Role of Digital Maps in Road Transport Security

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Key words: Intelligent transportation system, digital maps

SUMMARY

The European Project TransSec (Autonomous emergency maneuvering and movement monitoring for road transport security) is funded by European Commission within the program Horizon H2020 for three years. This project was started in February 2018 and its goal is to design and implement such an intelligent positional monitoring and maneuvering system to prevent the terror attacks.

Daimler AG is the project coordinator, Institute of Engineering Geodesy (IIGS) at University of Stuttgart is one of the five partners involved in TransSec project. Together with Daimler, IIGS has the task to design, develop and implement a prototype of map including the static environment as well as an electronic horizon provider for the vehicle based on a map aiding algorithm. Finally a local dynamic map will be created using the information of the current acquired situation from the sensors like cameras and laser scanners, so that the dynamic objects like vehicles, pedestrian around the trucks can be detected. And the other task of IIGS is to get the precise positioning of the trucks by integrating the data from GNSS and other additional sensors like odometer, gyroscopes and accelerometers, cameras and Lidar etc.

In this paper, the TransSec project will be introduced. The role of digital maps in Road Transport Security will be discussed and the first results of map data availability and quality analysis. At the end some future works will be introduced and discussed.

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1. INTRODUCTION

A new form of transport security is necessary to prevent the terrorists using trucks and other kinds of vehicles. An European Project TransSec (Autonomous emergency manoeuvring and movement monitoring for road transport security) is started in February 2018 and funded by European Commission within the program Horizon H2020 for three years.

To prevent this in future TransSec aims to create a system which will permanently monitor the vehicle and, in case of critical driving manoeuvres, automatically start emergency routines to reduce the arising danger. These emergency routines can be disabled by the driver in the current driving system, the aim of TransSec is to develop a non-override driving system. By this way, the misuse of the truck can be prevented.

The following technology will be combined within the project: satellite navigation technology (especially Galileo), multi-sensor positioning system, digital road maps, environment recognition, scene understanding and risk analysis and autonomous driving manoeuvring as well as communication of the truck with its environment.

One core feature of this new security system will be a robust and reliable positioning system. GNSS positioning will be improved by the newest developments of the Galileo navigation satellite system like signal authentication to detect spoofing, jamming and other manipulations. Additionally, the positioning system will be complemented by inertial sensors to ensure a reliable position, even in challenging urban environments like city canyons.

To detect forbidden driving manoeuvres, like driving in pedestrian zones or making prohibited turns, information of the digital road map will be used. The coordinate from the positioning system will be used to locate the truck in the map. If the trucks are driving near or towards a forbidden area, with use of the sensors for the environment recognition, like cameras and Lidar sensors, the static features of the map will be extended to a so-called local dynamic map with the current dynamic objects around the truck, like pedestrians or other cars. Based on this enhanced map data and the motion tracking of the surrounding objects and persons a risk analysis is carried out. If critical driving manoeuvres gets detected, the security system will intervene to reduce the danger. Additionally the surrounding is going to be warned through a vehicle to everything communication (V2X-technology) about the arising danger.

The project partners come from four European countries: Daimler AG (DAI) from Germany is the project coordinator, the other project partners are TeleConsult Austria GmbH (TCA, Austria), Vicomtech (VICOM, Spain) and Waterford Institute of Technology (WIT, Ireland) as well as University of Stuttgart, Institute of Engineering Geodesy (IIGS, Germany), more information can be got from the official project website TransSec (2019). The Institute of Engineering Geodesy (IIGS) works together with TCA on the multi sensor integration in positioning work package and of the digital road map work package. IIGS is the work package leader for the latter. Therefore, in this paper, the digital road map will be introduced firstly, and results of map data availability and quality analysis based on relevant use cases will be shown. Then the concept of realization of local dynamic map will be presented. Conclusion and outlook will be given at the end.

2. DIGITAL ROAD MAP

2.1 Introduction

The digital road map is a vital component for automotive navigation and driver assistance systems. It contains geometric, topologic, semantic information and the spatial relationships about the road network. As shown in Figure 1, a street junction in the real word is represented with nodes and links in the digital road map, which are connected together and form the road centrelines of the road network (Eskandarian, 2012).

Standardized formats are defined for interoperability of digital road maps by different providers (Ehmke, 2012). One of them is ISO Geographic Data File standard (GDF), which was normalized at the begin of 90er, today GDF is developed and used by the commercial map providers for automotive navigation purposes and for the development of Intelligent Transport System (ITS).

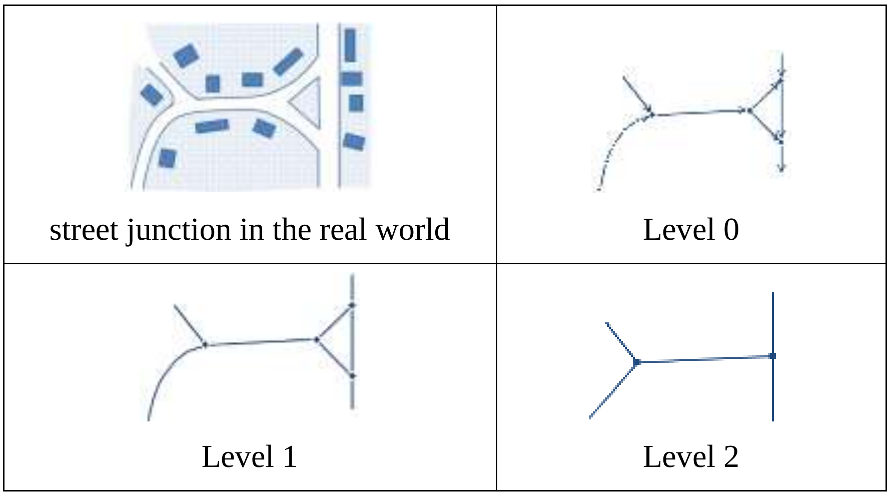


Figure 1: A street junction with traffic island (Wang et al., 2018)

The GDF standard divides the representation model into three levels (see Figure 1). Level 1 is the most used GDF level for route planning. It contains simple features (e.g. road elements, junctions/Intersections), relevant attributes (e.g. street name, direction of traffic flow, number of lanes, junction type) and relations (e.g. turn restrictions) for automotive navigation purposes.

NDS, developed since 2004 is a new worldwide map standard for automotive grade use. NDS is a standardized binary database format and enables the exchange of navigation data between different systems as well as flexible map composing and map update (NDS, 2019). Since 2012, NDS products have been available in the market, mostly used in BMW, Daimler and Volkswagen cars (Schützle, 2016).

In NDS format, all navigational data are assigned to the corresponding building block, which addresses specific functional aspects of NDS. The NDS building blocks are used as a "brick" that possess standardized interfaces and can be replaced individually. The NDS data is stored using a SQLite database that supports incremental map updates and enables searching within the building blocks using standardized parameters (Kleine-Besten et al., 2016).

In TransSec, the commercial digital road map in NDS format is used. In the first project phase, the map data availability and quality (especially the geometric accuracy) of the digital road map are investigated. Because most of terror attacks happened in typically busy areas with many people, e.g. terror attacks with trucks in Nice, Berlin and New York City, several use cases are defined, the map data are investigated based on four use cases: "Pedestrian Shopping Zone", "Shopping Street" and "Market Place" as well as "Tourist Promenade". The feature and attributes availability of these places was analysed in details and the results will be shown in following.

2.2 Map Data Availability Analysis

2.2.1 Map Features

There are three types of the map features: Point, Line and Area. Different objects could be presented by these features.

Point Features

To represent features like shopping centres and buildings, single points are usually used for basic map display, the shape points and junctions could be also presented as points. The POI (Points-of-Interest) like government buildings, museums, tourist attractions, park areas are digitized as point. Additionally, the base stations of the mobile network providers that may be useful for communication are not included in the map database. The truck POI (like Truck Stop/plaza, truck weigh station) is not contained in the standard map database, since it is provided as supplement to satisfy the requirements of specific applications related to trucks.

Line Features

Line features are generally used to represent roads, ferry connections, railway lines, and others. The roads are completely included in the line layer "streets". More important is the attributes of the streets, it will be described in section 2.2.2.

Area Features

NDS format provides three different area types. The two of them are of great importance for vehicle positioning and map-matching: land use, (e.g. built-up areas) and buildings (e.g. hospitals or industrial buildings).

There are several different types of area features in the layers land use (like Amusement parks, hospital, university/college, shopping centre) and land mark (like library, mosque). Additionally, in the map database, no pedestrian areas are defined. Whether an area is only allowed for pedestrians, is described using corresponding map attributes (see section 2.2.2).

2.2.2 Map Attributes

The map features have the attributes which can describe their characteristics.

Standard Attributes

The attributes of a digital road network are semantic data that are referenced to links, nodes and shape points. Standard map attributes for routing and navigation applications are for example street name, direction of travel, etc. The following standard map attributes which are important for this project are available: direction of travel, number of lanes, road access restriction, signpost, speed category, and speed limit as well as traffic sign.

It should be noted that the used commercial digital map data is not at the lane-level. It is a navigation map that does not contain the geometric information (coordinates) of centre lines of road lanes, it contains only the geometric information of center line of the road.

According to (RAA, 2008) the lane width in Germany may vary between 2.75 m and 3.75 m. On motorways is a common lane width around 3.50 m, whereas in rural or urban areas it is between 3.0 m and 3.75 m. For such navigation map, the geometric information of road lanes is not generated, but the lane-level attributes are available (e.g. direction of travel, number of lanes).

Truck-related Attributes

Within the TransSec project, the focus lies on the security application for trucks that vary greatly in size, power, and configuration. They can be very large and powerful. The driving restrictions for trucks are also an important aspect in the development of the TransSec system. All map attributes related to trucks are called truck-related attributes in this paper.

The available truck-related attributes in the digital map database are: zone access restriction, (e.g. construction area, some parts of urban area), road access restriction at specific time, direction of traffic flow with a restrictive time domain, limitation in weight and/or dimensions, speed limit with/without a restrictive time domain, specific signs for trucks (e.g. inaccessible for trucks), supplemental sign applies to (heavy) trucks, traffic sign (like railway crossing, school zone, tramway crossing, pedestrian crossing, etc.).

It should be mentioned that a single attribute layer in the NDS is extra defined for truck attributes that describes traffic restrictions for truck vehicle types like height/width/length limitation, and road width.

2.3 Map Data Quality Analysis

Most Autonomous vehicles and highly automated vehicle systems require high accuracy road maps that enable precise vehicle positioning. For developing a road transportation security system for trucks in the TransSec project, the accuracies of the digital road map data need to be firstly evaluated so that the potential improvements for an enhanced static map can be conducted.

The uncertainties of a digital road map are generally due to errors in data acquisition, map creation, and digitization (Eskandarian, 2012). Nodes and shape points of the digital road network are represented in the global coordinate system WGS84 (latitude and longitude). To measure the accuracies of digital road maps, reference trajectories based on GNSS technology were generated. The well-selected quality criteria are described in detail in this section.

2.3.1 Generation of reference trajectories

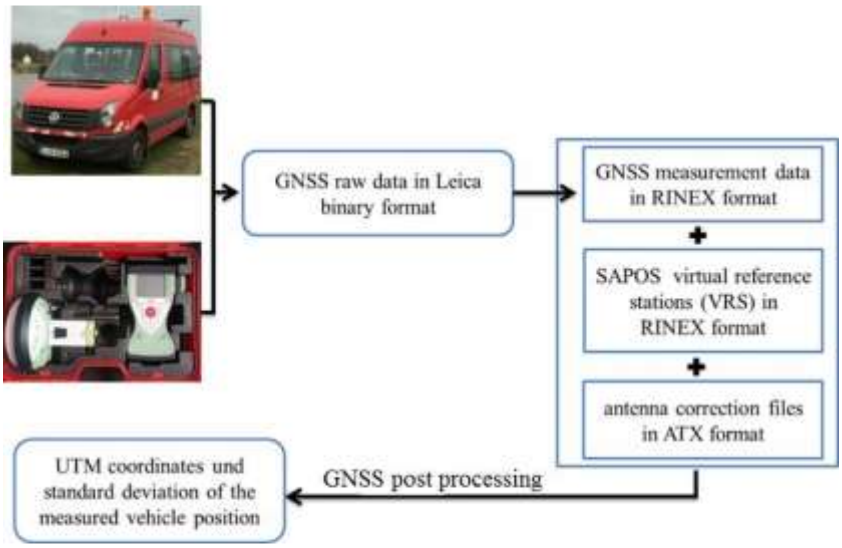


Figure 2: Generation of reference Trajectories based on kinematic GNSS measurements (Wang et al., 2017a)

Precise kinematic reference trajectories for evaluating geometric accuracies of digital road maps are generated based on GNSS technology that can also be combined with inertial sensors such as gyroscopes and odometer to enhance the positioning accuracy. For generation of reference trajectories, it is sufficient to use the geodetic GNSS receiver system. As shown in Figure 2, the measurement vehicle was equipped with a high-end geodetic GNSS two-frequency receiver (Leica Viva GS15) mounted on the car roof (Wang et al., 2017). For high accuracy GNSS solutions, the final coordinates of the kinematic GNSS tracks based on the recorded raw GNSS measurement data were computed by GNSS processing software Wa1 (Wa1, 2013). The coordinates of the reference trajectories are represented in the Universal Transverse Mercator (UTM) system. The coordinate accuracies are better than 10 cm. Moreover, the GNSS-trajectories are well-selected, while the consecutive GNSS points must represent smooth curved 2D shapes of the roads. Thus, trajectory data when driving through construction zones or changing lanes are not used for evaluating the absolute and relative accuracies.

Accuracy assessment of the digital road map data is conducted with a focus in particular on the following areas: urban area/non-highway road, autobahn entrance and exit, autobahn/highway. For this project, urban area/non-highway road is of importance.

The selected urban areas are in different districts in Stuttgart (Test Area 1-5). The investigated autobahn areas are composed of the entrance and exit ramps on one German autobahn and the autobahn itself. It should be mentioned that the autobahn, its autobahn entrance and exit ramps as well as the streets in urban areas are mostly multi-lane roads. For evaluating the positional map accuracy, the value of the calculated perpendicular distance from each GNSS (reference) point to the correctly identified road link is greatly dependent on the road width.

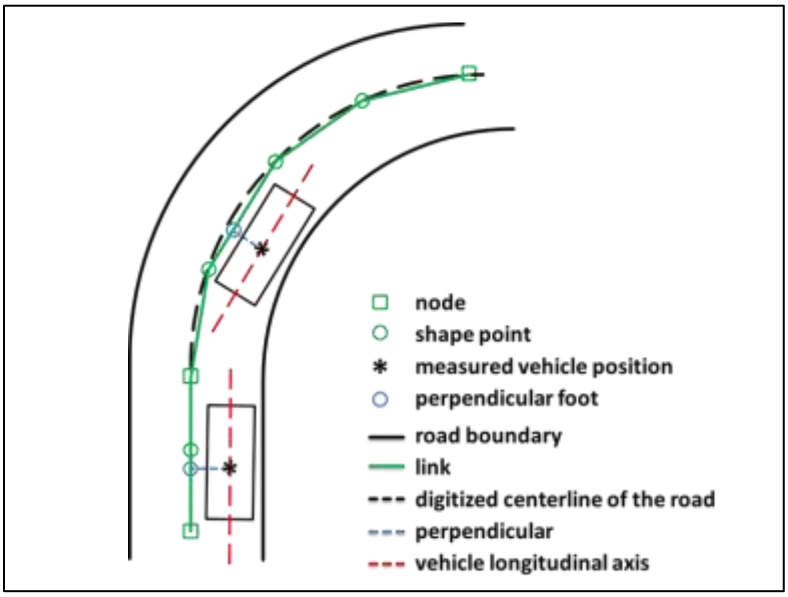


Figure 3: Illustration of the vehicle position relative to the road centreline (Wang et al., 2017b)

As illustrated in Figure 3, the perpendicular distance from the measured vehicle position (reference point) to the matched road link (see green lines in Figure 3) that is a two-lane road contains an offset of half a lane width: 1.75 m. The lane width is assumed to be 3.5 m. If the roads consist of three or more lanes, this offset of 1.75 m should be multiplied with (n-1), while n is the number of lanes.

For the quality evaluation of commercial digital map data, the total length of the evaluated roads is estimated to be 147 km using around 9000 GNSS reference points.

2.3.2 Absolute and Relative accuracy

Mostly, the shape of a road link is not a straight line, but rather smoothly curved. It is represented by the start and end node, and the shape points as well. The shape points are placed between the nodes, usually not at equidistant intervals (Eskandarian, 2012). To describe the geometric accuracies of the digital map data, both absolute and relative accuracy should be evaluated.

Absolute Accuracy

The absolute accuracy describes the positional deviation of the map points (nodes and shape points) relative to their true position on earth. In order to achieve more realistic assessment results, the shortest distance between each GNSS point and the circular arc determined from three consecutive map points (see Figure 4, K27-K29), two of which (K27 and K28) are the start and end nodes of the matched road link, is used to measure the accuracy of the absolute positions of the map points. The two-dimensional positional deviation ds of each map point can be calculated, the RMS values of trajectories are calculated and presented as map absolute accuracy result. The formulas of the calculation can be found in Wang et al. (2017a).

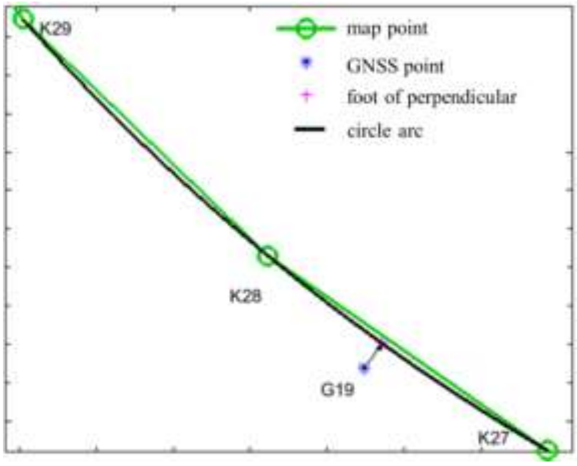


Figure 4: Relationship between map points, GNSS points and the foot of perpendicular of GNSS points (Wang et al., 2017a)

Relative Accuracy

The relative (positional) accuracy is defined to describe the correct relative position of map points to each other. It is described as the shape accuracy of the road centrelines in the map. For evaluating the relative accuracy of digital map data, two different quantities, the orientation change $\Delta\alpha$ and the curvature κ, are determined in order to achieve reliable results (Wang et al., 2017a). For evaluation of the relative positional accuracy, the difference of orientation changes $\Delta\Delta\alpha$ at the Point i as well as its RMS value can be expressed using the following formulas. For an easier and better comparison, the RMS values of $\Delta\Delta\alpha$ in degrees are converted to metric units, denoted by $rms\Delta\Delta\alpha$ * while Δl is the average distance between two successive GNSS points or rather the travel distance of the vehicle in one second under the assumption that the vehicle velocity is around 50 km/h (Wang et al., 2017a).

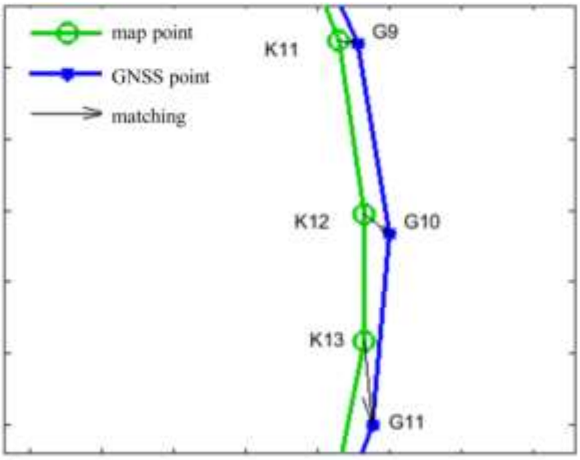


Figure 5: Three successive map points K11- K13 and their corresponding matched GNSS points (Wang et al., 2017a)

As illustrated in Figure 5, similar as by measuring the absolute accuracy, each map point is matched to the nearest GNSS point. For calculating the $\Delta\Delta\alpha$, $\Delta\kappa$ and their RMS values, three successive points are needed. In the example in Figure 5, the map trajectory consisting of points K11 to K13 are matched to the GNSS trajectory with G9 to G11. The RMS values of $\Delta\Delta\alpha$ and $\Delta\kappa$ at the point G10 and K12 are computed respectively. All the formulas of the calculation can be found in Wang et al. (2017a).

Results

From the evaluation results, it can be seen that the final average RMS values of the absolute geometric error of all the three road types (non-highway road, autobahn entrance and exit ramp and autobahn itself) are less than 2 m, while the digital map data of autobahn has the highest absolute accuracy of 1.33 m. In terms of the relative accuracy, the autobahn in test has reached an average RMS value of 0.29 m derived from calculated differences of orientation changes $\Delta\Delta\alpha$, and 2.8 1/km using the curvature difference $\Delta\kappa$ as criterion (see Table 1). In addition, it must be noted that the digital map data in certain autobahn sections have achieved a quite satisfied absolute accuracy of 0.68 m. According to the current specified map accuracy presented at the INTERGEO Congress in 2018, the commercial digital road map data provided by TomTom have a 2D absolute positional accuracy of 0.7 m, and the relative positional accuracy ranges between 15 cm and 20 cm for 100 m (Clauss, 2018), which agree well with the empirical map accuracies summarized in Table 1.

Table 1: Evaluation results of the absolute and relative accuracies of map data

Accuracy	non-highway road	autobahn entrance and exit ramps	autobahn
rms $_{ds}$ (abs.)	1.51 m	1.45 m	1.33 m
$\text{rms}_{\Delta\Delta\alpha}$ (rel.)	2.54°	4.32°	1.28°
$\text{rms}_{\Delta\Delta\alpha}{}^{*}$ (rel.)	0.58 m	0.98 m	0.29 m
$\text{rms}_{\Delta\kappa}$ (rel.)	$6.6\,\frac{1}{\text{km}}$	$5.8\,\frac{1}{\text{km}}$	$2.8\,\frac{1}{\text{km}}$
No. of GNSS reference points	4340	4022	733
Total length of road links	79.5 km	50.2 km	17.3 km

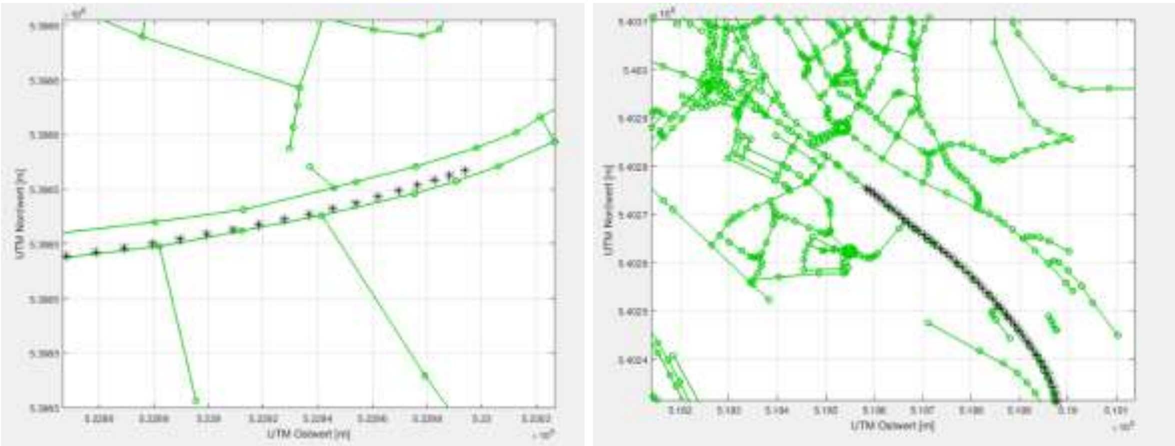
Table 2: Evaluation results of the absolute and relative accuracies of map data in selected urban areas

Accuracy	Test Area 1	Test Area 2	Test Area 3	Test Area 4	Test Area 5
rms $_{ds}$ (abs.)	1.45 m	1.47 m	1.54 m	1.57 m	1.53 m
$\text{rms}_{\Delta\Delta\alpha}$ (rel.)	2.7°	2.6°	2.6°	2.2°	2.6°
$\text{rms}_{\Delta\Delta\alpha}{}^{*}$ (rel.)	0.62 m	0.59 m	0.59 m	0.49 m	0.58 m
$\text{rms}_{\Delta\kappa}$ (rel.)	$7.9\,\frac{1}{\text{km}}$	$5.2\,\frac{1}{\text{km}}$	$5.7\,\frac{1}{\text{km}}$	$7.4\,\frac{1}{\text{km}}$	$6.7\,\frac{1}{\text{km}}$
No. of GNSS reference points	1048	225	559	1963	545
Total length of road links	19.6 km	2.6 km	10.7 km	34.5 km	12.1 km

Since the major concerns of use cases lie in the crowded urban areas, the evaluation results of the empirical accuracies of digital map data in selected urban areas are listed in Table 2 for analysis purposes. Compared with digital road map data in autobahn areas, the roads in urban areas are modelled with a slightly lower absolute accuracy varying from 1.45 m to 1.57 m and a similar relative accuracy ranging between 0.49 m and 0.62 m.

2.4 Map Preview in Demonstration

The GNSS positioning system was tested in January 2019 near to Stuttgart. In demonstration, the vehicle position was calculated by real-time PPP (Precise Point Positioning) software from the project partner TeleConsult Austria GmbH and was shown in a real-time map preview MATLAB program from IIGS. Interface between the positioning system and the map software was established. IIGS received the coordinates of the vehicle from the GNSS positioning system through a serial connection as NMEA strings. Once a new coordinate is provided by the GNSS positioning system, the vehicle position can be presented in the map by the MATLAB program in real-time.



(a) (b)

Figure 6 – Map representation with a higher (a) and lower (b) zoom factor

In Figure 6 one can see the street network with its lines and nodes in green and the vehicle positions with little black stars. More details about the demonstration can be found in TransSec (2019).

3. LOCAL DYNAMIC MAP

The goal of IIGS in digital street map work package is to generate a Local Dynamic Map (LDM), which is a database of neighbourhood traffic and could help vehicle drivers to take decisions in critical driving situations. The LDM consists of four layers that represent respectively (see Figure 7, SP3-SINTECH 2008, Schimada et al., 2015):

1. the static (semi-permanent) digital map database;
2. similar static information that is not included in the first layer;

3. temporary and dynamic information such as weather and traffic conditions;
4. dynamic and highly dynamic information of moving objects (vehicles, pedestrians, animals, etc.).

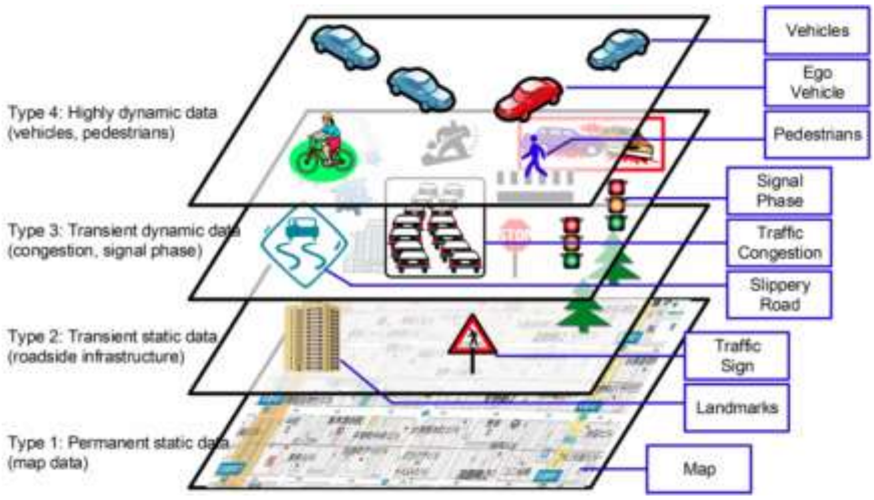


Figure 7: The layered architecture of the LDM (Schimada et al., 2015)

The (two-dimensional) digital road map data builds the first layer with static information about the geometry, the topology and attributes of the road network. Landmarks such as buildings and plazas are represented as point or area features in this layer. However, for advanced vehicular applications like the TransSec system, static information should be enhanced and road environment information is to be completed.

The potential objects for the enhanced static map were investigated, e.g. elements of 3D-city models of Stuttgart that potentially fill the LDM Layer 2, will be introduced in this section.

Additionally, the positional data of traffic signs are relevant environment information that is presently not available in map data. Traffic signs and lane markings could be detected by the project partner VICOM and integrated in the LDM.

3.1 3D-City Models

Predominantly, 3D-city models are built up for supporting urban planning processes und visualisation purposes. Thus, they are typically implemented on top of CAD systems or other visualization software. In the last decades, 3D-city data are being increasingly employed for a large range of applications beyond visualisation, such as aiding positioning in urban environments, routing and autonomous driving. Especially for navigating in urban spaces, 3D-city models can help to facilitate the vehicle driver’s orientation with familiar landmarks.

The official 3D-city data of Stuttgart (see Figure 8) are provided by the City Survey Department of Stuttgart (German: Stadtmessungsamt Stuttgart). As depicted in Figure 8, the two fundamental elements of the 3D-city models are 3D-Buildung models and tree models.

Additionally, 2D aerial images, City tour bus stops and VVS bus stops are integrated for touristic purposes (3D Stuttgart, 2019).

Figure 8: 3D-City Models in area of Stuttgart Schlossplatz (3D Stuttgart, 2019)

For efficient visualization purposes, the 3D-city data are represented in different levels of detail (LoD). One building is represented as a simple block using flat roofs in LoD1, as a textured object with roof structures and building facades in LoD2, and detailed building models with explicitly modelled doors, windows, balconies, etc. are used in LoD3 (Kolbe and Gröger, 2004). Commonly, 3D-city models are stored e.g. in the CityGML format or use a rational database to manage the vector data. The CityGML files can handle different levels of details in 3D-city models and enable multiple representations for 3D urban objects in different LoDs simultaneously (Kolbe and Gröger, 2004).

The 3D-Building models of Stuttgart City can be provided by the City Survey Department of Stuttgart and be integrated in the enhanced static map. Trees in Stuttgart City, as a considerable element in dense urban environments, can be also obtained in 3D-city models LoD2 provided by the City Survey Department of Stuttgart.

3.2 Positional Data of Traffic Lights and Road Signs and Lane Markings

Besides 3D-Buildings and trees, traffic lights and road signs are also stable urban features, since they stand out the road and constitute visual landmarks for vehicle localization in road scenes (Soheilian et al., 2013). It should be noted that the attribute traffic signs, road signs are available. The definition of the position of traffic signs, road signs can be found in the definition of NDS, whether the position data of traffic lights and road signs are really available in NDS format should be investigated in the future.

If their positions are not available in NDS format, they could be got from GNSS-RTK measurement. The other possibility is that traffic signs and road signs are detected on camera images and then reconstructed e.g. with a triangulation-based method, where sub-decimetric

3D accuracy can be reached (Soheilian et al., 2013). Besides, the lane marking and vehicles and pedestrians about the trucks could be detected by camera or Lidar. For this task, IIGS will work tightly together with project partner VICOM to perceive the vehicle's environment better and so that LDM can be completed for this application.

4. CONCLUSION AND OUTLOOK

In this paper, the TransSec project was introduced briefly at first. The results of map data availability and quality analysis are presented that include a comprehensive availability analysis and a detailed quality assessment of digital road map data with selected investigation areas in the German city Stuttgart and its neighbourhoods.

With a focus on the non-highway roads in urban areas, autobahn entrance and exit areas and the German autobahn, the proposed evaluation approach was carried out successfully using well-founded quality criteria and high-precision GNSS-based reference trajectories. The results show in test area, the map absolute accuracies is about 1.5 m, and relative accuracies is about 0.5 m.

In terms of improvement potential of the 2D digital road map data, 3D-city models with visual landmarks (buildings and trees, etc.) could enable enhancing the static map and provide the vehicle driver with more realistic representations, especially for navigation mission in dense urban areas. For developing a road transportation security system for trucks within the TransSec project, 3D-city models with semantic data may provide added value for enhancing static map, and the visualisation displayed by electronic horizon for the vehicle driver can improved as well in the future. Landmarks such as buildings and trees offer more intuitive nature than 2D maps. Depending on the data accuracies of the 3D-city models, it will be investigated in detail to see whether the 3D-city data can improve vehicle positioning or performance of map-matching in the future in urban areas.

In the context of autonomous driving manoeuvres, positional data (coordinates) of traffic signs for intersections, the lane markings, vehicles and pedestrians around trucks could also be helpful. It should be investigated in the future whether this information is available in NDS format. These objects could be detected by the camera or Lidar, the goal of IIGS here is to generate a LDM, to perceive and understand the vehicle's environment better, to detect the critical driving manoeuvres, to prevent the trucks-based terror attacks. Furthermore, the developed algorithm could be also adapted to prevent the vehicle-based terror attacks.

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