Engineering Geodesy - Definition and Core Competencies

Heiner KUHLMANN, Volker SCHWIEGER, Wolfgang NIEMEIER, Germany
And Andreas WIESER, Switzerland

Key words: Engineering Geodesy, Engineering Surveying, self-conception, definition

SUMMARY

This article summarizes the discussion of the self-conception of engineering geodesy within the respective section of the German Geodetic Commission. It demonstrates Engineering Geodesy by means of its tasks, methods and characteristics as an application-oriented science whose research questions often arise from observed phenomena or from unsolved practical problems. A fundamental feature is the professional handling of geometry-related problems considering the economic principle and including comprehensive quality assessment from planning through measurement to data processing and interpretation. The current methodical developments are primarily characterised by the increasing integration of the measurement and analysis into challenging construction, production and monitoring processes as well as by the transition to spatially continuous methods. A modernized definition of Engineering Geodesy is proposed at the end of this article.

Engineering Geodesy - Definition and Core Competencies

**Heiner KUHLMANN, Volker SCHWIEGER, Wolfgang NIEMEIER, Germany
And Andreas WIESER, Switzerland**

1 INTRODUCTION

The introduction of terms and their common understanding are fundamental in every scientific discipline. They enable the internal communication as well as communication with neighboring disciplines and they reflect the area of expertise within the discipline. Since Helmert (1880) specified geodesy as the „science of measuring and imaging the surface of the earth", numerous changes of methods, sensors and technology as well as scope of duties and fields of applications of geodesy occurred. Against this background a discussion of self-conception has taken place in the Section of Engineering Geodesy of the German Geodetic Commission, which covered core competencies and unique features as well as future key research questions and education at university level. This contribution summarizes the discussion from the point of view of the authors and updates the definition of „engineering geodesy" accordingly.

We understand engineering geodesy as an application-oriented science, whose research questions often arise from observed phenomena or from unsolved practical problems. Consequently, this contribution covers aspects of both scientifically as well as practically oriented engineering geodesy, in case such a separation is possible or necessary at all.

2 HISTORICAL DEVELOPMENT OF "ENGINEERING GEODESY"

The discussion of the term „engineering geodesy" is not new. As a reaction to broadened and new areas of application the discipline was redefined repeatedly, as shown in chronologic summary in table 1.

As shown in the table, engineering geodesy is relatively young as a self-contained geodetic sub-discipline. All definitions are derived from fields of application: the main focus was initially on civil engineering. Today the spectrum is seen wider. Technologic development of sensors and data analysis did not have any influence on the evolution of the definition. The definition given in [Brunner, 2007] is the first one derived not only from measured objects, and in [DIN 2009] the important bond to other disciplines is first established explicitly.

The term „engineering geodesy" has started to replace the formerly used term „engineering surveying", given that the latter often referred only to technical measurements, whereas the former one is broader and is understood to cover also the entire set of methods for data analysis, modelling of sensors, objects, processes and quality, interpretation and visualization of results.

Table 1: Published definitions of engineering geodesy / surveying

Source	Definition
[FIG, 1971]	„Technical measurements, which are necessary in connection with planning, execution, approval and later surveillance of buildings.“)*
[Rinner, 1971; Rinner, 1978]	„… Accordingly, all those measurement activities belong to engineering geodesy, which have to be conducted in connection with technical planning, setting-out and monitoring of technical objects. “ „…It [engineering geodesy] is the practical utilization of the entire realm of geodesy under the complicating conditions of turbulent practice when realizing technical projects.“)*
[FIG, 1997]	„Surveying in connection with planning, construction, approval and monitoring of buildings and other objects)*
[Brunner, 2007]	„Engineering geodesy is the production of geodetic information necessary for the planning of technical projects, setting out of the project design, control of the correct construction, and monitoring of deformations.“
[DIN 18710-1, 2012]	“Survey in connection with the site surveying, project planning, setting out, acceptance and monitoring of structures and other objects.” Note: The term “engineering survey”, as a synonym for engineering geodesy, covers the spectrum of surveying tasks associated with technical projects of other trades and disciplines (e.g. building construction).

) Definition translated from German original version.*

3 CORE COMPETENCIES AND UNIQUE FEATURES

Methods, processes and characteristics, which distinguish the activity of engineering geodesist in practice and science today, are outlined in the following subsections. The competent handling of geometrical question with end-to-end quality assessment from planning and measurement to analysis and interpretation under economic constraints appears to be a primary attribute. The fields of application are almost exclusively located in the interdisciplinary domain. So, the engineering geodesist needs to be competent in high-level processes and nomenclature in neighbouring disciplines.

3.1 Surveying

Surveying, field measurements [see DIN 18710-2, 2012] or – often used also synonymic – topographic, boundary and as-built surveying refer to geometric and semantic acquiring and modelling of the current state of an object or area, often also comprising further space-related parameters. The object can be a part of a machinery, a single building, a whole urban district, the slipped mass of a landslide, or an entire mountain range. Such field measurements are usually the basis for creating planning documents and spatial models subsequently required

for a construction, fabrication or transformation process.
The measurements may also provide the appropriate information for deciding on the approval of a technical object or deliverable for quality management and accounting. The survey of a current state after completion of the construction or modification process often serves for comparison to the respective target state. It is often described as check or control survey [Möser et al., 2012] in this context.
For a few years a trend can be identified to survey also during the construction, production or transformation process. It allows documenting and evaluating intermediate steps. The evaluation is often implemented in real-time or with a short time lag. In this context, a thorough understanding of the related processes is needed in excess of engineering geodetic core competencies. In this case, data acquisition and surveying can be seen as fundamental parts of monitoring [Heim, 2002; Möhlenbrink and Schwieger, 2007; Wunderlich, 2013].
The totality of activities related to surveying measurements, their task-specific and quality-assured planning and analysis as well as the development of the related methods and instruments is an important field of action in engineering geodesy and surely represents one of the engineering geodetic core competencies.

3.2 Setting-out

Setting-out is defined as the transfer of predetermined geometric dimensions from a planning model to the construction site [DIN 18710-3, 2012]. Thereby, target dimensions like coordinates or distances are transferred to reality and marked recognizably on site using a feedback-control loop. Setting-out is a core competence and a unique feature of engineering geodesy.
Often high demands are made on relative accuracy of adjacent or nearby elements. For example, standard deviations of 0.5 mm have to be achieved for the 3-dimensional setting-out of high-speed train rails [Möhlenbrink et al., 2004]. Today, the measurement processes themselves are highly automated; only the design and installation of the measurement system are generally carried out manually by experts.
Engineering geodesy is particularly challenged by the setting-out of the alignment of long tunnels where the demands on reliability and accuracy are very high and the working conditions are very unfavorable.The engineering geodetic processes in this context are fully automated and integrated into the building process today [Stolitzka and Scharler, 1996; Niemeier, 2006]. This complete automation is required because tunnelling is a continuous process that requires real-time geodetic information without interruption e.g. for controlling the tunnel boring machines or for placing the blast holes. In terms of engineering navigation machine control can be seen as kinematic generalization of setting-out [Möhlenbrink et al., 2004; Wunderlich, 2013].
This form of kinematic setting-out is already widely spread in road and railway construction and is appearing also more generally in civil engineering [Stempfhuber and Ingensand, 2008]. It is still a topic of research and development for construction above ground. For example, a combination of GNSS and total stations has been developed and successfully used for quasi-kinematic setting-out and for seamless documentation of the building process of extremely high-rising buildings like the Burj Chalifa in the United Arab Emirates [Van Cranenbroeck, 2007].

The setting-out of geometry, the integration of measurement and analysis processes into feedback control loops, and the indispensable real-time quality management, are core elements of engineering geodesy within the canon of the geodetic disciplines.

3.3 Monitoring / Monitoring Measurements

In engineering, monitoring comprises generally data acquisition, observation and supervision [DIN 18710-4, 2012] of natural and artificial systems. A monitoring system thus allows also intervention or even control, if it turns out that the observed process is not taking the desired progress, e.g. if movements do not remain within the defined range of tolerance [Niemeier, 2006; Schwieger et al., 2010].

In engineering geodesy, monitoring denotes in particular the metrological registration of the geometric current state of an object and its comparison to the state in the past. The primary goal is usually to detect rigid body motion and deformation and to analyze them in relation to the cause of the changes. For this purpose, monitoring networks and/or measurement systems, that carefully balance the required information content and various constraints, have to be planned, developed and implemented. They have to be optimized regarding the sensitivity with respect to the critical deformations and movements, provide acceptable false alarm rates, be robust and fulfil all further technical and economic criteria.

For the detection, identification and analysis of changes, engineering geodesy applies a variety of independently developed statistical methods, which allow distinguishing point displacements, object movements and deformation while properly taking into account the uncertainty of all measurements and models [z.B. Heunecke u.a., 2013; Pelzer, 1985].

Current research addresses the transfer of these methods from point- and network-based approaches to area-based ones. Furthermore, dynamic deformation modelling is researched intensively [Lienhart, 2007], which includes both the temporal changes of the observed geometry and the forces causing these changes; structural health can be assessed by comparing structural models and geodetic measurements. This approach builds on the well established characterization of evaluation models as congruence model, kinematic model, static model and dynamic model [Welsch und Heunecke, 2001]. Apart from the treatment of time as a separate dimension, this requires knowledge of the factors generating changes of the monitored objects, as well as at least an approximate knowledge of the transfer behaviour of the object and thus of dynamic systems. Measurement of the input and output parameters (geometric changes) allows system identification, which in turn allows drawing conclusions on the condition of the monitored object. A variety of parametric and non-parametric approaches have been developed in engineering geodesy to describe the temporal behaviour of monitored objects.

The deformation analysis itself can be carried out only interdisciplinary. Civil engineer, geologist, geotechnical engineer and representatives of other neighbouring disciplines provide the dynamic model representation of the object, e.g. the finite element model of a dam [Gülal, 1997]. The engineering geodetic core competence is in the integration of this model with actual measurements [Lienhart, 2007] e.g. using a Kalman Filter [Heunecke, 1995; Eichhorn, 2005].

Typical applications of engineering geodetic monitoring are for instance the observation and analysis of landslides, ground settlements, and deformations of buildings such as bridges, dams or tunnels [Heunecke et al., 2013]. Besides the determination of the time-evolution of geometric changes, monitoring is also applied for conservation of evidence. For the geodetic monitoring of natural phenomena, especially changes of the earth surface and of the cryosphere, the term „geomonitoring“ is being established in engineering geodesy.

3.4 Geometry Related Phenomena

In almost every engineering discipline or natural science measurements represent the base for problem solving and gain of knowledge. Often measurements refer to physical dimensions without direct relation to geometry. Engineering geodesy concentrates primarily on geometric parameters like coordinates, distances, angles and quantities derived there from like altitude differences, straightness, bend or inclination. However, most engineering geodetic problems require to determine and model also further spatial parameters, e.g. atmospheric conditions along the signal propagation paths, surface temperature or material properties. All these parameters and their spatial and temporal variations are summarized using the term „geometry related phenomena“.
The variations can thereby concern the modelled object as well as the measurement system itself; the latter for instance with kinematic mapping of objects and whole cities using mobile-mapping-systems, the former e.g. with the automatic control of construction machines in tunnelling [Stolitzka and Scharler, 1996] – and both when setting-out from a moving platform [Foppe et al., 2004].
In the past the spatial discretization was an essential method of engineering geodesy, see [Brunner, 2007]. Even today there are applications where conclusions referring to a spatial continuum are drawn from measurements of distributed single points [Zeimetz, Kuhlmann, 2011]. Meanwhile point-wise approaches are often substituted by line-based and areal measurement and analysis methods, and are denoted as spatially continuous measurement. This is realized by sampling with nearly constant, negligibly small discretization intervals replacing carefully planned single measurements.
Process-oriented approaches to determining and modelling geometry related phenomena play an increasing role. The processes, e.g. related to the construction of a tunnel or a bridge, are observed and the observation results are used partially for the improvement of the process models and partially for processes control.

3.5 Spatial Scale: Local and Regional Phenomena

Traditionally, nowadays and in the future, engineering geodesy is highly involved in geometry related problems in the field of civil engineering. Typical applications may also be related to machine construction, geotechnics and further neighbouring disciplines. In terms of geodesy, the observed and modelled phenomena therefore often have a local character, but they also reach regional dimensions. Exemplary scale ranges and application fields are [Niemeier and Riedel, 2006]:

- 1 – 100 cm: form control for quality management in machine construction [Hennes, 2009; Hennes and Runge, 2006]; determination of geometry and growth of agricultural crops [Paulus and Kuhlmann, 2011];
- 10 – 100 m: setting-out out of a family home, surveying of a bridge [Kuhlmann,

1996];

- 1 – 10 km: installation of a monitoring network [Kahmen et al., 1998]; control of a tunnel excavation [Stolitzka and Scharler, 1996];
- 10 – 1000 km: mapping of road infrastructure by means of a mobile multi-sensor-system [Gräfe, 2007]; acquisition of postglacial and tectonic movements [Adler et al., 1994].

Clear demarcation of engineering geodesy with respect to neighbouring disciplines is not possible in terms of spatial scales or geometry related aspects. There is an overlap with state survey and physical geodesy towards the top end of the scale range and with geotechnics and mechanical engineering at the bottom one. However, a core competence of engineering geodesy – and a distinction from neighbouring disciplines – is the consistent treatment of geometry related problems stretching across several of the above scale ranges within a single reference frame.

3.6 Quality Assessment and Quality Management

Engineering geodesy has always paid particular attention to definition, planning and assurance of quality of the measurements and analysis results. This is a prerequisite for fulfilling the various requirements of different applications under the economic constraints of practice. Simultaneously the risk of consequential errors is limited.

For a long time there has been a focus on accuracy as a measure of quality. The research of modelling, propagation and mitigation of random deviations and their quantification using statistic measures like standard deviations, confidence ellipses or scalar functions (e.g. the determinant) of covariance matrices in linear or non-linear models are without doubt core competencies of engineering geodesy. Also the evaluation of reliability in the sense of detectability of model errors and of preferably low effects of undetected model errors have been adopted early. Thorough knowledge of measuring instruments and measuring processes including all relevant factors as well as the redundant acquisition of information using different physical principles are the backbone for the evaluation of accuracy based on precision and reability.

Through calibration and appropriate choice of measurement setup and evaluation processes systematic influences have been eliminated or at least mitigated sufficiently. It also seemed to be possible to randomise systematic effects through appropriate measures in the course of measurement and evaluation [Schmitt, 1977]. In the meantime, the sensors, measurement processes and analysis procedures have been improved for many fields of application. The random deviations have therefore been largely reduced but the systematic ones have not. So, the remaining systematic deviations can often not be neglected anymore. A deepened understanding of the measurement procedures as well as the physical sensor models has led to the conclusion that randomizing is not possible to the required degree [Kutterer, 2002] or leads to correlations [Koch et al., 2010] and auto-correlations, which inevitably required including stochastic processes into the methodical toolbox of engineering geodesy [Li, Kuhlmann, 2010]. The modelling and propagation of accuracy had to be expanded to include the systematic contributions to uncertainty. Today we refer more generally to uncertainty modelling [Kutterer, 2002; Neumann, 2009] and consider the „Guide for the Expression of

Uncertainty in Measurements (GUM)“ [ISO, 1995; Heister, 2001; Niemeier 2008] also in engineering geodesy for evaluation of the accuracy of measurement systems.
Engineering geodesy is often associated with the capability and the presumed disposition to particularly high measurement accuracy. This does not correspond to the self-conception of the discipline: engineering geodesists measure as accurate as necessary, not as accurate as possible. This integrated consideration of efficiency for the derivation of quality demands from the understanding of the related processes, and the corresponding implementation are core competencies of engineering geodesy, although not unique features [Rehr et al., 2011]. But in fact, engineering geodesy is distinguished within the canon of geodetic disciplines by the fact that it achieves, if necessary, measurements of very high accuracy at local scales; e.g. it can define a distance of 1 km length through special measurement procedures, deterministic and stochastic modelling of different influences with an accuracy of better than 1 mm [Heunecke, 2012], or it can adjust components of a particle accelerator with independently developed instruments and procedures relative to each other with an accuracy better than 1 μm.
Engineering geodesy has early given up the reduction of the term quality to the attribute accuracy and has built an extensive set of methods for evaluating e.g. geodetic networks using a broad quality model which comprises also parameters of sensitivity and separability, see e.g. [Grafarend et al., 1979; Niemeier, 1985a and 1985b; Li, 1986]. Currently, in interdisciplinary collaboration a comprehensive quality model for application in construction with appropriate methods for propagation of quality parameters is developed [Schweitzer and Schwieger, 2011].
Due to the typical combination of highly technical requirements on the one hand, economic, temporally and local constraints as well as adverse working and environmental conditions on the other hand the examination of compliance with quality parameters plays an immense role in engineering geodesy. This control has often to be carried out on in the field and preferably already while carrying out the measurements. So, quality testing can be integrated seamlessly in measurement, evaluation and building processes [Möhlenbrink and Schwieger, 2007; Schwieger u.a., 2010].

3.7 Sensor Technology and Geodetic Metrology

Engineering geodesy is a measuring science. The authors are convinced that engineering geodesy - and also geodesy in general – would lose its relevance for society and science without this metrological component. However, just taking measurements is not in the centre of the metrology competence of engineering geodesy. This competence comprises deterministic and stochastic modelling of the measurement processes, the knowledge of physical sensor models, the acquisition and modelling of the relevant environmental conditions and of all other relevant factors, as well as the indirect determination of required parameters and the quantification of their quality. The data processing with a known system model often leads to a least-squares or maximum-likelihood estimation within a linearized Gauß-Markov- or Gauß-Helmert-Model. The methodical basis of parameter estimation has been broadened recently to include robust estimators [Wieser, 2002; Caspary, 2013] and Bayes-estimation [e.g. Niedermayr and Wieser, 2012] as well as stochastic procedures like Monte-Carlo algorithms [e.g. Schweitzer and Schwieger, 2011] or heuristic methods like

genetic algorithms [e.g. Rehr et al., 2011].
Corresponding to the variety of application fields and requirements engineering geodesy relies on a large selection of measurement instruments, sensors and sensor systems. Total stations, GNSS receivers and antennas, level instruments and terrestrial laserscanners are now the typically used standard instruments. Photogrammetic systems, inertial measurement units, optical plummets, hydrostatic levelling systems, gyrotheodolites and lasertrackers are further instruments frequently used in engineering geodesy. Terrestrials microwave interferometers with real or synthetic aperture currently emerge as another addition to this toolbox of instruments. In addition, engineering geodesists access a pool of sensors, especially in connection with monitoring tasks, such as inclinometers, extensometers, position detectors, fibre-optic strain sensors, or temperature sensors. In connection with calibration, testing and development of sensors, further instruments like laser-interferometers, collimators and others are needed. In particular cases engineering geodesy develops also new sensors for special applications. A good overview of established instruments and sensors is given by [Deumlich and Staiger, 2001; Schlemmer, 1996; Schwarz, 1995]; information on the newer instruments and sensors can be found e.g. in [Rödelsperger, 2011; Habel and Brunner, 2011; Juretzko et al., 2008].
To fulfil the requirements of the superordinate processes, the engineering geodesist needs to design optimal measurement concepts, plan and realize data acquisition, and carry out data analysis with quality control of the results. The necessity of temporal and spatial integretation of several sensors and instruments in a multi-sensor-system can result from these requirements. Multiple multi-sensor-systems can be integrated as redundant or complementary systems, or they can be deployed as spatially distributed sensor networks [Heunecke, 2012]. Conception, development and calibration of such systems including their components are key tasks of engineering geodesists in practice and in research. Thereby calibration takes a special role [Hennes, 2010]. On the one hand it is the requirement for achieving utmost accuracy as is shown for instance with GNSS measurements with sub-millimetre-standard deviation [Zeimetz and Kuhlmann, 2013]. On the other hand it is increasingly more challenging, because measurement systems are getting more complex and their components may be black-box systems for the operators. System calibration therefore increasingly replaces component calibration [Rüeger and Brunner, 2000; Hennes and Ingensand, 2000; Heister et al., 2005; Fuhlbrügge, 2004].

3.8 Reference Systems

Location, orientation and connection of measurements – and particularly the subsequent analysis based on coordinates – require the introduction of appropriate reference systems where it has to be distinguished between observation domain and coordinate domain [Brunner, 2007].
For object volumes of a few cubic metres the reference system can be realised directly and mechanically using a coordinate measuring machine [Schwarz, 1995]. This is not possible anymore for bigger dimensions. The reference frame is then indirectly realized by marked points. The necessity of establishing such reference frames, determining and expressing geometric relations through a link to those frames, and at the same time considering all relevant physical influences – like deflections of the vertical and geoid heights in the course

of staking out a tunnel or particle accelerator [Albert and Schwarz, 2004] – is an important reason why the handling of the geometry-related phenomena mentioned above is not only a core competence but also largely a unique feature of engineering geodesy.
An additional challenge with engineering geodetic applications is often, that the points representing the reference frame are not fixed and stable. In fact the frame may change significantly during the project duration through differential movement of marked points or through deformations of the external reference frame [Schlemmer, 1998]. Due to this instability, the acquisition and modelling of moving objects and the increasing combination and integration of several sensors to multi-sensor-systems, time as fourth dimension has become vitally important in engineering geodesy. Well defined and stable reference frames are essential for the modelling of temporal processes and for the synchronization of sensors and instruments [Foppe et al., 2004].

4 SUMMARY AND CONCLUSION

This contribution summarizes the discussion of the self-conception of engineering geodesy within the section Engineering Geodesy of the German Geodetic Commission. It presents engineering geodesy as an application-oriented science with its own conceptional and methodical approaches that has initially been defined with respect to the measured objects and tasks in connection with civil engineering, but is now increasingly considered as a discipline in an interdisciplinary field.
Methods, processes and characteristics, which distinguish the work of an engineering geodesist in practice and science today, have been outlined in chapter 3. In summary, the development and optimization of measurement concepts, setups and data analysis strategies based on a variety of technical and non-technical criteria and applying theoretic-methodic as well as numeric simulation and optimization approaches belongs to the core competences of an engineering geodesist.
With regard to the actual developments the following trends can be seen:

- The object to be mapped or monitored is now often not represented by a few carefully chosen individual points but by a point-cloud created by a laserscanner or derived from registered images of digital cameras. The relevant object information is not extracted during the measurement but afterwards during data processing.
- An increasingly close link is given with photogrammetry, regarding image processing, object extraction, or orientation and positioning algorithms, e.g. laserscanning registrations. Also the newest total stations and scanners or particular add-on systems of laser trackers, like probes and hand scanners include essentially photogrammetric concepts and solutions.
- Often, the measurement system is not static anymore but moves along the measured object. This also holds for setting-out, when the planned geometry is transferred to the reality directly through a guided or controlled machine without marked waypoints.

We expect that „engineering geodesy – continuous in space and time“ [Kuhlmann, 2004] will further develop and change in the future, providing innovative and exciting developments.
Based on the above discussion of core competencies and characteristics as well as the self-conception of engineering geodesy, we finally propose the following new definition of this discipline:

Engineering geodesy is the discipline of reality capture, setting-out and monitoring of local and regional geometry-related phenomena paying particular attention to quality assessment, sensor systems and reference frames.

REFERENCES

Adler, R., Pelzer, H., Foppe, K., Melzer, Y., 1994, Geodetic Monitoring of Recent Crustal Activity along the Dead Sea Jordan Rift. In: Perelmuter Workshop on Dynamic Deformation Models, Workshop Proceedings, 29.8.-1.9., Haifa, Israel, S.56-68.

Albert, J., Schwarz, W., 2004, Messtechnische Entwicklungen für die Zukunftsprojekte "Linearbeschleuniger". In: Ingensand, H. (Hrsg): Ingenieurvermessung 2004, ETH Zürich, Zürich, S. 39-50.

Brunner, F.K., 2007, On the methodology of Engineering Geodesy. In: Journal of Applied Geodesy (1), S. 57-62.

Caspary, W., 2013, Fehlertolerante Auswertung von Messdaten: Daten- und Modellanalyse, robuste Schätzung. OldenbourgWissenschaftsverlag, 313 S.

Deumlich, F., Staiger, R., 2001, Instrumentenkunde der Vermessungstechnik. 9. Aufl., Herbert WichmannVerlag, 435 S.

DIN 18709-1, 1995, Deutsche Norm: Begriffe, Kurzzeichen und Formelzeichen im Vermessungswesen, Teil 1: Allgemeines, Beuth Verlag, Berlin.

DIN 18710-1, 2012, Deutsche Norm: Engineering Surveys –Part 1: General Requirements, Beuth Verlag, Berlin.

DIN 18710-2, 2012, Deutsche Norm: Engineering Surveys –Part 2: Site surveying, Beuth Verlag, Berlin.

DIN 18710-3, 2012, Deutsche Norm: Engineering Surveys –Part 3: Setting out, Beuth Verlag, Berlin.

DIN 18710-4, 2012, Deutsche Norm: Engineering Surveys –Part 4: Deformation measurements, Beuth Verlag, Berlin.

Eichhorn, A., 2005, Ein Beitrag zur Identifikation von dynamischen Strukturmodellen mit Methoden der adaptiven KALMAN-Filterung. Deutsche Geodätische Kommission, Reihe C, Heft 585.

FIG, 1971, FIG-Fachwörterbuch, Heft 10 – Ingenieurvermessung. Verlag des Instituts für Angewandte Geodäsie, Frankfurt.

FIG, 1997, FIG-Fachwörterbuch, Band 10: Ingenieurvermessung. Bundesamt für Kartographie und Geodäsie, Frankfurt.

Foppe, K., Schwieger, V., Staiger, R., 2004, Grundlagen kinematischer Mess- und Auswertetechniken. In: Schwieger, V., Foppe, K. (Hrsg.): Kinematische Messmethoden – „Vermessung in Bewegung“. Beiträge zum 58. DVW-Seminar, Schriftenreihe des DVW, Band 45, Wißner Verlag, Augsburg, S. 3-18.

Fuhlbrügge, H.-J., 2004, Untersuchungen zur Prüfung von GPS-Echtzeitsystemen als Beitrag zur Qualitätssicherung im Vermessungswesen. Mitteilungenaus den

GeodätischenInstituten der Universität Bonn, Nr. 91, Bonn.
Grafarend, E., Heister, H., Kelm, R, Kropff, H., Schaffrin, B., 1979, Optimierung Geodätischer Messoperationen. Herbert Wichmann Verlag, Karlsruhe, 499 S.
Gräfe, G., 2007, Kinematische Anwendungen von Laserscannern im Straßenraum. Dissertation, Universität der Bundeswehr München, http://athene.bibl.unibw-muenchen.de:8081/doc/86001/86001.pdf.
Gülal, E., 1997, Geodätische Überwachung einer Talsperre: eine Anwendung der Kalman-Filtertechnik. WissenschaftlicheArbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 224.
Habel, W.R., Brunner, F.K., 2011, Faseroptische Sensoren für den Einsatz im Monitoring: ein Überblick. AllgemeineVermessungs-Nachrichten (118), S. 204-211.
Heim, M., 2002, Die zeitnahe Leistungsfeststellung von Baustellen – unter besonderer Berücksichtigung von Bildinformationssystemen. Technische Universität Darmstadt, Cuvillier Verlag, Göttingen.
Heister, H., 2001, Zur Angabe der Meßunsicheheit in der geodätischen Meßtechnik. In: Heister, H., Staiger, R. (Hrsg.): Qualitätsmangement in der geodätischen Meßtechnik. Beiträge zum 54. DVW-Seminar, Schriftenreihe des DVW, Band 42, S. 108-119.
Heister, H., Woschitz, H., Brunner, F.K., 2005, Präzisionsnivellierlatten, Komponenten- oder Systemkalibrierung? AllgemeineVermessungs-Nachrichten (112), , S. 233-238.
Helmert, F.R., 1880, Die mathematischen und physikalischen Theorien der Höheren Geodäsie. Teubner, Leipzig.
Hennes, M., 2009, Freiformflächenerfassung mit Lasertrackern - eine ergonomische Softwarelösung zur Reflektoroffsetkorrektur. Allgemeine Vermessungs-Nachrichten, S. 188-194.
Hennes, M., 2010, Ausgewählte Initiativen zur Qualitätssicherung in der Messtechnik. In: Kutterer, H., Neuner, H. (Hrsg.): Qualitätsmanagement geodätischer Mess- und Auswerteverfahren, Beiträge zum 93. DVW-Seminar, Schriftenreihe des DVW, Band 61, WißnerVerlag, Augsburg, S. 239-252.
Hennes, M., Ingensand, H., 2000, Komponentenkalibrierung versus Systemkalibrierung. In: Schnädelbach, K., Schilcher, M. (Hrsg.): Ingenieurvermessung 2000, WittwerVerlag, Stuttgart, S. 166-177.
Hennes, M., Runge, P., 2006,Chancen der IngenieurvermessungimmodernenMaschinenbau. AllgemeineVermessungs-Nachrichten, S. 242-250.
Heunecke, O., 1995, Zur Identifikation und Verifikation von Deformationsprozessen mittels adaptiver Kalman-Filterung (Hannoversches Filter). WissenschaftlicheArbeiten der Fachrichtung Vermessungswesen derUniversität Hannover, Nr. 208.
Heunecke, O., 2012, Auswertung des Ringversuchs auf der neuen Kalibrierbasis der UniBw München zur Bestimmung der Sollstrecken. AllgemeineVermessungs-Nachrichten (119), S. 380-385.
Heunecke, O., 2012, Anwendungen von Geosensornetzen in der Ingenieurgeodäsie. In: Schwarz, W. (Hrsg.): Interdisziplinäre Messaufgaben im Bauwesen – Weimar 2012. Beiträge zum 115. DVW-Seminar, Schriftenreihe des DVW, Band 68, WißnerVerlag, Augsburg, S. 171-186.
Heunecke, O., Kuhlmann, H., Eichhorn, A., Neuner, H., Welsch, W., 2013,AuswertunggeodätischerÜberwachungsmessungen. WichmannVerlag,

Heidelberg.
ISO, 1995, Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization, Genève.
Juretzko, M., Hennes, M., Schneider, M., Fleischer, J., 2008, Überwachung der raumzeitlichen Bewegung eines Fertigungsroboters mit Hilfe eines Lasertrackers. AllgemeineVermessungs-Nachrichten (115), S. 171-178.
Kahmen, H., Wunderlich, T., Retscher, G., Kuhn, M., Plach, H., Teferle, F., Wieser, A., 1998, Ein modulares Konzept zur Absteckung von Hochgeschwindigkeitstrassen. Zeitschrift für Vermessungswesen (123), S. 115–121.
Koch, K.R., Kuhlmann, H., Schuh, W.D., 2010, Approximating covariance matrices estimated in multivariate models by estimating auto- and cross-covariances. Journal of Geodesy (84), S. 383-397.
Kuhlmann, H., 1996,EinBeitragzurÜberwachung von BrückenbauwerkenmitkontinuierlichregistriertenMessungen, WissenschaftlicheArbeiten der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 208.
Kuhlmann, H., 2004,Bestimmung von Bewegung – eine geodätische Sicht. In: Flächenmanagement und Bodenordnung, VerlagLuchterhand, Heft 5, S. 225-231.
Kuhlmann, H., Heister, H., 2006, Steering problems and solutions during constructions of roads. In: Proceedings of the 3rd IAG Symposium on Geodesy for Geotechnical and Structural Engineering and 12th FIG Symposium on Deformation Measurement Baden, Österreich, 22.-24.05.
Kutterer, H., 2002, Zum Umgang mit Ungewissheit in der Geodäsie - Bausteine für eine neue Fehlertheorie. Deutsche Geodätische Kommission, Reihe C, Heft 553.
Lienhart, W., 2007, Analysis of Inhomogeneous Structural Monitoring Data. Shaker Verlag, Aachen.
Li, D., 1987, Trennbarkeit und Zuverlässigkeit bei zwei verschiedenen Alternativhypothesen im Gauß-Markov-Modell. Zeitschrift für Vermessungswesen (112), S. 555-563.
Li, L., Kuhlmann, H., 2010, Deformation Detection in the GPS Real-time Series by the Multiple Kalman Filter Model. Journal of Surveying Engineering (136), S. 157-164.
Möhlenbrink, W., Kuhlmann, H., Dünisch, M., 2004,Prozessintegrierte kinematische Absteckung am Beispiel „Feste Fahrbahn“. In: Schwieger, V., Foppe, K. (Hrsg.): Kinematische Messmethoden – „Vermessung in Bewegung“. Beiträgezum 58. DVW-Seminar, Schriftenreihe des DVW, Band 45, WißnerVerlag, Augsburg, S. 265-282.
Möhlenbrink, W.; Schwieger, V., 2007, Zur Prozessintegration der geodätischen Messtechnik. AllgemeineVermessungs-Nachrichten (114), S. 403-410.
Möser, M. , Hoffmeister, H., Müller, G., Staiger, R., Schlemmer, H., Wanninger, L., 2012, Handbuch Ingenieurgeodäsie: Grundlagen. Herbert Wichmann Verlag, Heidelberg.
Neumann, I., 2009, Zur Modellierung eines erweiterten Unsicherheitshaushaltes in Parameterschätzung und Hypothesentests. Deutsche GeodätischeKommission, ReiheC, Heft 634.
Niedermayr, S., Wieser, A., 2012, Combination of feature-based and geometric methods for positioning. In: Proceedings of 3rd International Conference on Machine Control and Guidance, Stuttgart, S. 301-310.
Niemeier, W.: Netzqualität und Optimierung. In: Pelzer, H. (Hrsg.), 1985,GeodätischeNetze

in Landes- und Ingenieurvermessung II. Verlag Konrad Wittwer, Stuttgart.
Niemeier, W., 1985, Analyse von Überwachungsnetzen. In: Pelzer, H. (Hrsg.): Geodätische Netze in Landes- und Ingenieurvermessung II. Verlag Konrad Wittwer, Stuttgart.
Niemeier, W., Riedel B., 2006,MehrskaligesgeodätischesBeobachtungskonzept für die ÜberwachunggroßflächigerRutschungsgebiete. In: Proceedings 7. Geokinematischer Tag, TU Freiberg.
Niemeier, W., 2008, Ausgleichungsrechnung – Statistische Auswertemethoden. 2. Aufl., de GruyterVerlag.
Niemeier, W., 2006, Geodetic Techniques for the Navigation, Guidance and Control of Construction Processes. In: Proceedings of 3rd IAG International Symposium on Geotechnical and Structural Engineering and 12th International Symposium on Deformation Measurements, Baden, Österreich, 22.-24.05.
Paulus, St., Kuhlmann, H., 2011, Nahbereichsscanning – Messprinzipien und Einsatzmöglichkeiten bei Nutzpflanzen. In: Wunderlich, T., Ohlmann-Lauber, J. (Hrsg.) TerrestrischesLaserscanning - TLS 2011 mit TLS-Challenge, Beiträgezum 107. DVW-Seminar, Schriftenreihe des DVW, Band 66, Wißner Verlag, Augsburg, S. 17-30.
Pelzer, H. (Hrsg.), 1985,GeodätischeNetze in Landes- und Ingenieurvermessung II. VerlagKonradWittwer, Stuttgart.
Rehr, I., Rinke, N, Kutterer, H., Berkhahn, V., 2011,MaßnahmenzurEffizienzsteigerungbei der DurchführungtachymetrischerNetzmessungen. AllgemeineVermessungs-Nachrichten (118), S. 2-14.
Rinner, K., 1971, Über die zunehmende Bedeutung der Ingenieurgeodäsie. Zeitschrift für Vermessungswesen (96), S. 209 – 217.
Rinner, K., 1978, Entwicklungstendenzen in der Ingenieurgeodäsie. AllgemeineVermessungs-Nachrichten (85), S. 161-166.
Rödelsperger, S., 2011, Real-time Processing of Ground Based Synthetic Aperture Radar (GB-SAR) Measurements. Deutsche GeodätischeKommission, Reihe C, Heft 668.
Rüeger J.M., Brunner, F.K., 2000, On System Calibration and Type Testing of Digital Levels. Zeitschrift für Vermessungswesen (125), p. 120-130.
Schlemmer, H., 1996, Grundlagen der Sensorik: Eine Instrumentenkunde für Vermessungsingenieure. Wichmann Verlag.
Schlemmer, H., 1998, Trends in der Ingenieurvermessung – gegenwärtige Leistungsfähigkeit und Perspektiven für die Zukunft. In: Schwarz, W. (Hrsg.): Ingenieurvermessung aktuell, Beiträge zum 47. DVW-Seminar, Schriftenreihe des DVW, Band 32, VerlagKonradWittwer, Stuttgart, S. 11-16.
Schmitt, G., 1977, Monte-Carlo-Design geodätischer Netze. AllgemeineVermessungs-Nachrichten (84), S. 87-94.
Schwarz, W. (Hrsg.), 1995, Vermessungsverfahren im Maschinen- und Anlagenbau. VerlagKonradWittwer, Stuttgart, 1995.
Schweitzer, J., Schwieger, V., 2011,Modeling of Quality for Engineering Geodesy Processes in Civil Engineering. In: Journal of Applied Geodesy (5), S. 13-22.
Schwieger, V. , Beetz, A., Wengert, M., Schweitzer, J., 2010, Echtzeit-Integration ingenieurgeodätischer Messsysteme in Bauregelkreise. In: Wunderlich, T. (Hrsg.): Ingenieurvermessung 10 , Wichmann, Berlin, S. 45-56.

Stempfhuber, W., Ingensand, H., 2008, Baumaschinenführung und -steuerung - von der statischen zur kinematischen Absteckung , Zeitschrift für Vermessungswesen (133): S. 36-44.
Stolitzka, G., Scharler, H., 1996,Funktionskriterien für die Beurteilung von TBM-Leitsystemen. In: Brandstätter, G., Brunner, F.K., Schelling, G. (Hrsg.): Ingenieurvermessung 96, Dümmler, Bonn, S. B4/1-7.
Van Cranenbroeck, J., 2007, Advanced Surveying Control Services for Building the Vertical Cities. In: Proceedings, FIG Working Week 2007, Hong Kong, China, 13.-17.05.2007, 13 S.
Wieser, A., 2002, Robust and fuzzy techniques for parameter estimation and quality assessment in GPS. Shaker Verlag, Aachen, 274 S.
Wieser, A., Aschauer, R.: Estimating platform kinematics using multi-antenna GNSS. Vermessung und Geoinformation (99): S. 180−190, 201.
Welsch, W., Heunecke, O., 2001, Models and terminology for the analysis of geodetic monitoring observations. FIG Publication No. 25, ISBN 87-90907-10-8.
Wunderlich, Th., 2013, Die Zukunft der geodätischenAbsteckung von Bauwerken. In: Tagungsband „Geodätische Arbeiten für Bundeswasserstrassen“, Bundesanstalt für Gewässerkunde, in Druck.
Zeimetz, Ph., Kuhlmann, H., 2011, Use of parametric models for analyzing ground movement measurements in the Rhenish lignite mining area. World of Mining - Surface & Underground (63), S. 256-264, ISSN 1613-2408.
Zeimetz P., Kuhlmann H., 2013,Einsatzkalibrierter GNSS-AntennenzurgenauenLängenmessung. AllgemeineVermessungs-Nachrichten (120), S. 3-8.

BIOGRAPHICAL NOTES

CONTACTS

Prof. Dr.-Ing. Heiner Kuhlmann
Rheinische Friedrich-Wilhelms-Universität Bonn
Institute of Geodesy and Geoinformation
Nussallee 17
53115 Bonn
GERMANY
+49/228/73-2620
+49/228/73-2988
heiner.kuhlmann@uni-bonn.de
www.igg.uni-bonn.de

Prof. Dr.-Ing. habil. Volker Schwieger
University of Stuttgart
Institute of Engineering Geodesy
Geschwister-Scholl-Str. 24D
70174 Stuttgart
GERMANY
+49/711/685-84040
+49/711/685-84044
volker.schwieger@ingeo.uni-stuttgart.de
www.uni-stuttgart.de/ingeo

Prof. Dr. Andreas Wieser
ETH Zürich
Institut für Geodäsie und Photogrammetrie
Wolfgang-Pauli-Str. 15
CH-8093 Zürich
SWITZERLAND
+41/44 633 05 55
+41/44 633 11 01
andreas.wieser@geod.baug.ethz.ch
www.igp.ethz.ch

Prof. Dr. Wolfgang Niemeier
TU Braunschweig
Institut für Geodäsie und Photogrammetrie
Pockelsstraße 3
38106 Braunschweig
GERMANY
+49/531 391 94574
+49/531 391 94599
w.niemeier@tu-bs.de
www.tu-braunschweig.de/igp