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Needs and potential of 3D city information and sensor fusion technologies for vehicle positioning in urban environments

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Abstract. We proposed a concept for an absolute vehicle positioning architecture in urban environments by accomplishing 3D city data and car side laser scanner. Today there is no reliable technology for a long time stable and absolute positioning in urban environments. While GNSS suffers from outtakes, SLAM and dead reckoning technologies are only precise during a limited time span. Because car mounted laser scanner produce bevel cuts, real 3D façade information is needed to apply a feature extraction algorithm. Our approach is based on a web feature service connecting the vehicle to a 3D city database. Starting from an initial position, a spatial request is phased to the database and geometries are sent to the car. There, feature extraction and map matching algorithm support an absolute positioning.

1 Introduction

While traffic situation in fast growing cities with increasing advent of individual traffic is going to become confusing, driver assistance systems play a more important role in safety concepts of carmakers. We will discuss the shortcomings of today’s approaches and propose a solution for these. Our approach combines up-to-date 3D city data with feature extraction algorithms on the vehicle.

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Today, advanced driver assistant systems (ADAS) are already able to support the driver in many situations like automatic distance control in stop-and-go scenarios, emergency braking or during lane changes [1]. All these systems have one thing in common: they take their decisions based on sensors which are observing the surrounding environment relative to the car. This approach is feasible as long as the ADAS is working in a non-collaborative way.

In the future, Car-2-Car communication technology will allow a wide range of new ADAS applications based on the exchange of detected obstacles or the current position of the own car [2]. The next step in the development of ADAS assumes that all positions are known in a global and therefore exchangeable reference frame. A fundamental precondition for a transformation of, for example, observed obstacles into a global representation is a well known ego-state of the car. This ego-state usually includes the global position and velocity as well as the attitude.

Up to now, a global positioning was only necessary for the strategic routing process within the vehicle’s navigation system. The use of the vehicle state for driver assistance systems, especially for safety critical ones, leads therefore to increasing requirements concerning the reliability of such information. These requirements can be divided into accuracy, availability, continuity and integrity of the determined states. In contrast to conventional navigation systems a highly accurate vehicle state has to be continuously available to the ADAS application. Furthermore, the integrity of the provided information plays a much more important role due to the fact that this application will not only provide information but warnings or, to some extend, automatically initiates a control input to the car (e.g. emergency braking).

Today digital information about infrastructure is available and could support the absolute positioning of a vehicle under the assumption of the use of additional sensors. The main source in Germany is the Automatisierte Liegenschaftskarte (ALK) which was initiated by the Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV) in the early 80ies. Next to properties, land parcels, and streets it covers detailed geometries about and street furniture like trees and gully covers etc. Geometries are associated with a catalogue of objects representing a semantically data model. The ALK is a 2D-based digital information system which incompletely holds information about building heights. Therefore the ALK can serve as one data input for a vehicle positioning system though it is insufficient in terms of 3D information.

A true 3D-data model for virtual cities was developed by the Special Interest Group 3D (SIG 3D) of the initiative Geodata Infrastructure North-

Rhine Westphalia, Germany and first presented by [3] in German. Today it has become a standard of the Open Geospatial Consortium (OGC) [4] and is well documented in [5]. Within well-defined level-of-details from LoD0 to LoD4 with increasing accuracy and structural information, CityGML presents an information model to describe the semantics and geometry of virtual 3D city models. While LOD1 as a blocks model can be roughly produced by the use of 2D footprints and building height, sophisticated data acquisitioning procedures are needed to describe more detailed information about building façades stored in LoD3.

This paper describes needs and potentials for an absolute vehicle positioning in urban environments. We follow an approach that combines 3D infrastructural information with sensor fusion technologies on the vehicle. Therefore we first review the problems of absolute positioning techniques in urban environments without additional city data. Then we argue the problems of 2D data for this approach (Chap. 2). In chapter 3 we propose an overall concept for a positioning approach. This includes data integration from different sources, data transfer via a Web Feature Service and information fusion on the vehicle.

2 Problems and Limitations for an absolute vehicle positioning

This section focuses on problems and limitations of current and future localisation technologies. First, a short review of state-of-the-art positioning systems is presented, followed by a discussion of major shortcomings.

2.1 State-of-the-art of localization technologies

Global vehicle positioning is usually done be means of satellite navigation. The most popular global navigation satellite system (GNSS) is the Global Positioning System (GPS) operated by the U.S. department of defence. Applying this system the user is able to localize itself with an accuracy of 10 meters depending on the environmental conditions [6]. Especially in urban environments the occurrence of disturbances can increase dramatically. Fig. 1 summarizes the most important error sources.

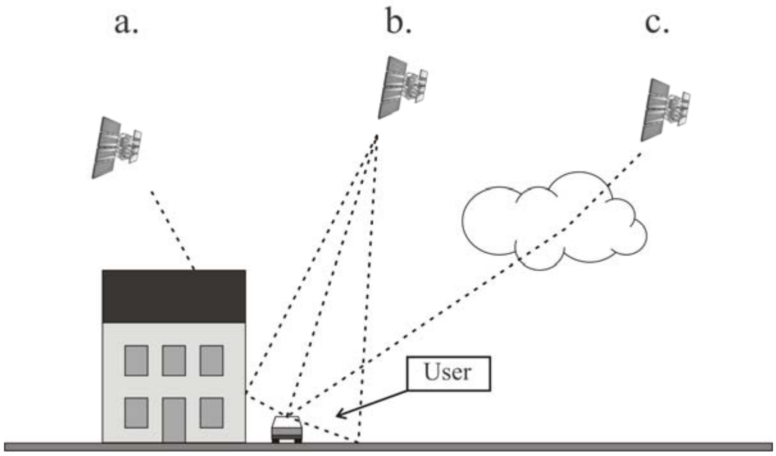

Fig. 1: Most important error sources of GNSS, namely a) shading, b) multi path effects and c) atmospheric effects.

To overcome drawbacks of GNSS, complementary sensor like odometers, steering encoders and in some application inertial measurement units (IMU) are integrated with satellite navigation. The basic principle which is applied by this group of sensors is known as dead reckoning (DR) which describes the integration of measurement values (e.g. velocity, acceleration) over time to get a position estimate [7]. The exclusive use of DR sensors would lead to a position drift depending on the sensor quality.

In addition to this conventional approach of fusing GNSS with DR sensors a third group of localization systems is especially known to the robotic community. There, visual sensors like laser scanners or cameras are used to extract landmarks (e.g. walls or corners) from a single scan or frame. These landmarks are tracked over time and used to re-localize the user as well as the landmark itself. This approach leads to a simultaneous localization and mapping (SLAM) of the user and the landmarks respectively [8].

2.2 Major shortcomings in urban environments

SLAM benefits from the fact that non a-priori knowledge like landmark positions is necessary. On the other hand this fact limits the approach to relative positioning. The use of additional information like detailed maps can lead to an absolute positioning system as illustrated in Fig. 2. In this test arrangement a laser scanner was mounted horizontally on the roof of a test vehicle which turns the localization problem into a 2D one. A high precision digital city map provides geographically referenced positions of buildings and even trees. By matching this a-priori knowledge with the observed landmarks, absolute positioning becomes possible. However, this procedure needs to assume that the extrusion of building footprints into 3D is a valid one.

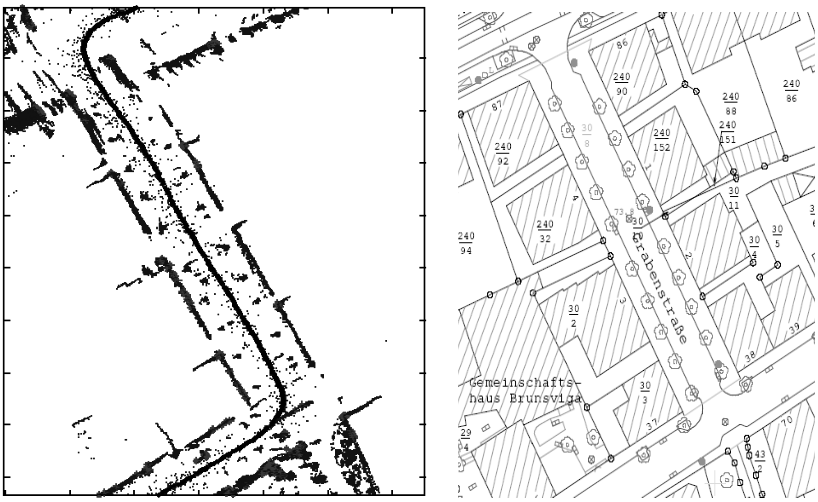

Fig. 2: Example of a 2D localization system using a digital city map in combination with a horizontal 2D laser scanner. The left figure shows the accumulated raw data, the right one a cut out from the digital city map.

In practice, this approach suffers from the fact that laser scanners are usually situated in the bumper of a car. Due to the horizontal alignment of the laser scanner the resulting scan images in an urban environment like a residential area would be mainly dominated by parked cars and other non-infrastructural obstacles. The observed geometries are therefore not included in any map due to the fact that they are non-permanent objects. This problem can be solved by rotating the laser scanner plane as described in more detail in chapter 3. In this case the a-priori knowledge needs to be extended to 3D.

Basically the resulting 3D city map / laser scanner localization system has additional complementary properties to conventional GNSS / DR integrations. An overview can be found in Table 1. A robust positioning system for safety critical ADAS expects at least two positive qualities per row to keep redundancy.

	SLAM	GNSS	DR	Map/Lidar
drift	yes (-)	no (+)	yes (-)	no (+)
geo. reference	no (-)	yes (+)	no (-)	yes (+)
ext. disturbance	no (+)	yes (-)	no (+)	no (+)
data rate	medium (+/-)	low (-)	high (+)	medium (+/-)
urban performance	high (+)	low (-)	high (+)	high (+)
free field performance	low (-)	high (+)	high (+)	low (-)

Table 1: Sensor complementarities

Especially in an urban environment, where GNSS outages can occur frequently, the use of laser scanner measurements in combination with appropriated a-priori knowledge can enhance the overall system accuracy and availability. Furthermore integrity algorithms will profit from redundant position estimates in the case of GNSS and city map / laser scanner availability.

2.3 Need for up-to-date 3D data

3D building representation can be roughly produced by the fusion of building footprints and height data. Whereas building footprints are stored in ground plans like the ALK, height information can be obtained from floor numbers or airborne laser scanner data. This is a current procedure when producing CityGML’s LoD1 building representation (e.g. [9]). A major problem is the incorporation of 3D data, especially information about the façades. Even the building’s vertical bounding edges are hardly to detect using 2D ground plans. In the first approach outlined in fig. 0.2, horizontal information is extrapolated to 3D space withoutin information about building heights and other error sources. When using the ALK, only under roof surfaces can be identified. There is no direct information about heights of gangways which leads to errors in assuming information about the façade. Fig. 3 illustrates a typical error case when extruding the ALK to the third dimension. While the 3D model shows the geometry of a gangway, it is only betoken in the 2D dataset of the ALK. These errors would lead to misinterpretations of the laser supported positioning system of the vehicle.

Extruding 2D data to 3D façade representation definitely fails when detailed information is required. While a vehicle launched laser scanners and according edge extraction algorithms are able to detect ridges in a feasible resolution, window apertures and doorways are of interest. These features can be stored in CityGML’s LoD3 building model. The incorporation of as many vertical and horizontal edges as possible will enhance plausibility of the positioning algorithm.

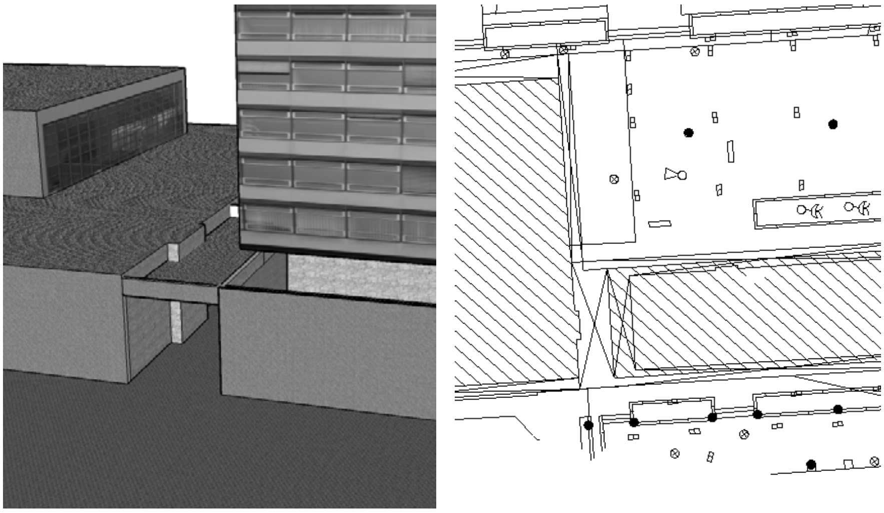

Fig. 3: Gangway represented left in a true 3D model and right in the ALK. It is only implied by the ALK but no height information is available.

Next to precision, actuality of 3D data is essential for a reliable positioning solution. In fast growing and changing urban environments, up to 10 % of infrastructure changes within one year. Change rate of 3D city information often changes even faster then 2D data [10]. While this statement is made for roof surface geometry it is not clear how change rates are valid for building façades. Nevertheless, when incorporating footpaths, trees, traffic signs and other city furniture it is apparent that it is deficient to carry a static database on the vehicle. In this approach we suggest the development of a Web Feature Service to organize the data transfer from an integrated database to the car.

3 Overall concept for a service oriented navigation architecture

The above discussed limitations of common technologies for vehicle positioning in urban environments have to be overcome. We suggest a highly precise concept that links up vehicle sensors and 3D city data. It is meant to fulfil the requirements of advanced driver assistant systems relevant to security and is complementary to global navigation satellite systems. Communication between the vehicle and an integrated database will be realized using a modified web feature service (WFS). The overall concept is depicted in Fig. 4.

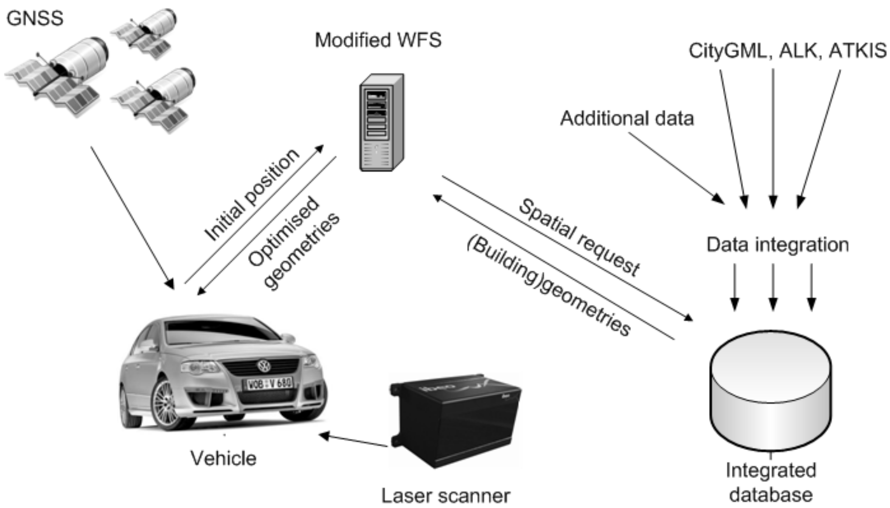

Fig. 4: Overall vehicle positioning concept.

A GNSS based initial position is transmitted from the vehicle to the WFS. The service phrases a spatial request that is communicated to a database holding information about the features relevant for the positioning algorithm. This database is a result of integration process incorporating typical data sources known for urban features. In our case this would be CityGML data if available, the German ALK, and additional data of façade information if needed. The geometries are sent back to the vehicle via the WFS. There, a map matching algorithm is applied to identify the position of the vehicle using the geometries identified by the on board laser scanner and the data as a-priori information. In a next step more information than the initial position can be transferred to the WFS causing different spatial requests on the database.

In the following we will discuss the concept and its problems in more detail. We will focus on first, the data integration process needed to allocate data relevant to the positioning concept. Second, we describe concepts for a vehicle-to-database service and third, we discuss the object extraction and information fusion on the vehicle. Our approach is meant to be an absolute and long time stable positioning system.

3.1 The data integration problem

Today, data integration of city data from different sources still represents a major challenge. Reasons for this are heterogeneous database schemas as well as the middleware adapted to these schemas. In Germany many data sources for infrastructural information are available. Information about a building’s footprint, footpaths, street furniture, and more are stored in the Automatische Liegenschaftskarte (ALK) or the Amtliches Topographisch-Kartographisches Informationssystem (ATKIS) [11]. While the latter is only available in parts of Germany today, both databases store absolute 2D coordinates. Furthermore, 3D city models of various qualities are under construction by order of public communities and GIS companies.

Evaluation of existing data sources and their ability to support the vehicle positioning approach is the first step that needs to be performed. Quality in terms of precision, actuality, and completeness has to be in the focus of recognition. As a result a catalogue of requirements can be compiled defining essential properties of data sets intended to use for the vehicle positioning approach.

None of the data schemas mentioned above may be used for positioning directly. While the German cadastre allocating the ALK and ATKIS is still 2D these data would need to be upgraded to the third dimension. Extruding a 2D footprint of a building, for instance, but raises the problems discussed in section 2.3. The lack of façade data is a not acceptable limitation for this approach. CityGML data on the other hand seams to be too complex in terms of semantics and geometry. As CityGML’s LoD4 model of course would offer many information about façades, semantics and geometry of interior and roof structures are redundant. This is partly true for roof surface information encoded in CityGML’s LoD3, also. Besides, the GML inherent overhead would causes needless data transfer costs. Although only very few data concepts are considered here, it seams to be clear, that additional data has to be acquired.

The next step will be the development of a database schema. It has to meet the demands of an effective allocation of infrastructural data needed for vehicle positioning as façade information, street furnitures, trees and so forth. This schema then is a starting point for data integration from known data sources. It is desirable to develop mapping tools for automatic integration of known sources. This would enable a nearly real time integration and update of the data basis for vehicle navigation. It is reasonable to consider a multi-scale approach. If so, the database directly supports an effective data transfer to the vehicle against demanded data precision, service agreement or available bandwidth for transmission.

3.2 A vehicle-to-database-service

Due to permanent changes of infrastructural data the database can not be stored on the vehicle directly, but has to be accessed in real time. Therefore a vehicle-to-database-service that is based on an OGC Web Feature Service [12] has to be developed. This service organizes the bidirectional communication of the vehicle and the database. Further it has to interpret the request of the vehicle and organize the spatial request to the database. Finally the service will prepare the transmission of optimized infrastructure data to the vehicle. The transmission can be performed using the Universal Mobile Telecommunications System (UMTS).

The implementation specification of the vehicle-to-database-service needs to be capable to interpret different information types coming from the vehicle. In the initial state of a positioning procedure this will be a imprecise position which might be derived from GNSS measurements. As no additional information is available at this time, a bounding box algorithm will be applied to request the geometries needed. A time step further, the covered route and velocity may need to be converted. For the amount of data this would mean that a more precise spatial request can be applied. As the covered route is known, only half of the requested bounding box would apply for transmission. As many cars carrying traditional navigation systems the planed route can be transmitted via the well known Geographic Data Files (GDF) [13]. Again this would mean to query a more restricted subset of data for the positioning procedure. However, as GDF data is only a planned route, not only the geometries of the streets transmitted have to be queried but the side roads as well. To conclude, the longer the positioning service runs, the more precise the spatial request can be performed. Therefore it is clear that the first request of the vehicle causes the most amount of data that has to be transferred. With each step the transmission costs for spatial data required by the vehicle is going to decrease.

3.3 Object extraction and information fusion

Within the positioning procedure, a conventional system architectures consisting of a GNSS / DR fusion is combined with the city map / laser scanner approach. Hence, the complementary properties of both global positioning techniques mentioned above are utilized. It is expected that this combination leads to an effective enhancement of the localization system reliability especially in urban environments.

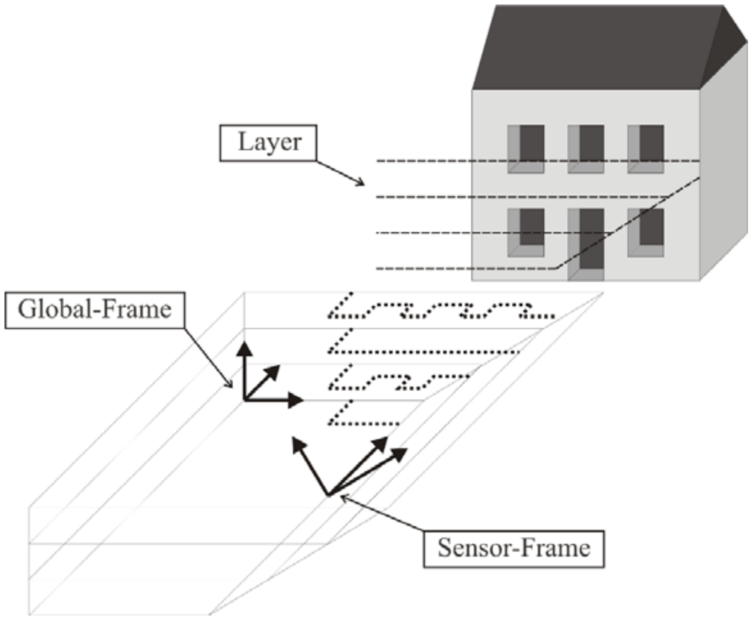

Fig. 5: 3D data acquisition using a single 2D laser scanner.

In a first step, the laser scanner’s field of view problem mentioned before has to be solved. Therefore the measurement plane of a 2D laser scanner mounted at the front bumper of a car is screwed like illustrated in Fig. 5. The spatial allocation of the measurement points to horizontal section planes leads to a 3D image of the surrounding objects. Due to the rotation of the scan plane, the influence of non-permanent obstacles is substantially reduced.

After a batch mode collection of data, the measurement points are segmented within each section plane and between them. In a next step object edges are extracted in 3D from the resulting cloud of measurement points. Based on these edges a matching process with a 3D city model can be conducted. This leads to a relative position information with respect to an absolute referenced object. Finally, this information can be fused with GNSS and DR sensors. The resulting system architecture is presented in Fig. 6.

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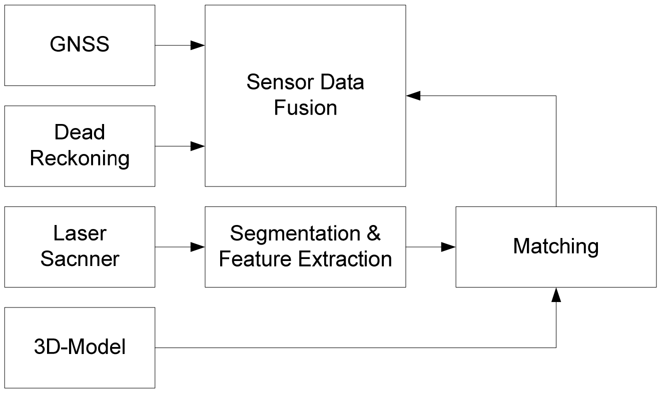

Fig. 6: Localization system architecture

Against the background of a potential use of such an urban localization system for safety critical applications like future ADAS, the integrity of the presented approach plays an important role. Therefore an appropriated vehicle autonomous integrity monitoring has to be implemented as part of the fusion algorithm.

4 Conclusion

We proposed a concept for an absolute and long time stable vehicle positioning architecture in urban environments. It benefits from accomplishing 3D city data and car side laser scanner and feature extraction algorithms. Data is requested directly from the vehicle and supported by an web feature service that communicates with an updated database holding integrated 3D city data from different sources.

We outlined the present state of positioning technology for vehicles in urban environment that is not able to support an absolute, long time stable and reliable location today. While global navigation satellite systems (GNSS) deliver sufficient positioning solutions in a free field situation, due to outtakes they are inadequate within an urban environment. These outtakes emerge from shadowing effects and multi path effects. Simultaneous localization and mapping (SLAM) and dead reckoning technologies are only applicable to the disadvantage of long time stability and an absolute geo referenced position.

We see the largest potential for absolute and long time stable vehicle positioning in the combination of map data and feature extraction algorithms. First results show that a 2D localization system using a digital city map in combination with a horizontal 2D laser scanner has the ability to support an absolute positioning architecture. Installation location of car mounted laser scanner and obstacles unfortunately necessitate the inspection of façade information by rotating the laser scanner plane when applying the feature extracting algorithm. Acquisition of a-priori data input for the positioning algorithm however can not be done by just extruding 2D maps to the third dimension. Errors may happen while few characteristics like gangways are not marked in 2D maps sufficiently. Hence, façade information has to make assessable to the vehicle's feature extraction algorithm.

Our approach is meant to improve the discussed shortcomings for vehicle positioning in urban environments. It is based on a web feature service (WFS) that interconnects the vehicle with a 3D city database. Receiving a initial GNSS based position the service processes a spatial request sent back to the car. This approach assures the transmission of up-to-date data as it is stored on the data base. Data acquisition still is a major challenge. Although it is planed to integrate the most promising data formats like the German Automatisierte Liegenschaftskarte (ALK) or CityGML, it is likely, that additional data of building façades needs to be collected.

The proposed service may be applicable as a real core for a Car-2-Car infrastructure. Once a communication infrastructure for vehicle and database is established, the car may serve for data supplier for temporal data like density of traffic or working sites itself. It can easily recognized by subtracting the effective laser scanner data from the 3D features delivered from the integrated data base. This information itself can be stored on the database and referred to other vehicles. Besides, information of changes in city geometry would assist data providing companies to keep their datasets in a current state.

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