Integrated Tunnelling Data Management, Analysis and Visualization
New IT Tools for Better Projects

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Abstract: This paper presents the tunnel information system Kronos developed to integrate, manage and utilize underground construction project data. The experiences gained from implementing, maintaining and daily use of this information system in large European metro construction projects as for example in Budapest, Athens and Thessaloniki are reported. Especially highlighted are the particular benefits arising from integrated automatic services supporting monitoring, alarming and reporting operations on site. Finally, new interactive virtual reality visualizations that can be produced by the information system to support the interpretation and understanding of tunnelling processes are shown and discussed. The conclusion summarizes Kronos as an efficient and useful IT tool contributing to an economic and safe tunnelling.

1. Introduction

In tunnelling projects today we are confronted with rapidly growing amounts of many different kinds of data. These data are produced in different ways, formats, at different times and places, by different parties and sources. The situation is complex and often causes a data chaos on site where severe problems arise from data loss, inconsistency, redundancy and non-actuality. To fight these problems, the tunnel information system Kronos allowing for integrated data management, analysis and visualization has been developed. Its aim is to make construction projects safer and their data generally better managed and utilized.

Fundamental parts of the Kronos system got developed in the course of two research projects, TUNCONSTRUCT [1] (funded by the European Commission under its 6th framework programme, 2005–2009) and VSOE (Vienna Spots of Excellence, funded by ZIT, the Center for Innovation and Technology, Austria, 2008-2010). The system has already been transferred to the market and found its way to tunnelling practice some years ago. Meanwhile, experiences from various project installations can be reported. In particular, these installations include the current big European metro projects at Budapest, Athens and Thessaloniki. In what follows, the system is shortly presented, the site installations and the gained experiences are described and the overall system benefits summarized. Finally, the recently added virtual reality visualizations are shown.

2. KRONOS - Tunnel Information System

Kronos [2] is an information system based on latest relational database technology (MS SQL Server). It got specially designed and developed for underground construction to allow for the management of any kind of digital data produced in the course of a tunnelling project. To accomplish this, Kronos can handle all relevant data categories found in tunnelling. Authorized users can access these data through two front ends, a local client application (Kronos Client) and/or a web site (Kronos Web) (see Figure 1). By use of these front ends, all required data management operations such as data input and output, import and export, etc. can be done either interactively or by making use of automatic data upload and download services. A variety of data exchange formats is supported.

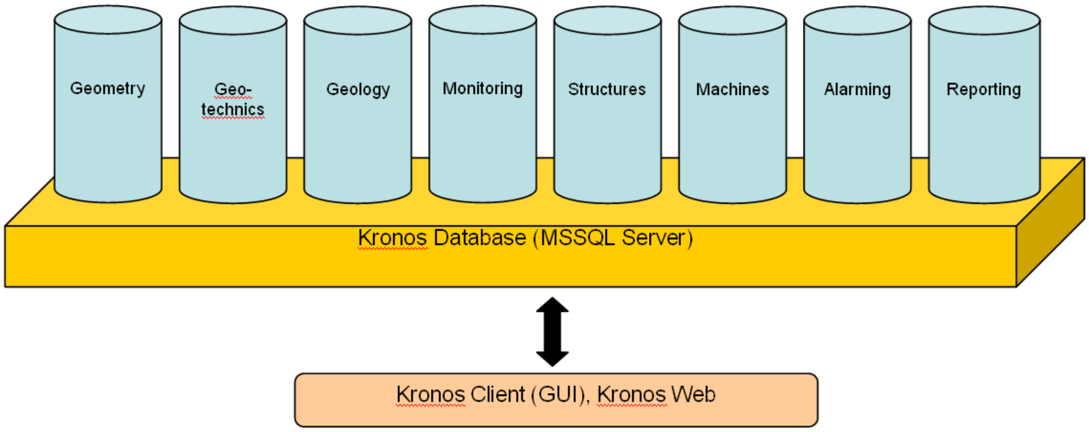

Figure 1: KRONOS data categories and components (database and user interfaces).

For monitoring, alarming, reporting, analysis and visualization several database applications and data services have been developed. They can be configured individually and flexibly with regard to the given project requirements.

3. KRONOS implementation for Metro Budapest – Line M4

The new line M4 of Budapest Metro (see Figure 2) connects the districts Kelenföld in Buda and Rakospalota in Pest. The line has a length of 7,2 km with 10 stations. The excavation of the two parallel running tunnels is done with two tunnel boring machines each having a total length of 113 m and a cutter head diameter of 6,1 m. Difficult geological conditions on the side of Pest, the underpassing of historical buildings and the crossing of the river Danube with low overburden are big challenges for the engineers making necessary the execution of an extensive geotechnical monitoring program.

Geodata has been contracted by the construction consortium Bamco Kft. to install Kronos as an alarming system for the monitoring carried out. In the project, the monitoring is based on daily, manual measurements that are carried out with typical sensors such as totalstations, levels, tilt meters, inclinometers and rod extensometers. Nearly 10.000 monitoring points are spread over the entire project area. In a daily routine, monitoring data files are transferred via ftp-upload from Budapest (Hungary) to the Geodata office in Graz (Austria), where the Kronos database server is run. There, automatically, all files are quality-checked, their data imported into the database and further provided to an alarming service. This service permanently executes 260 alarm rules of 3 alarm levels (warning, alert, alarm) and, in case, immediately sends alarm messages (via SMS and/or e-mail) to about 30 different alarm receivers back on site.

As the system not only can manage monitoring data but also further data like the TBM progress, an extended and dynamic alarming can be performed. As an example, it can be changed the alarm thresholds of monitoring points dynamically and automatically with respect to their current distance to the actual TBM position. Monitoring points can thus be switched to a higher 'level of interest' and also be displayed accordingly in the graphic user interfaces.

Special in this project is that Kronos is operated following a server hosting concept where data is no longer stored locally on site but transferred over hundreds of kilometers (even across a state border) to a remote, sub-contracted data management center that can only be accessed via internet. The whole system is easily maintained by one system administrator.

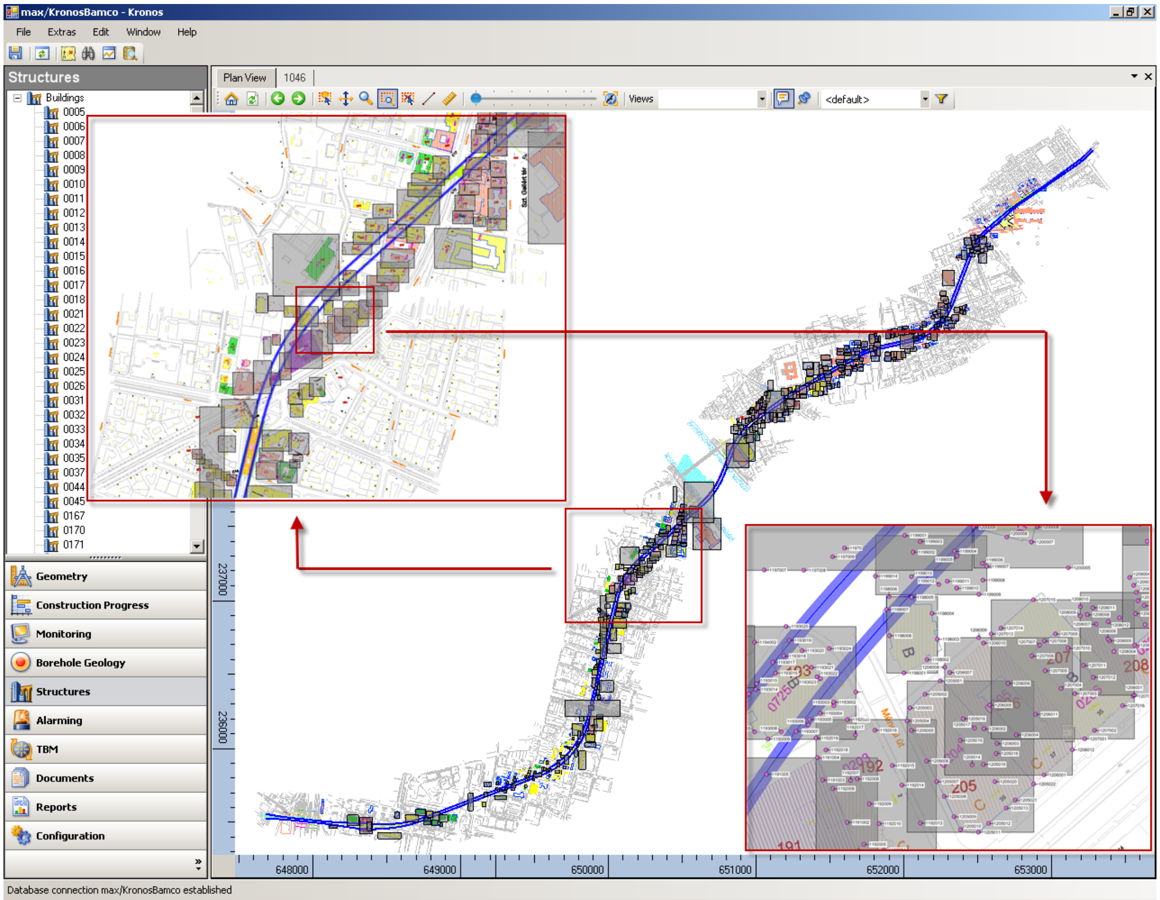

Figure 2: KRONOS Client displaying the Metro Budapest area, zoom into areas of interest.

From March 2006 to November 2009 the Kronos database has grown to 8.8 GB of size storing more than 5.000.000 monitoring measurements (sensor readings).

Our practical experiences at Metro Budapest so far have been:

- System installation and maintenance have been difficult at the beginning of the project. It took several months and some effort until the monitoring data producers/providers could (or were willing to) deliver their data according to the requested data format. This was due to contractual rather than technical problems as the use of Kronos initially was not planned but decided some time after project start. Feeding in data produced extra work for the data providers. In addition, it took some time for the system administrator to get rid of mistakes and errors in the data files provided.

- Since this starting phase the system runs smoothly and maintenance has become routine work. Although server hosting has been a new experience for all involved parties it has proved feasible and successful. Alarming is performed reliably without producing false or missing alarms. The geographic distance between data producers/receivers and data storage/management could be bridged via internet without problems worth mentioning.

4. KRONOS implementation for Metro Thessaloniki

The currently built Thessaloniki metro network (see Figure 3) comprises 13 modern center platform stations and 9,5 km of line (with two independent single track tunnels) constructed mostly (7,7 km) by means of two tunnel boring machines. The remaining section of the line is constructed by the cut and cover method.

Figure 3: Metro Thessaloniki area.

Geodata has been contracted to install Kronos locally on a site server to serve as the project's Geomechanical and Structural Monitoring Database (GSMDB). Compared to Budapest, in this project the system additionally has to control various online monitoring sensors, to manage the data of surface structures (e.g. buildings), boreholes, TBMs, etc. and to serve as a document management system. In addition to the alarming service also a reporting service is integrated that can automatically create monitoring reports out of the database and provide them to the responsible experts. With this service it is no longer necessary to daily search for and manually put together all data needed for interpretation as all relevant data is extracted from the system and provided automatically. On site, more than 30 different users (experts from the client and contractor) are connected to the system and benefit from its services.

To guarantee the safety of the overlaying and adjacent buildings and to verify the assumptions made during the project planning a huge geotechnical monitoring program is executed. It especially employs numerous automatic monitoring sensors such as geodetic totalstations (see Figure 4) that measure hundreds of 3d targets installed on building facades, tunnel walls, on the ground, etc. every few minutes.

Figure 4: Online totalstations monitoring deformations underground and on the surface.

Figure 5 below shows the monitoring statistics of the project in more detail. From May 2007 to November 2009 the Kronos database has grown to 86 GB of size storing 11.360.000 measurements from 7.600 monitoring sensors as well as the data of about 350 boreholes and 500 buildings. In addition, each of the two TBMs transfers 319 parameters every 10 seconds online into the database. More than 300.000 documents (images, protocols, reports) are meanwhile stored in the document management section of the information system.

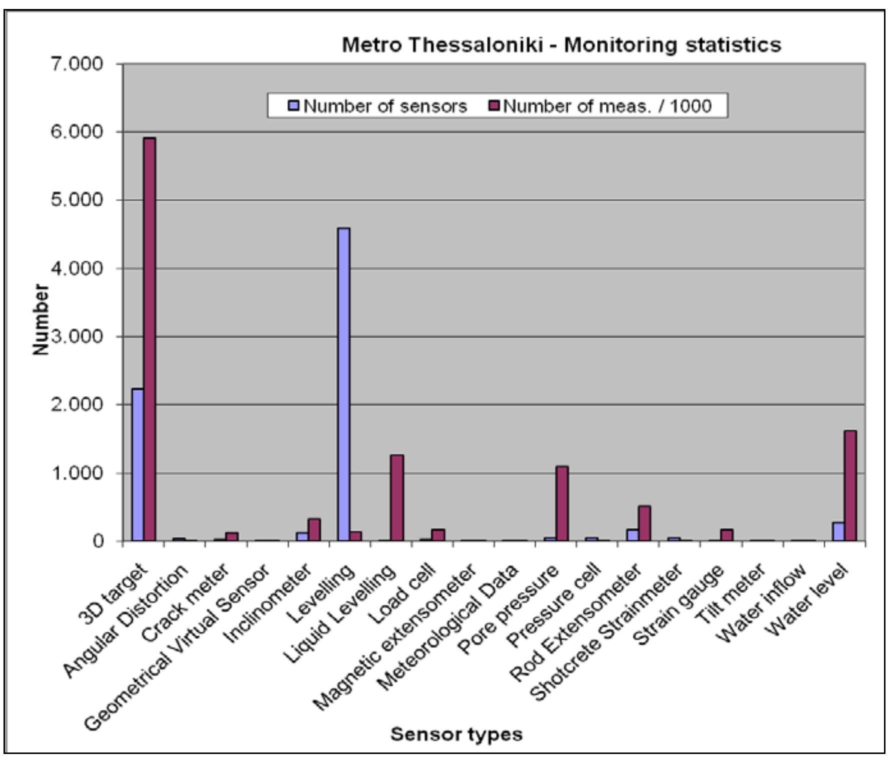

Figure 5: Monitoring statistics of Metro Thessaloniki.

Our practical experiences at Metro Thessaloniki so far have been:

- System installation has been a stepwise process finally taking more than a year until all desired system features and functions could be made available. This process basically has been delayed due to unclear initial system specifications and also new desires that came up during the project. Additional software had to be developed and several updates made until reaching a final system version that satisfied all parties.

- As the system server is deployed locally on site, Kronos is maintained by local staff. As system developer, Geodata can access the system remotely via internet for administrative reasons, so for example to install new updates or to check system performance and integrity. No severe problems have been encountered since the beginning of the project. The system and all its services (most importantly the alarming) run without interruptions or breakdowns. Data safety is guaranteed by a second backup server.

5. Conclusion

The described examples of two major urban tunnel sites represent best practices of how modern information technology is applied to efficiently support tunnelling data management. Of particular benefit is regarded the concept of integrating all project data into one central data management platform and establishing a systematic and automatic data transfer from and to this platform. This makes possible the integrated use of data for analysis and interpretation purposes. The presented system Kronos enables all connected users (experts) to access project data in a modern and comfortable way, either locally or remotely. It offers useful automatic services like monitoring sensor control, alarming and reporting that essentially contribute to a safe and economic tunnel construction. To further extend and enhance the system, integrated data visualizations are under development among which also virtual reality techniques play an important role [3]. In the following outlook, these new visualizations and their particular characteristics and benefits are explained.

6. Outlook: Virtual reality visualization

In order to enhance the presentation and visualization capabilities of the Kronos system virtual reality techniques have been tested and implemented as a prototype viewer application. These new techniques allow for combining different Kronos data sources and make possible individual walkthroughs of 3-dimensional tunnel models. Their main advantage is that they contribute to a better understanding of a planned or already built tunnel and also the tunnelling processes going on. The different data sources so far include:

- 3d tunnel models (e.g. automatically processed from analytical tunnel axes and profile data or derived from laserscan data),

- 3d geological ground models (e.g. a CAD model produced by geological experts, maybe also including orthophoto images or topographic maps of the surface),

- other 3d models (e.g. for tunnel equipment like lights, generators, ventilation, etc.),

- measured or predicted displacement vectors,

- real images or manual drawings (e.g. of the tunnel face),

- construction progress documentation.

Below Figures show some visualization examples for the data mentioned above and describe their purpose of use.

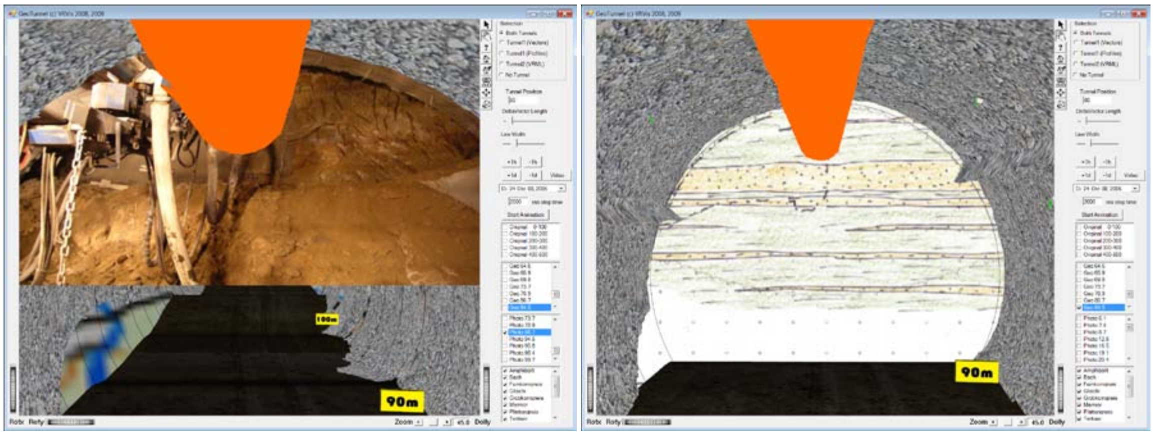

Figure 6: Prototype viewer showing a 3D model of a tunnel (rendered from laserscan data) combined with a real image (left) or a geological sketch (right) of the tunnel face.

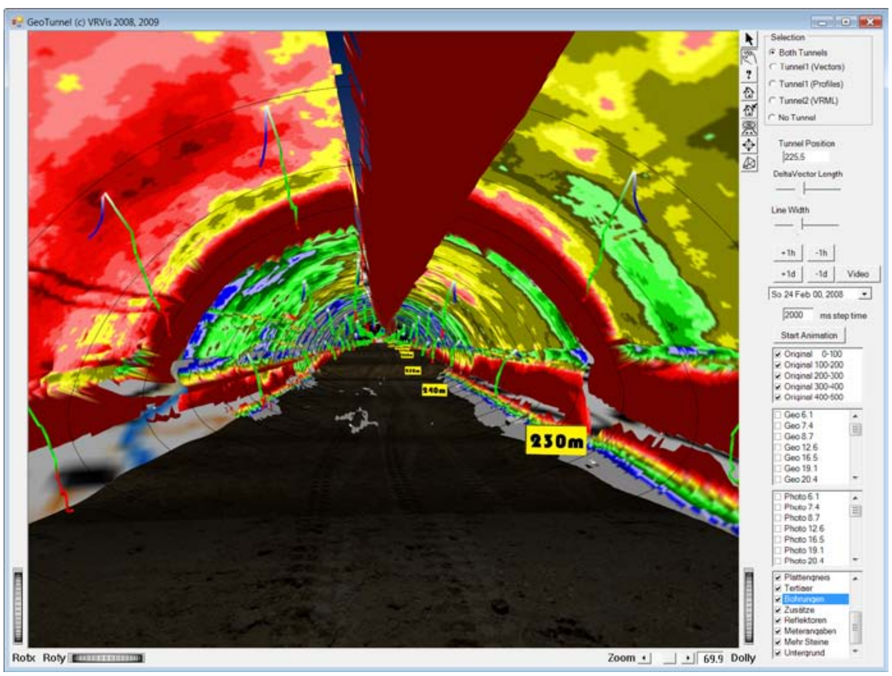

Figure 7: Prototype viewer showing a 3D model of a tunnel (rendered from laserscan data) combined with measured and predicted displacement vectors as well as with colour-coded data mapped on the tunnel wall (e.g. the actual degree of shotcrete utilization).

During the construction phase of a tunnel 3d displacement vectors are measured and have to be continuously compared with their predictions calculated during tunnel design in order to verify the design assumptions and to assure safety. Both vectors can be displayed within the 3d model in a time-dependent way meaning that their growth with time can be watched interactively by the user. Fading in tunnel face images and geological face sketches at certain tunnel stations can help to understand strange (local) displacement behaviour (e.g. deviations from what was expected).

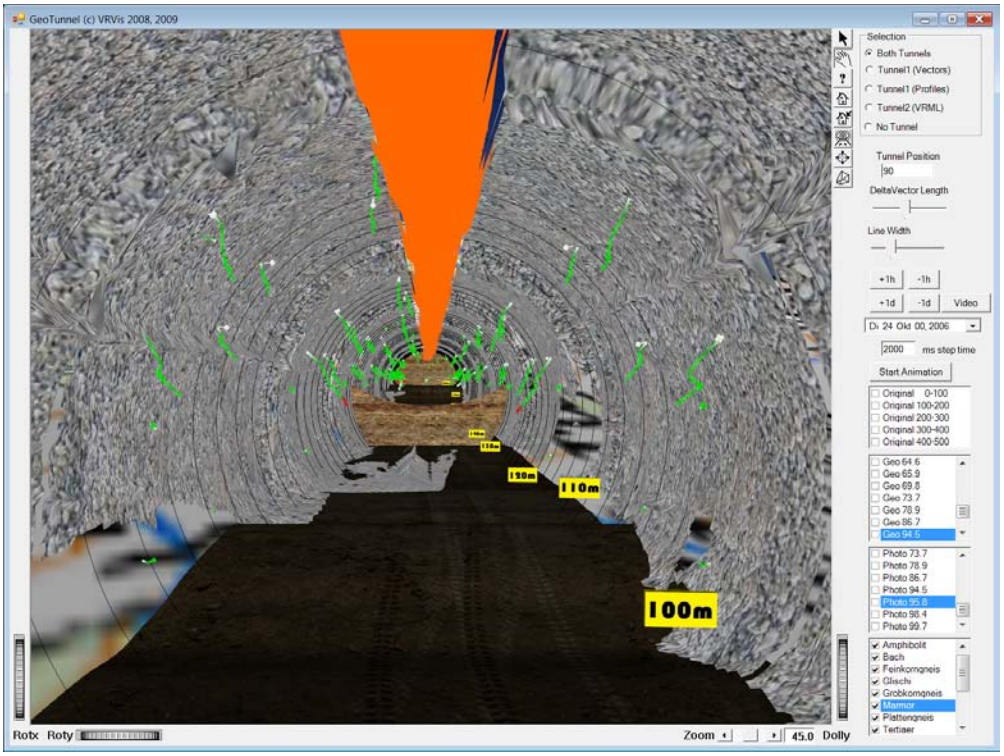

Figure 8: Prototype viewer showing a 3D model of a tunnel combined with two tunnel excavation faces (top heading and bench) and measured displacement vectors.

The growth of the measured displacement vectors, in particular their speed, highly depends on the actual position and progress of the tunnel faces. This dependency can be watched by animating the excavation progress (by moving the tunnel faces stepwise forward) and the displacement vectors simultaneously. It can be interpreted if the tunnel's stabilization behaviour is as expected and normal.

Furthermore all these renderings are easily extendable to use 3d stereo rendering methods (e.g. passive stereo with polarized glasses) to gain even more insight into the visualized tunnel and combined data. The users are then fully immersed in this virtual tunnel environment.

References

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