Geodetic Techniques for the Navigation, Guidance and Control of Construction Processes

NIEMEIER, Wolfgang
Institute of Geodesy and Photogrammetry
Technical University Braunschweig, Germany
Email : w.niemeier@tu-braunschweig.de

Abstract: One of the main objectives in engineering geodesy is a stronger integration into the construction processes of large scale structures. Nowadays it seems to be possible to come closer to this target, due to the development of powerful new sensors, adequate communication links and the ability of real time processing of the observations. At first general requirements for a more intensive participation in construction processes are outlined. Then the potential of modern geodetic techniques and new concepts for a real integration are presented and typical examples for already existing solutions are given: Steering for compaction control, guidance for tunnelling, understanding tunnelling as a combined system and geometric aspects of adjustments during the construction of large bridges.

1 TERMINOLOGY

Since several years in the geodetic literature papers are found on the navigation of construction machinery. The geodesy-related industry has developed systems for machine guidance and control and they seem to be quite successful or at least optimistic. Here we want to discuss and - to a certain extend - answer the question : What can be the potential of geodetic techniques for navigation, guidance and control of construction processes, where are their limitations and what can be done in the future ?

To clarify terminology, at first we want to define the frequently used term "*Navigation*": Navigation is a purely geometrically defined expression, it is information and action required to come from A to B. Navigation of machinery therefore asks for geometric information on the actual position and orientation of the machine and where is has to go. In this understanding navigation includes the technical process of steering a machine to its final position, too.

"Guidance" is the look at this process from a different point of view, mainly the view of the driver of the machine: To achieve the best/optimal path from A to B, he needs external geometrical information on the (route). With this information for him the steering is possible.

Most complex is the challenge of *"Control"* , where the objective is to determine and realise the "best way", which can be defined in terms of length, time or effort. Adequate actions or adjustments have to be initiated, if the optimal path is not followed. To realise an optimal control system, a well defined interaction has to be established between the individual sensors, who determine the actual path and the mechanical, hydraulic and electrical actors, who bring the machine back into its ideal path. Here the main problem is to know precisely, by which action of the steering system which geometric movement can be achieved.

A principally different and complex area, which has an important impact in practise are errors during the construction process and effects of external forces, like wind loading, temperature, temporal loading, etc. In terms of system theory, for a complete guidance and control problem a system identification has to be performed, taking into account all these effects.

2 GEOMETRIC REQUIREMENTS FROM THE CONSTRUCTION PROCESS

To define the requirements of construction processes and the geodetic possibilities for navigation, guidance and control, at first the temporal development of construction projects will be outlined. Classical phases of the life-cycle of structures are given in Table 1. At the end of its life a complete demolition and/or a new construction follows, starting with phase 1 again.

In this table the usually required information from the area of geodesy and geoinformatics is summarised, too. In general, in every step of the construction progress some geodetic information is required, but it differs in quality, actuality and completeness.

Life-Cycle Phases in Construction		*Deliverables from Geodesy/Geoinformatics*
1. Idea/ Feasibility study	<=	*Maps, Geoinformation*
2. General Planning / Architectural Design	<=	*Detailed Geoinformation, Cadastrial Aspects*
3. Constructional Design / Detailed Planning	<=	*Coordinate References, Main Axes*
4. Realisation Phase / Construction	<=	*Stacking-Out, Quality Control and Monitoring*
5. Utilisation Phase / Reconstructions / …	<=	*As-Built Documentation and Monitoring*

Table 1: Actual services from Geodesy and Geoinformation during the construction phases

What is pointed out in this table is a *one-way-delivery*, i.e. the information from geodesy and geoinformatics has to be provided to the construction office. It has to be establishment in time and responsibility independently from the construction progress itself. The geodetic engineer gets his tasks and time schedule from the central construction office, but he is – normally – not part of this team !

In the time domain critical tasks are surveying jobs during the realisation phase. Here e.g. for the construction of high buildings precise position of form-works, quality of surfaces, verticality of walls or correct position of pillars between different floors have to be determined. The time-span for these surveying tasks should be as short as possible, best would be a solution, where no time-delay is related to the surveying work.

Due to the tremendous progress in sensor developments in geodesy, made during the last years and the advent of modern communication and real-time processing capabilities for geodetic data, a much more rapid geodetic information can be achieved. An outline of the relevant geodetic concepts are given in the next section.

On the other hand, the following requirements from the construction site exist, which have to be fulfilled, before the geodetic engineer is attractive enough to become part of the team. The requirements can be formulated as follows :

i. *Development of measuring techniques to determine geometry of arbitrary forms and structures without targets, but with sufficient precision and reliability*

ii. *Real-time processing techniques to compute each geometric form and the derivation from a design model*

iii. *Set-up of a communication and data structure for perfect interaction with information systems used in construction*

Only if these requirements are fulfilled, the position of the geodetic engineer on a construction site will be improved. It should be possible that he becomes responsible for all geometric aspects during the planning and realisation phase.

3 POTENTIAL OF GEODETIC TECHNIQUES TO FULFILL THE CONSTRUCTION REQUIREMENTS

The classical activities of the surveying engineer during a construction process itself are staking out and quality control. The requirements in terms of precision, actuality and completeness of the geometric information are derived from the design of the structure and the construction technology itself by the site manager or his management team, mainly without real cooperation with the geodetic engineer.

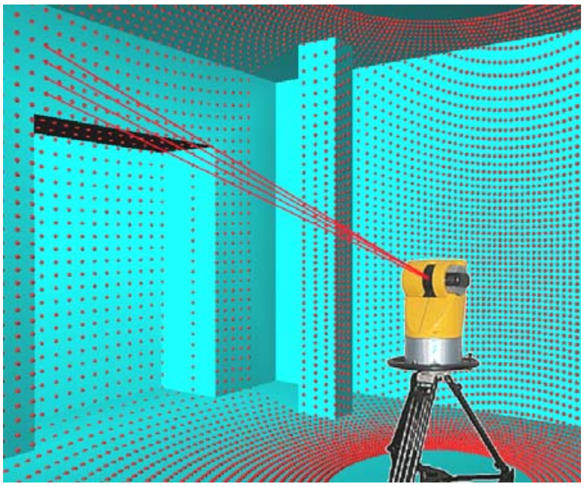
With the advent of new sensors, modern communication and efficient processing concepts this situation can be changed completely. It is important to point out the real advantages of modern geodetic techniques. Best would be to estimate the shortening of the construction time and the reduction of the construction costs due to adequate geodetic integration, see the example in section 6. Further advantages are to avoid (geometrical) conflicts before they become critical and to improve the final quality of the structure/building.

3.1 Modern Sensor Systems

Well established in geodesy but not sufficiently applied in construction are modern satellite positioning systems, like GPS, GALILEO and GLONASS. For navigation of construction machines for earth work these systems are already in use, see Table 1 and section 4. But there is a much higher potential within these systems, as they provide real-time information with high accuracy and this is needed in further construction areas as well.

Modern sensors like *Automated Total Stations, Laserscanners* and *Lasertrackers,* see Fig. 1, are best suited to fulfil the first requirement, mentioned above, i.e. to determine the geometry of arbitrary forms and structures without any physical targets. With these measuring systems a complete determination of geometric forms can be achieved, therefore these systems can be used for tasks which are characterized as being "*Continuous in Space"*.

In Figure 1 the main concepts for these polar sensor systems are depicted, where the observations are the polar coordinates "horizontal direction", "vertical angle" and "slope distance". With these instruments an almost arbitrarily dense capture of geometric objects even without physically marked targets is possible. While a Lasertracker can only be used with additional tooling to be in touch with the surface, the other systems are developed for remote data capture. In terms of precision the Lasertracker gives a standard deviation in the range of 0.1 mm or better, the Automated Total Station of about 1 mm and the Laserscanner up to how in the range of about 5 mm for single shot.



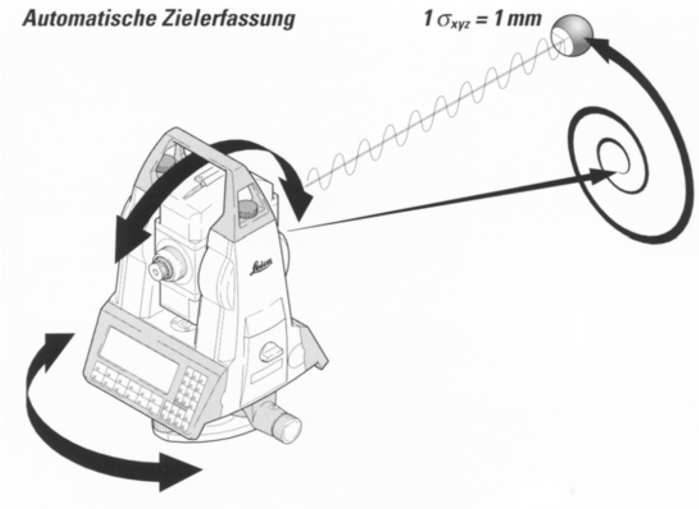


Figure 1:

Modern geodetic polar measuring systems :

Laserscanner
Lasertracker
Automated Total Station
(usable without target, as well)

It is obvious, that not all geometric problems can be solved with these mainly geodetic techniques alone, but that further systems like optical sensors, inclinometers, pendulums and others have to be taken into account to find the best suited solution. It is an absolute “must”, that at in the definition phase of a project all disciplines have to discuss as a team, what are the normal requirements and what are the critical phases during the construction process. The complete measuring concept has to be set-up to find the best measuring solution for all these phases, see Kovari/Bosshard (2003).

3.2 Real-Time Processing

Real-Time in this concept means “the geometric information (form of an object, derivation from the design model) has to be available, before the next user needs it”. This practical definition of real-time leads to time discreet determinations, which are much easier to handle than a continuous real-time description of the structural behaviour and the construction phases.

The main difference in relation to well-known surveying techniques is the much more complex data processing : As result of data capture without targets in general one achieves a point cloud with numerous single points, which represent the object and not a coordinate set for a well defined single point. Sophisticated and efficient software is required to derive the final geometric information out of these data and at the moment intensive research activities are focused to derive and realise the optimum concepts for the geometry extraction out of these point clouds, see Niemeier (2005).

A second challenge for research is the development of strategies and procedures for an integrity check of the observations and results. This starts with adequate estimates for the precision and reliability of the observations but includes on-line calibration procedures and self-checking of the devices, which often have to be used independently for a longer time span on a construction site.

Only if these problems are solved, real-time processing techniques can be established to compute each required information out of the geodetic data. Finally for the control of the construction and a necessary adjustment procedure the deviation between a design model, i.e. the theoretical structure, and the reality on the construction site has to be derived in real-time, too.

3.3 Communication and Data Structure

A further problem is the set-up of powerful communication links between the sensors and central processing offices, which can be on the site and far away, e.g. in another city. The set-up of the communication is a really interdisciplinary approach, as these links have to be valid between the different groups on the construction site and the site management, as well.

A general requirement is a common data-structure for observations and the designed and computed geometry in all steps of the process. Here “common” means that all groups on the construction site and in external planning and evaluation offices have to use this structure. One possibility to set-up such a system is the use of internationally accepted standards for the representation of geometry, like Industry Foundation Classes (IFC) or Geography Markup Language (GML). Gielsdorf (2004) has analysed and compared these standards and came to the conclusion that both are not ideally suited for the here mentioned purposes. His own new concept, based primarily an the topology of the structures, seems to bring real progress.

Once the data structure is defined, one has to establish intelligent, i.e. error redundant and stable communication links on the construction site. To achieve this the maximum data rates, possible disturbances e.g. by the concrete masses, temporary machine positions and material transport, power failure and many other effects have to be taken into account. Here electrical engineers are the specialists and finally they should set up the communication system.

Finally a readable or understandable presentation of the results in attractive graphical form has to be established. This helps the communication between the groups and is an important prerequisite, if problems arise and have to be discussed with external experts or the customer.

4 COMPACTION CONTROL

Due to the wide range of construction projects the methodology, sensors, data structure and processes may differ to a large extend, but the basic ideas are similar. As examples here the potential and impact of modern geodetic concepts on typical large scale projects are outlined.

4.1 Objectives for Compaction Control

Well established are methodologies for the navigation of construction machines for earth work. Retscher (2002) gave an overview an applications on different types of construction machines and compared the specifications, see Table 2.

	Dozer	Grader	Road paving machine	Slipform paving machine
Major application field	Bulk eartworks and earthmoving	Fine grading, sideslop work	Asphalt surface for highways, concrete surface for runways	Concrete surface for highways, high speed railways, runways
Precision requirements	up to ± 2 cm	up to ± 5 mm	up to ± 5 mm in plane ± 3 mm in height	up to ± 5 mm in plane ± 2 mm in height
Guidance systeme	3-D systems: GPS or total station	Laser systems 3-D systems: total station	String lines or stakes Laser systems 3-D systems: total station	String lines or stakes Laser systems 3-D systems: total station

Table 2 : Comparison of different types of construction machines (Retscher 2002)

Sensor on top of compactor
a) D-GPS
b) Azimuth Sensor
c) 2 -Axis Inclinometer

Figure 2: Compactor on a landfill with sensor head

Presented here will be project of our institute, the use of geometric real-time information for the steering and control of *compaction machines*, which are used in landfill work. The objectives of this project are :

Volume accounting :

- Daily, monthly and/or yearly determination of the actual volume of the landfill body
- Control of the emplacement process : Estimation of the remaining volume within the permitted dimensions of a landfill site.

Optimization of the emplacement technology :

- Estimation of the achieved density of the compaction process
- Guiding the efficient use of the compaction machinery, i.e. limitation of the crossings to a minimum