit" [5] will require additional information about the specific road geometry. Detailed information about lane boundaries is clearly critical, and the exact position of signs, poles or gantries will be used and must be constantly updated, as well.

From level 3 IIHS/NHTSA on, the assistance system must be capable of working in a fail-degraded mode until a safe state has been reached [5]. The system will need a description of possible locations and an understanding of different approaches to take to transition to a safe state. Imagine a full stop on a highway as the common safe state. Stopping beyond a sharp curve or a steep hill might be a more dangerous place to stop and to wait for assistance, for example, compared to somewhere else. If the driver needs medical assistance, the ideal place to stop would be one that can be easily reached by an ambulance. On German highways, for example, ambulances are not allowed to drive on the wrong side of the road. Therefore, stopping the car beyond a highway entrance ramp would be better than stopping prior to it. Since work is currently ongoing to define or detail such features, their group will be referred to as "safe state-supporting features" in the pages to follow.

2.3. Comfort supporting functions

Comfort supporting functions do not take over driving tasks but enrich the driving experience. The super elevation feature combined with the curvature feature, for example, is useful for a lateral force-reducing application [6]. The tunnel feature can be used by an air conditioning system to alternate air circulation and ensure the best quality air flow in the car. Another prominent application is the adaption of head lights to the upcoming street geometry. This is possible by using the curvature feature of maps.

2.4. Safety functions

Safety functions help to avoid collisions or mitigate collision hazards. State-of-the-art safety functions do not rely on map data - which can be unreliable and outdated - but instead trust in the locally perceived environment model confirmed by different sensors. However, in situations where the sensors cannot provide sufficient information, map features can help. At a crossroads, for example, the lanes may not be clearly marked. The driven tracks, their topological connection, and the right-of-way rules will be useful features for safety-oriented functions of the future.

3. Crowd sensing

Map features can lack reliability, which is why their use is limited in automated driving. Current map feature providers are recognized as non-safety relevant functions from the perspective of ISO26262. Within functions that require an Automotive Safety Integrity Level (ASIL), a non-safety relevant data supplier can only be used for core decisions if there is a plausibility check based on independently perceived data. However, a map can be seen as a virtual sensor if in-car sensors are not able to gather information. In this situation, there would be no independent on-board sensor.

Crowd sensing is a possible way to overcome these challenges. If many cars with sensor fusion techniques collect data to evaluate the same map features, and these are accumulated in the cloud and distributed to each car, the plausibility check can be done using several sensor loggings from different sources. Hypothetically, this can enable the data provider to be considered as a valid source in the sense of ISO26262. This is a debated topic, because careful thought has to be given to the requirements ISO26262 imparts on ASIL-rated data. For example, it must be free from interference by non-safety relevant data, which would require all data that is aggregated in the cloud to come from ASIL-certified sources. A certification process for cloud contributors could be introduced to ascertain this.

Since map features are considered as important data suppliers for future automated driving functions, they are a valuable topic for research and development. The following chapters will address some of the questions regarding the future of mapping and automated driving, starting with the crowd-sensing architecture.



Figure 2: Collected and analyzed data creates an “electronic horizon” that enables and improves ADAS features

Certain aspects of the vehicle’s reality can be easily captured, while others are not directly accessible via on-board sensors. In order to fill this gap, a base map has to be provided by either commercial or free sources. Aspects of the base map which cannot typically be captured via on-board sensors are administrative information (like street names), land use polygons, points of interest (POIs), and traffic information (e.g. TMC locations). This data often has a tight coupling to the road network, for example, names are associated with city centers and roads, POIs have access roads, and TMC locations represent a part of the road network. A very important step of the data processing in the cloud is to apply the sensor data to the base map. The data in the base map may be inaccurate or outdated, so a perfect match is not always possible. In case of a mismatch of, the road geometry, for example, manual or automated correction mechanisms can be applied. Point information like, for example, speed limit values, can usually be matched and corrected more easily than line or area information. The reason is that line or area objects often have relationships to other line or area objects, resulting in a modification cascade. When the map-enrichment step is complete, the resulting map data is transformed into a format suitable for embedded systems like for example NDS [7]. In order to reduce the data volume of map updates, the data is split into a larger part that is updated less frequently and a smaller part that is updated more frequently. Content that is updated less frequently has its origin often in the base map (like e.g. names for destination input), whereas frequent updates are usually based on the data collected by the sensor vehicles. When an update package is received by an automated driving vehicle, the package is applied to the existing map, resulting in an update of the on-board memory. The data can now be transferred and used by the ECUs in the vehicle, which closes the sensor loop. Other data used in the sensor loop includes traffic and weather information. This information is the basis for functions such as real-time in-vehicle traffic display and is also used as a verification source in the map-enrichment process in the cloud.

4. Crowd sensing – the architecture

Today’s series production vehicles are equipped with a variety of sensors. The captured sensor data is processed in several consecutive steps in order to keep the data volume manageable. Inside a sensor, the data is typically aggregated as an object model and then transferred via a data bus to various electronic control units (ECU). The ECUs provide driver-assistance features like ACC or lane change assistant (LCA). In order to realize these functions, an environment model is generated inside an ECU by matching the data from the different sensors with the help of fusion algorithms. The environment model consists of a road model, static as well as dynamic objects, descriptions of free spaces, global-georeferenced data, an ego-motion estimation, positional information, and further attributes such as whether an object has a fixed position or is moving. By using all of this information, an ECU is able to determine whether a surrounding object is relevant for a certain driver assistance function.

In addition to in-car usage of the sensor data, some of the data is processed further in a sensor loop that is partially outside the car with a connection to the cloud. (cf. **Figure 3**). This loop is essential for providing up-to-date and detailed information about the road network and the surrounding environment to the automated driving vehicles. The communication between the vehicles and the cloud is done via a connectivity front-end in the vehicle and a connectivity back-end that forms part of the cloud architecture. From a systems architecture perspective, this front-end and back-end provide gateways to handle all communication between the vehicle and the cloud. For the data transmission both connectivity gateways take care of safety and security functionalities to ensure that the transmitted data is not modified and that only authorized vehicles send and receive data. Once the sensor data has been received by the back-end, it is anonymized and stored in the cloud. Data mining algorithms (clustering, classification) are applied to the data originating from an entire car fleet in order to generate a comprehensive representation of the road network and the adjacent environment.

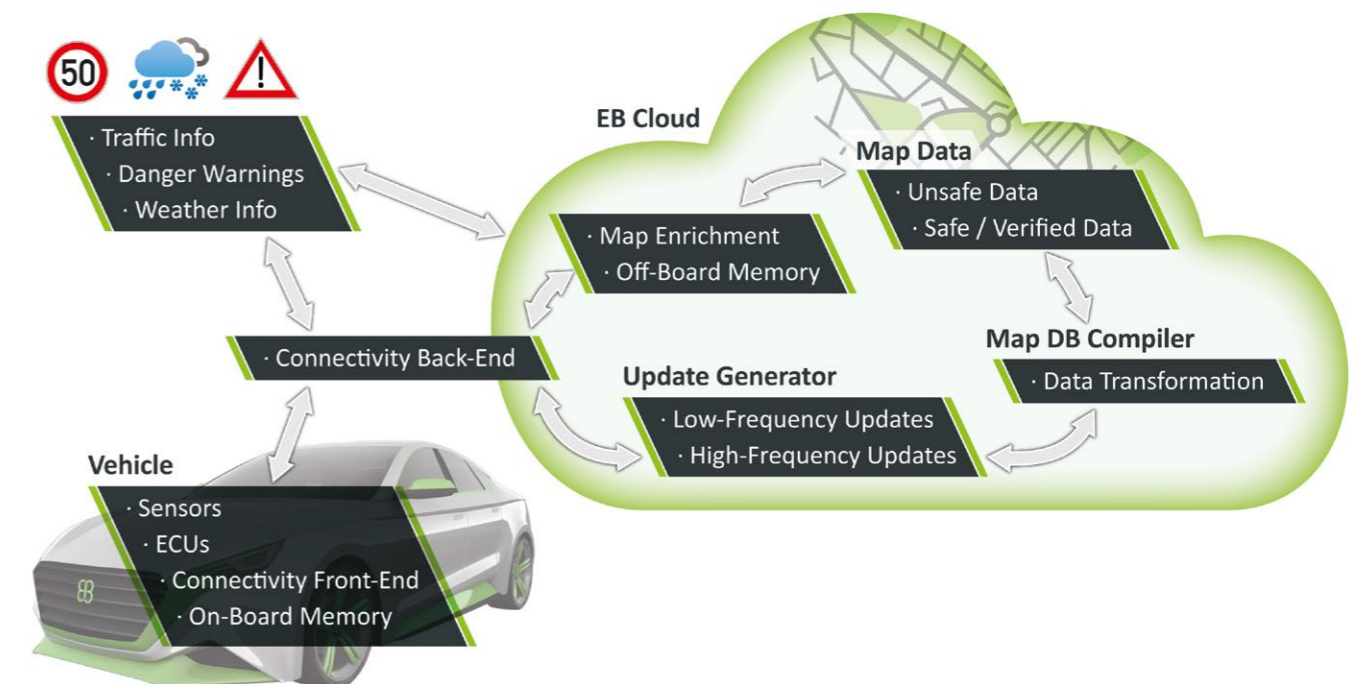


Figure 3: The crowd sensing architecture realizing the sensor loop

5. “Safe” map

The navigation map in conventional vehicles is usually updated at a car dealer during a service inspection. Alternatively, consumers can buy map updates in a store or via a download portal and then conduct the update personally. A recent innovation is in-car online updates based on a subscription model where the map is automatically updated in the background without further user interaction. A common thread among all update types is the rather lengthy interval between updates, often weeks or even months. The duration between updates has traditionally been determined by the business model of commercial raw data providers who typically update their base maps four times per year. However, efforts are now underway to increase the release frequency of new base map data. Nevertheless, reducing the release cycle to less than one week for commercial data seems unrealistic because of the data modification and qualification efforts required, as well as current distribution models.

In the context of automated driving, an up-to-date map is essential because it is not possible for an automated driving vehicle to capture all important aspects of the environment all the time. There can be situations where for example traffic signs are not recognized because of bad weather conditions, reflections, or trucks blocking the view. In such cases, the on-board map has to fill this gap. Because of the reasons mentioned previously, a map consisting of conventional base map data only is not suitable for this purpose. The base map data would be weeks or even months old and thus not accurately reflect the current reality. As such, there needs to be a way to enrich the base map with more up-to-date information. This is where the sensor loop comes into place. The vehicles in the field are acting as probes, constantly reporting their observations to the cloud. A single car with sensors will not be able to create a comprehensive model of the environment in all possible situations, but a fleet of cars with sensors can. A single vehicle with sensors will always be subject to dead spots where no observation is possible or where the quality of the observed information is quite low. However, an entire fleet will have numerous advantages including that on the more well-traveled or “important” road classes like highways (e.g., roads can be divided in different classes depending on their importance), multiple vehicles drive by a particular location on a single day. From the statistical point of view, it is highly unlikely that all of them will fail to capture the same traffic sign or road characteristic. So an advantage of a sensor data-enriched road map is that it contains more up-to-date information than a traditional base map.

A map used for automated driving also has to fulfill certain safety aspects. An advantage of separating map updates into low- and high-frequency updates is that safety hardening needs to be applied to the latter map part only. Using the base map for safety-critical functions is not possible for the time being because, to the best of our knowledge, there is no map data provider which captures, processes and distributes map data according to established and relevant safety standards (e.g. ISO-26262). So the challenge for any car manufacturer working on automated driving vehicles is to fill this gap by storing all safety-critical attributes in the more frequently updated portion of the map. Establishing safety and security standards for this map data is critical, and must incorporate all parts of the sensor loop: the data acquisition by vehicle sensors, the map enrichment in the cloud, the data transformation by the map compiler, the update package generation and application, and the access and usage of the map data in automated vehicles, as well as the data exchange between the front- and backend gateways.

Some of these parts are already quite well understood with regard to safety, for example, the capturing of data by sensors and the data transfer and usage inside a vehicle. Established techniques for authentication and data integrity can be applied to the data exchange between the two gateways. New safety concepts will need to be developed for all of the parts of the sensor loop that modify the sensor data in some way or where a selection or aggregation is performed. The data volume control, which determines which captured data is redundant and which data is sent to the cloud, is especially critical. The data-mining algorithms (especially clustering and classification) inside the cloud must be safe. This is challenging because the output of clustering algorithms often depends on the order of the input data, some even work by approximation or use randomization.

The result of classification algorithms is influenced by class-dependent parameters in the unsupervised case or by a training set in case of supervised classification. The map data-compilation step - transforming the enriched base-map data into the target format - is complex but a validation of the target map is, for example, possible by using a decompiler on the target map and compare its results with the enriched base map. In order to save transmission volume and update time, high-frequency update packages need to be individually created for each autonomous driving vehicle. Because the update comprises only a corridor along the current route, it has to be ensured that all relevant map data inside a safety margin around the route is included in the update.

From the safety point of view, it is also important to determine how reliable the information about a certain object in the map is. The questions “what was observed?” and “where was something observed?” can be answered by conducting a significant number of observations and applying suitable data mining algorithms. Because it is not possible to constantly monitor all road infrastructure objects all the time, objects in the map are subject to aging. This means the information about some objects will be more recent, while other objects will not have been confirmed for a while. The aging is realized by attaching a time stamp to all observed objects and propagating the time information through the entire sensor loop.

6. Car as a sensor

We previously described the role of the car as a probe for map generation. It is interesting to observe how, in this case, the sensors are used for a complementary purpose with regard to the typical driver assistance systems. Driver assistance systems have to look far ahead to make the right adjustments to the vehicle dynamics. The further they have to look, the more imprecise their observation is about the environment. Observations at closer distances are often of higher quality because some sensors are more precise the closer the range. Also, model-based sensor data fusion algorithms are used to improve estimate quality over multiple measurements so the observation reaches higher quality as the vehicle approaches the object. The best information about a spot is obtained when the vehicle passes it. This information is no more valuable for the vehicle itself but it becomes paramount if correctly propagated to other vehicles.

For example, a lane detection sensor has difficulty delivering precise width about the lane 150m ahead. This is because one pixel in the image corresponding to the region might have a real-world resolution between 50cm and 1m. The computed width will then lack accuracy. Additionally, other cars might obstruct one of the markings, making the computation impossible. On the other hand, if the view just in front of the car is clear, the pixel resolution will be at least a couple of centimeters and the computed width results will be quite precise.

The software architecture in the car needs to be adapted to be used for sensor data collection. On the one hand we have the standard driver assistance architecture, roughly consisting of:

- ▶ Sensors that gather data about the environment (in the following the GPS receiver will play a special role).
- ▶ A map updater that takes care of retrieving and installing newly available maps.
- ▶ On-board memory that determines the current vehicle position via GPS and distributes a description of the surroundings based on map data to all ECUs via the vehicle’s bus system. This description object is called “electronic horizon”.
- ▶ Ego-motion that estimates the vehicle’s dynamics parameters based on the sensor data. This allows vehicle position updates with higher frequency than that offered by GPS alone and can improve the location positioning in the map.
- ▶ ECUs that are used, for instance, to control ACC and lane keeping. These work by using the electronic horizon and the sensor data as input.

For interacting with the cloud, the vehicle shall include:

- ▶ A sensor data processing module that analyses sensor data to extract the features that will be uploaded to the cloud. For instance, the lateral acceleration and the vehicle speed could be used as an estimator for the road curvature.
- ▶ Map matching to give global coordinates to the recognize features. Whereas the data in the car can work flawlessly using a coordinate system that is local to the car, cloud data needs global referencing. Map matching requires the current GPS position, but its precision can be improved by considering the ego-motion estimation or even some landmarks coming from the electronic horizon.
- ▶ A difference detector that determines if it is necessary to upload the data to the cloud. It checks if the measured values differ from the expectations. This module serves a double purpose: it is the first one that detects a possible change of an attribute and is in charge of reducing communication bandwidth to the cloud by transmitting only relevant information. Changes detected by this module might be due to noisy sensor readings, but the cloud will be in charge of identifying this reading as an outlier and ignoring it.
- ▶ A connectivity front-end (**See 5. "Safe" map**)

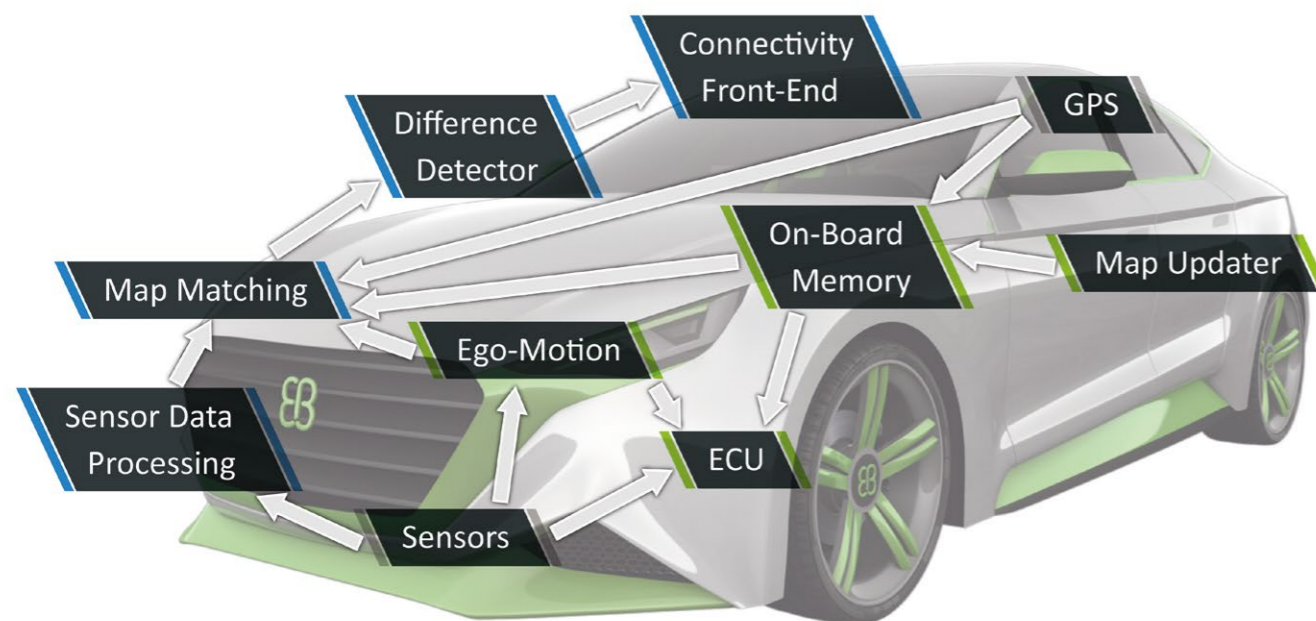


Figure 4: The car as a sensor

7. Summary

Highly accurate and integrated map and sensor data is crucial for automated driving. Advanced in-vehicle systems and software are necessary for interacting with the cloud and enabling the creation of the sensor-enriched road map that will guide vehicles safely and securely.

8. Related work

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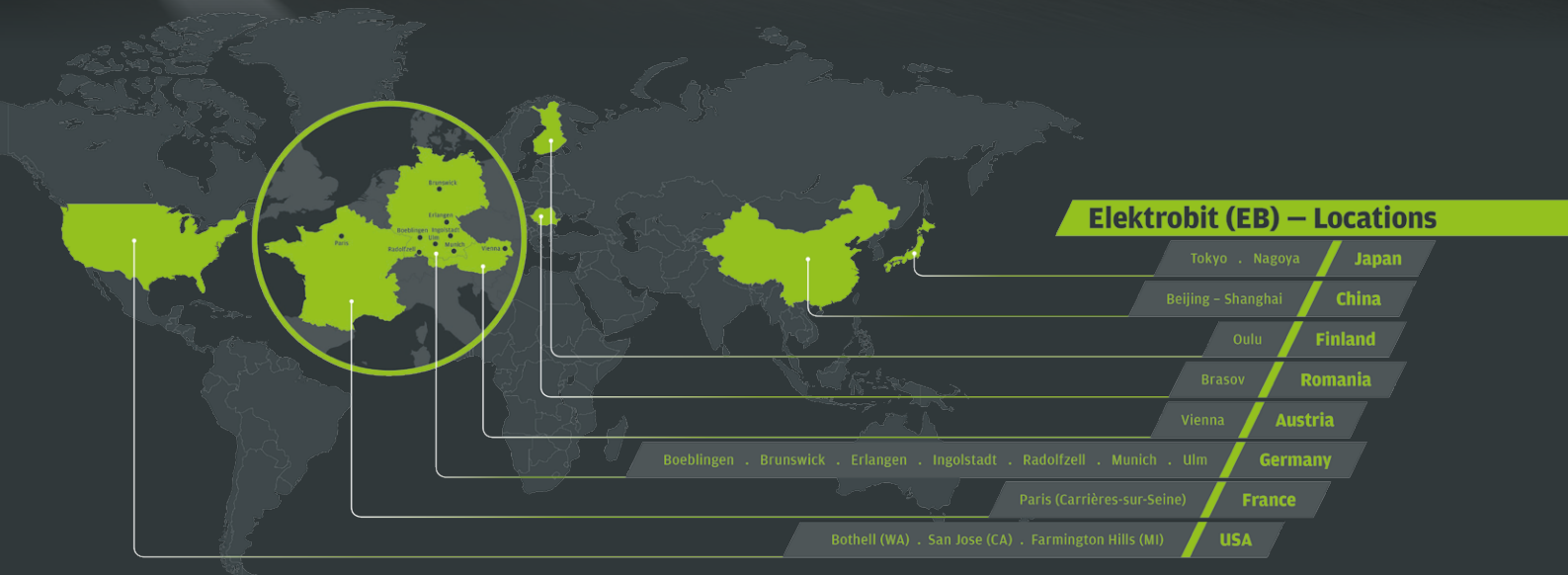
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