Accuracy and Quality Assessment of Various Digital Road Maps for Wrong-Way Driving Detection on the German Autobahn

Jinyue WANG, Martin METZNER, Volker SCHWIEGER, Germany

Key words: Digital Road Map, Geometric Accuracy, Completeness, Map Matching Algorithm, Wrong-way Driving.

SUMMARY

Digital road maps that are navigable and contain detailed traffic-specific and environmental information like the lane curvature or the lane width contribute significantly to improving the performance and the reliability of many advanced driver assistance and safety systems. In the last two decades, both the quality assessment of various digital road map data and the development of novel map matching technologies are becoming increasingly important and popular issues, particularly for safety-critical applications, such as control system of automobiles, trains or ships. With the rapid development of digital road maps over the years, current quality-assured digital road map data can be provided with required accuracy and level of details.

For the purpose of the wrong-way driving detection on the German autobahn (autobahn: a German, Swiss or Austrian expressway) of the research project Ghosthunter, which is operated by the Institute of the Engineering Geodesy (IIGS) in cooperation with the University of the Federal Armed Forces Munich (UniBwM) and the company NavCert from Braunschweig, a valid, reliable and comprehensive quality assessment of digital road maps of four different data providers (two commercial mapmakers: HERE and TomTom; the volunteered geographic information: OpenStreetMap data; the German official topographic-cartographic information system: ATKIS-Basis-DLM) is performed with proposed quality criteria in this work. It aims to investigate the potential use of these digital road maps for preparation and development of an intelligent wrong-way driving detection system. The quality criteria utilized for evaluation of geometric accuracy (absolute and relative positional accuracy) of the map data are presented in this work. Moreover the attribute completeness of each dataset is compared and discussed with prominent examples.

The results show that the map data which have been analyzed can satisfy the level of accuracy specified in the current literature. The investigated map data have achieved 2 m RMS absolute positional accuracy and 1 m RMS relative positional accuracy. It can also be demonstrated that HERE and TomTom have a higher completeness of traffic-related attributes, particularly the travel direction and the number of lanes, and hence are more compliant with road safety applications than OpenStreetMap and ATKIS-Basis-DLM.

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1. INTRODUCTION

In recent times, ghost driver incidents become a major concern for every individual road user (BU-Wuppertal, 2012 and ADAC, 2010). A ghost driver is an individual who travels in a wrong direction or completely against the traffic flow. Every year there are almost 2,000 ghost drivers that are responsible for approximately 80 accidents and 20 fatalities on the German autobahn (BU-Wuppertal, 2012 and ADAC, 2010). In order to enhance road safety, particularly by entering and exiting an autobahn, a telematics system for preventing ghost driver incidents will be implemented within the research project Ghosthunter. This project covers the development of a robust (D)GNSS-(Standalone GNSS or Differential GNSS or RTK-GNSS) based real-time algorithm for recording accurate vehicle trajectory data and various types of map matching algorithms for estimating continuous and reliable vehicle location on the identified road segment.

Before designing and developing map matching algorithms, the first major task of the Institute of Engineering Geodesy (IIGS) at the University of Stuttgart in the project Ghosthunter is a valid, reliable and comprehensive quality assessment of digital road maps of four different data providers HERE, TomTom, OSM and ATKIS, amongst which the ATKIS is known as the German official topographic-cartographic information system and might provide spatial map data of the highest quality.

Digital road maps that are navigable and contain detailed traffic-specific information like the lane curvature or the lane width (ADV, 2010) help to improve the performance and reliability of many intelligent navigation systems and become increasingly popular and useful for road safety applications. With the growing interest in quality evaluations of digital road network data, many efforts have been made and a variety of research methods has been applied to study map accuracy.

Goodchild and Hunter (1997) developed a simple probabilistic method to estimate the positional accuracy for geospatial line elements in 1997 applying a buffer polygon of a defined width along the reference track. After this early attempt, Helbich et al. (2012) made a statistical comparison between OSM, TomTom and reference data for a well-mapped German city concerning positional error of junction points using bidimensional regression and concluded that both OSM and TomTom had a spatial accuracy within 5-6 meters. Despite the above mentioned investigations, a research on OSM's evolution during the years of 2007-2011 is described in Neis et al. (2012), which deals with the changes in data completeness and topological accuracy of the OSM road network covering the whole of Germany. These preliminary studies show that the digital map quality has obviously improved in recent years due to the rapid technological progress and a growing number of users.

In this paper, an efficient and practical method of determining data accuracy for digital road maps based on well-founded criteria in terms of absolute positional error and form deviation compared to reference location is proposed. A quality assessment of spatial road network data in well-chosen map areas (typical autobahn junctions in Stuttgart, which is the capital of Baden-Württemberg, Germany) is presented, including an illustration and analysis of the results.

The short paper is organized as follows: First previous studies related to the evaluation of map accuracy assessment are presented. Then the generated reference trajectory based on GNSS and the quality criteria are described. Finally the assessment results and the main conclusion are discussed.

2. GENERATION OF REFERENCE DATA

For the evaluation of absolute positional and shape accuracy of road segments in the given digital maps and hence the comparison of map quality between commercial, official and free datasets, precise kinematic reference trajectories based on differential carrier-phase GNSS positioning were generated using a high-end geodetic GNSS two-frequency receiver (Leica Viva GS15) mounted on a land vehicle with CS15 field controller. The final coordinates of the kinematic GNSS tracks in the Universal Transverse Mercator (UTM) system with accuracies better than 10 cm were computed by a specialized GNSS baseline processing software, named Wa2 (Wa2, 2015), which provides a reliable and precise offline solution as well as a detailed output protocol. In the software Wa2, the raw GNSS measurement data in the RINEX format were used as primary input data. Additional data, such as antenna phase center corrections in the ANTEX format and precise ephemerides in the SP3 format, can be utilized to improve the GNSS solution accuracy. The Wa2 also provides another advantage that it is possible for the user to set the output coordinate system: 1) WGS84 X-, Y- and Z-coordinate); 2) UTM east, UTM north and ellipsoidal height; 3) WGS84 latitude, longitude and ellipsoidal height (Wa2, 2015).

It also has to be mentioned that, while travelling outside the cities and in the autobahn areas (cp. Figure 1), the vehicle was allowed to reach a speed of 80 or 100 km/h. And in some sections of the German autobahn, there is no speed limit. However, in the test drives conducted for this work, the test vehicle has travelled long distances, e.g. the first test course is about 60 km long, but with a smooth driving style. The distance between successive GNSS points are from 10 to 20 meter (see Figure 2). As solely the centerline of the roads is digitalized, the position data of the road lanes are not available in the digital road map datasets. Usually, the autobahn has multiple lanes, and the exit and the entrance ramp are single lane or double lane roads in the investigation area. Thus, the vehicle location relative to each lane can just be determined roughly under the assumption that the lane width is from 2.75 to 3.75 meter (RAA, 2008).

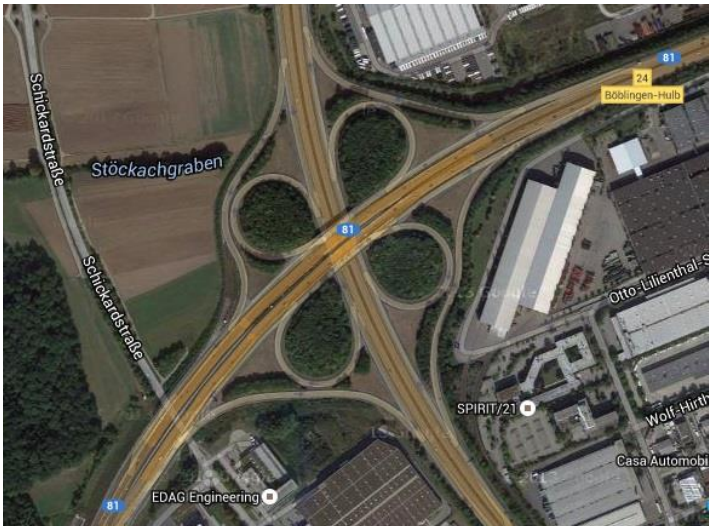

Fig. 1: Autobahn junction Böblingen-Hulb on Google Maps Satellite View

In this paper, the investigations of the quality of the spatial road network data were concentrated in entrance and exit areas on the German autobahn close to Stuttgart, while eight exemplary autobahn junctions with different geometric designs along the state highway A81 near Stuttgart (Germany) including eighteen autobahn entrances and seventeen autobahn exits are considered for the quality evaluation in Section IV. Figure 1 illustrates one example of the investigated region, which is a typical cloverleaf interchange with two entrances and two exits on each side of the autobahn. As shown in Figure 2, the UTM coordinates of the measured points based on high-rate (1 Hz) kinematic GNSS observations and the road locations in HERE Maps match apparently very well. Nevertheless, the geometric map data to be assessed (HERE, TomTom, OSM and ATKIS-Basis-DLM) may differ from each other due to the fact that the road networks from various providers are probably acquired using different methods.

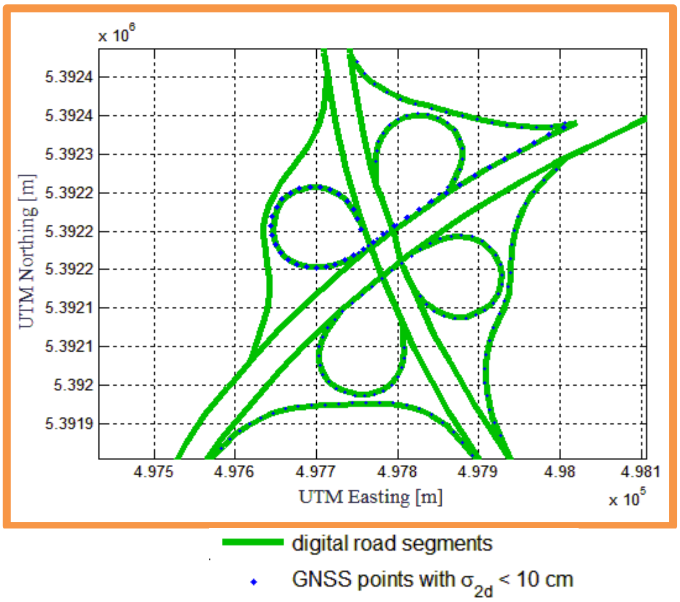

Fig. 2: Digital representation of Autobahn junction Böblingen-Hulb derived from HERE Maps data in comparison to GNSS-based trajectories

As illustrated in Figure 2, the precise coordinate solutions of the in kinematic mode measured GNSS points (the small blue dot as shown in Figure 2) which provide a horizontal (2D) positional accuracy to less than 10 cm match perfectly with the digital road segments (the green lines that connect the map points according to the direction of the traffic flow). In order to achieve more realistic assessment results, the shortest distance between the GNSS point and the circular arc determined from three successive map points of the identified edge in the digital map has been used to describe the absolute positional accuracy instead of those from the GNSS point to the identified edge itself, since the shapes of actual roads, especially at the autobahn junctions, are mostly neither straight nor polygonal~~,~~ but rather smoothly curved.

3. QUALITY CRITERIA

The two most important components of spatial data quality for road safety-related applications, such as ghost driver (wrong-way driving) detection, are geometric (absolute positional and relative positional) accuracy and completeness of attributes (HERE, 2015 and Neis et al. 2012). To determine the absolute positional accuracy of each map point located at $(\boldsymbol{x}_{\mathbf{map}}, \boldsymbol{y}_{\mathbf{map}})$ within ~~of~~ a road segment, the coordinate deviations of UTM easting $\boldsymbol{x_i}$ and UTM northing $\boldsymbol{y_i}$ (grid zone 32U) and the RMS value for the two-dimensional position deviation *ds* with respect to the reference coordinate $(\boldsymbol{x}_{\mathbf{gnss}}, \boldsymbol{y}_{\mathbf{gnss}})$ can be expressed as

$$dx_i = x_{\text{gnss},i} - x_{\text{map},i}, \; dy_i = y_{\text{gnss},i} - y_{\text{map},i} \quad (1)$$

$$ds_i = \sqrt{dx_i^2 + dy_i^2} \quad (2)$$

$$rms_{ds} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} dx_i^2 + dy_i^2} \quad (3)$$

where i is the number of shape points varying from 1 to n and $x_{\mathrm{map},i}$ and $y_{\mathrm{map},i}$ denote UTM easting and UTM northing of the foot of perpendicular from each GNSS point to the correctly identified road link, respectively. As shown in Figure 3, the shortest distance between the GNSS point marked with a blue asterisk symbol (*) and the circle arc through three successive map points (the small green circle) is determined with the Equations (1) and (2) and is equal to the position deviation *ds* as described above.

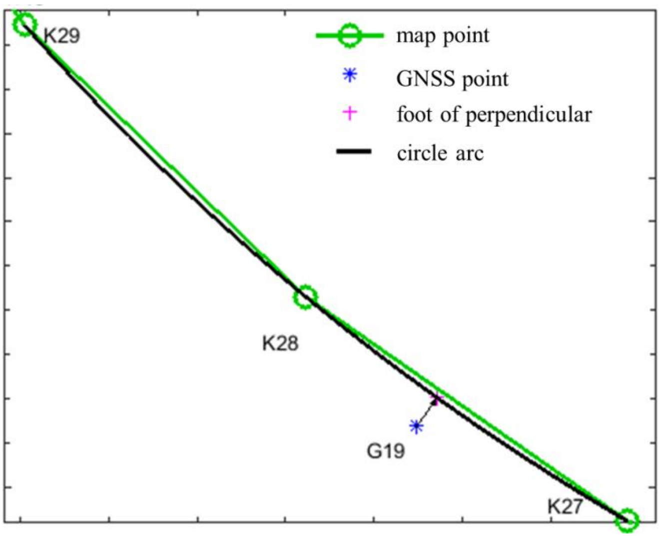

Fig. 3: The relationship between the map points, the GNSS points and the foot of perpendicular of the GNSS point on the circle arc which pass through map points K29, K28 and K27

Besides the absolute positional accuracy it is needed to measure whether an accurate shape of the road is represented (HERE, 2015). According to the reference manual of the commercial digital map data HERE Maps, the relative positional accuracy is used to evaluate whether the map points within a digitalized road segment are located in the correct position relative to each other (HERE, 2015). As illustrated in Figure 4, two different quantities, the orientation change $\Delta\alpha$ and the curvature κ, are joints utilized to describe the shape of a road. Solely one of these two quality parameters will not deliver the complete results for estimating the relative positional accuracy of a road in certain critical situations. The two circles in Figure 4 are obviously with different curvatures κ and κ^*, but their corresponding orientation changes $\Delta\alpha_2$ and $\Delta\alpha_2^*$ are the same.

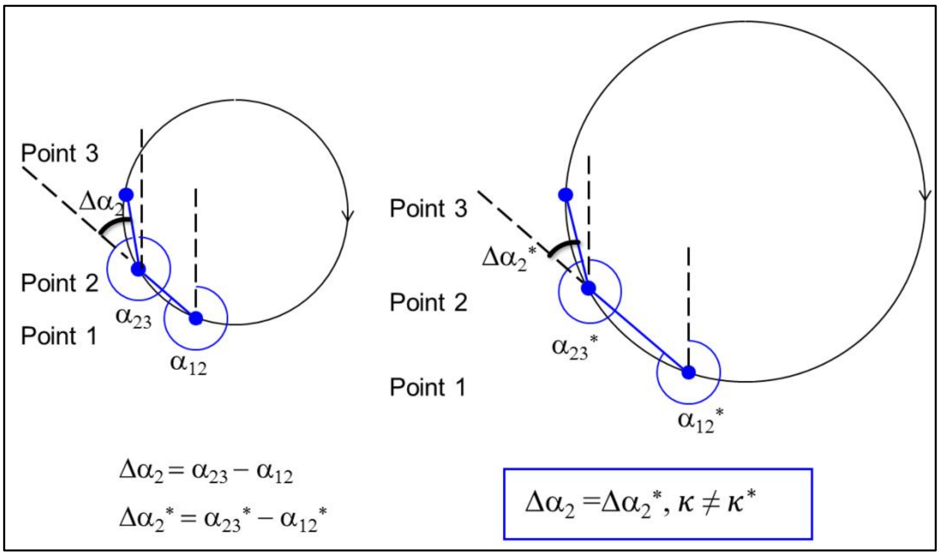

Fig. 4: The relationship between the orientation changes Δα and the curvature κ

Here the proposed approach for the quality evaluation of the relative positional accuracy combines two different criteria, namely the difference of orientation changes

$$\Delta\Delta\alpha_i = \Delta\alpha_{\text{gnss},i} - \Delta\alpha_{\text{map},i} \tag{4}$$

$$rms_{\Delta\Delta\alpha} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\Delta\Delta\alpha_i^2} \tag{5}$$

$$rms_{\Delta\Delta\alpha}{}^* = rms_{\Delta\Delta\alpha} \cdot \frac{\pi}{180} \cdot \Delta l \tag{6}$$

and the curvature difference

$$\Delta\kappa_i = \kappa_{\text{gnss},i} - \kappa_{\text{map},i} \tag{7}$$

$$rms_{\Delta\kappa} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\Delta\kappa_i^2} \tag{8}$$

at the GNSS points that are derived from the reference trajectory as compared to the homologous map points of linear features (road segments) in the digital map data. Here the RMS values of the difference of orientation changes $\Delta\Delta\alpha$ and the curvature difference $\Delta\kappa$ are calculated according to the equations (6) and (8). The orientation changes at the GNSS points and at the map points are denoted as $\Delta\alpha_{\text{gnss}}$ and $\Delta\alpha_{\text{map}}$, respectively; and their corresponding curvatures are defined as κ_{gnss} and κ_{map}. To allow for an easier and better comparison for relative accuracy in respect to $rms_{\Delta\Delta\alpha}$, degrees to meters conversion has been computed with a factor Δl of 13 meters in Equation (6), which equals about the average distance between two continuous GNSS points. The converted RMS values are denoted by the symbol $rms_{\Delta\Delta\alpha}{}^{*}$ (see Table 1). It has to be mentioned that, the map points and the GNSS points must be matched to each other in order to determine the orientation changes Δα and the curvatures κ in a correct and reasonably efficient way, as shown in Figure 5.

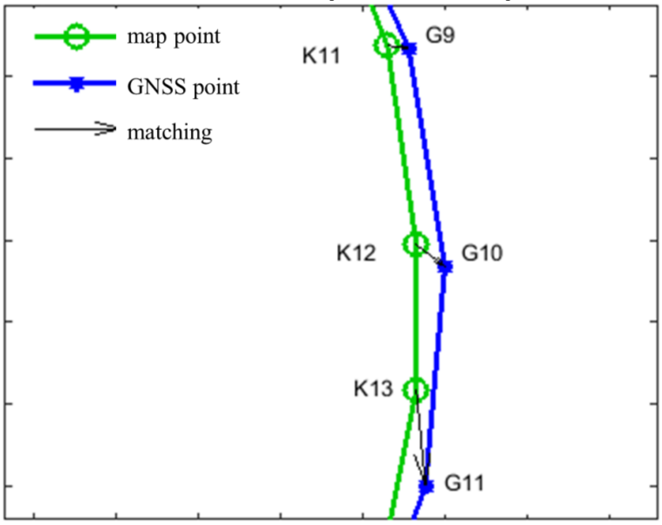

Fig. 5: The successive map points K11, K12 and K13 and their corresponding matched GNSS points G9, G10 and G11, respectively.

Taking advantage of the above-described criteria, the absolute and relative positional accuracy of digital road network data to be investigated in this work can be calculated efficiently. Furthermore, the completeness of attributes which provide essential information for routing applications and road safety, such as the direction of traffic flow and the number of lanes, should be considered (HERE, 2015 and TomTom, 2014).

4. RESULTS AND DISCUSSION

The achieved absolute and relative positional accuracy of the spatial roads database HERE, TomTom, OSM and ATKIS-Basis-DLM are given in Table 1. From the accuracy assessment results, it can be seen that the final average RMS values of absolute position error of all four datasets are around 2 meters, while the differences between these RMS values are small: maximum 0.22 meter. In terms of the relative positional accuracy, the average RMS values of difference of orientation changes $\Delta\Delta\alpha$ and the curvature difference $\Delta\kappa$ varies from 4.1° to 5.1° and from 5.3 km^{-1} to 8.7 km^{-1}, respectively.

Tab. 1: Comparison of absolute and relative positional accuracy between HERE, TomTom, OSM and ATKIS-Basis-DLM

Accuracy	HERE	TomTom	OSM	ATKIS
rms $_{ds}$ (abs.)	2.02 m	2.00 m	1.95 m	1.80 m
$\mathbf{rms}_{\Delta\Delta\alpha}$ (rel.)	4.1°	5.1°	4.2°	4.8°

$\mathbf{rms}_{\Delta\Delta\alpha}{}^{*}$ (rel.)	0.93 m	1.17 m	0.95 m	1.09 m
$\mathbf{rms}_{\Delta\kappa}$ (rel.)	$5.3\,\frac{1}{\mathrm{km}}$	$7.9\,\frac{1}{\mathrm{km}}$	$5.5\,\frac{1}{\mathrm{km}}$	$8.7\,\frac{1}{\mathrm{km}}$

On the other hand, the positional accuracies in the table above, which are based on our criteria, should be verified by comparing them to the accuracy specifications in the literature. As reported in AdV (2010), HERE (2015) and TomTom (2014), both HERE and TomTom data that are in compliance with ADAS (Advanced Driver Assistance Systems) can reach an absolute positional accuracy better than 5 meters and a relative positional accuracy better than 1 meter.~~,~~ ATKIS-Basis-DLM has a geometric accuracy of 3 meters, however, for the crowdsourced OSM no available information about data accuracy has been found.

Obviously, the four datasets of spatial road network data are within the absolute accuracy values specified in the literature, while the relative positional error of TomTom and ATKIS has slightly exceeded 1 meter. It has to be mentioned that there are also road data with lower levels of positional accuracy that do not fulfil the ADAS requirement. The results of accuracy assessment of such comparably inaccurate road segments based on only one autobahn entrance and two autobahn exit ramps show that the absolute positional accuracy is about 4 meters, while the level of the relative positional accuracy remains at around 1 meter.

In addition to positional accuracy, attribute completeness of geographic data is also one of the main quality elements of our investigation (Wiltschko & Kaufmann, 2005). Table 2 summarizes several relevant attributes for vehicle telematics applications (such as routing and navigation) that are contained in our spatial databases: Here, TomTom, OSM and ATKIS-Basis-DLM, respectively. Although OSM and ATKIS, as shown in the table below, lack the attribute of travel direction, the disadvantage has been compensated by our own acquired information.

Tab. 2: Overview of traffic-related map attributes of our digital road network data, as documented in the literatures AdV (2010), HERE (2015), OSM (2016) and TomTom (2014)

Attribute	**HERE**	**TomTom**	**OSM**	**ATKIS**
Road name	yes	yes	yes	yes
Road width	no	no	no	yes
Road length	yes	yes	no	no
Road type	yes	yes	yes	no
Travel direction	yes	yes	no	no
Travel time	no	yes	no	no
Number of lanes	yes	yes	no	yes
Speed category	yes	yes	no	no
Speed max.	yes	yes	yes	no

Accuracy level of position	yes	yes	no	no
Curvature	yes	no	no	no
Heading angle	yes	no	no	no
Angle of slope	yes	no	no	no
Attributes in total	10	8	3	3

5. CONCLUSION

In this paper a detailed assessment of the geometric accuracy and attribute completeness for four different spatial road network datasets that cover commercial, official and free data source has been performed. With a focus on the autobahn entrance and exit, our proposed evaluation approach based on high-precision GNSS trajectories was implemented successfully. The investigated map data products have achieved a higher level of accuracy than specified in literature: an absolute positional accuracy of 2 meters and a relative positional accuracy of 1 meter. The difference of the accuracy values for the four datasets is small and is based on a sample of limited size for comparison of investigated digital map data.

On the other hand, HERE and TomTom have a higher completeness of telematics-related attributes, particularly the travel direction and the speed category, and hence are more compliant with road safety applications than OSM and ATKIS-Basis-DLM.

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BIOGRAPHICAL NOTES

M.Sc. **Jinyue Wang**

2007 – 2008	Studies of Geodesy in the People's Republic of China (University of Wuhan)
2009 – 2015	Studies of Geodesy in Germany (University of Stuttgart)
2015	Research Associate at the Institute of Engineering Geodesy, University of Stuttgart

Dr.-Ing. **Martin Metzner**

1995 – 2001	Studies of Geodesy in Darmstadt (Technical University of Darmstadt)
2001 – 2006	Research Associate at the Institute of Geodesy, Technical University of Darmstadt
2006	Dr.-Ing. in Geodesy (Technical University of Darmstadt)
2006	Deputy Director at the Institute of Engineering Geodesy (formerly Institute for Applications of Geodesy to Engineering), University of Stuttgart

Prof. Dr.-Ing. habil. **Volker Schwieger**

1983 – 1989	Studies of Geodesy in Hannover
1989	Dipl.-Ing. in Geodesy (University of Hannover)
1991 – 2000	Research Associate at the Institute of Geodesy, University of Hannover
1998	Dr.-Ing. in Geodesy (University of Hannover)
2000 – 2001	Research Associate of GFZ German Research Center for Geosciences in Potsdam
2002 – 2010	Senior Research Assistant at the Institute for Applications of Geodesy to Engineering, University of Stuttgart
2003	Head of Department "Metrology" at the Institute for Applications of Geodesy to Engineering, University of Stuttgart
2004	Habilitation (University of Stuttgart)
2010	Director of the Institute of Engineering Geodesy (formerly Institute for Applications of Geodesy to Engineering), University of Stuttgart

CONTACTS

M.Sc. Jinyue Wang / Dr.-Ing. Martin Metzner / Prof. Dr.-Ing. habil. Volker Schwieger
University of Stuttgart
Institute of Engineering Geodesy
Geschwister-Scholl-Str. 24 D
D-70174 Stuttgart
GERMANY
Tel. + 49/711-685-84060 | -84043| -84040
Fax + 49/711-685-84044
Email: jinyue.wang@ingeo.uni-stuttgart.de / martin.metzner@ingeo.uni-stuttgart.de
volker.schwieger@ingeo.uni-stuttgart.de
Web-site: http://www.uni-stuttgart.de/ingeo/