3D Overarching Scientific Information System for the FE experiment

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Summary

Comprehensive monitoring programs include numerous sensors using both standard fixed point "static" sensors and newer technology sensors such as fiber-optic distributed temperature sensing (DTS). Management and overview of the hardware, installation, operation and monitoring becomes challenging in larger experiments. Monitoring often continues for years and measurements can be recorded frequently. Over time, billions of measurements can be recorded making the data processing for review, evaluation and analysis both labour intensive and time consuming.

Nagra implemented the Full-Scale Emplacement (FE) experiment at the Mont Terri rock laboratory to demonstrate as realistically as possible the construction, waste emplacement and backfilling processes for a spent fuel / high level waste disposal tunnel according to the Swiss repository concept at a 1:1 scale. The FE experiment is a long-term heating experiment currently 4 years in operation and monitoring is foreseen for more than 10 years.

With more than 1 million measurements recorded each day the FE experiment data quickly overwhelmed standard desktop software. We developed the OASIS – Overarching Scientific Information System to manage all the FE information (construction details, monitoring data, geophysical logs, chemistry data and documentation). The system consists of a high-speed client server database and web app that runs on any computer with a modern internet browser. Review, evaluation, plotting, reporting and data export are fast even with the nearly 2 billion measurements recorded to date. Nagra refers to the OASIS system for the FE experiment as the FE Information System (FEIS).

The DTS system records measurements related to a fiber optic cable length. FEIS calculates the physical 3D position of the measurements along the cable within the FE experiment on-the-fly at run time. Temperature measurement accuracy from the DTS system was greatly improved by deriving values using the DTS raw Raman backscatter measurements (Stokes and anti-Stokes) with coefficients determined using a comprehensive calibration system.

Centralizing the project information promotes transparency, consistency and accountability. Relating data together allows investigators to correct inconsistencies so more spatially and temporally accurate information are available. The system also improves findability, accessibility, interpretability, and reuse of the digital assets. Archives of the database and

monitoring system data files collected by the data-pipeline are automatically produced, improving long-term care of the valuable digital assets. Relating data together within the database is a benefit to the experiment. The web browse app allows password-controlled access to the project data and documentation for all stakeholders.

1. Introduction

Large scale experiments in underground rock laboratories, e.g. experiments on coupled thermal-hydraulic-mechanic processes, include comprehensive monitoring programs with many sensors using both standard fixed point "static" and newer technology sensors such as fiber-optic distributed temperature sensing (DTS) for temperature measurements and time-domain reflectometry (TDR) for water content measurements. Management and overview of the hardware, installation, operation and monitoring becomes challenging in larger experiments. Monitoring often continues for years and measurements can be recorded frequently. Over time, billions of measurements can be recorded making review, evaluation and analysis of the data challenging and time consuming.

The Full-Scale Emplacement (FE) experiment at the Mont Terri rock laboratory [1] was implemented to demonstrate as realistically as possible the construction, waste emplacement and backfilling processes for a spent fuel / high level waste disposal tunnel according to the Swiss repository concept at a 1:1 scale (Fig. 1). Three electrical heaters were installed on bentonite blocks in the tunnel to simulate the heat output of nuclear waste canisters. After installation the tunnel was backfilled with granulated bentonite material. The 2.7m (diameter inside shotcrete) x 50m tunnel and surrounding rock (Opalinus Clay) are instrumented with more than 1800 static sensors, 2.4 km of fiber optic cables for DTS, TDR sensors and monitored boreholes. The sensors are distributed in boreholes, in the tunnel lining, in the bentonite buffer surrounding the three electrical heaters as well as in and on the heaters themselves.

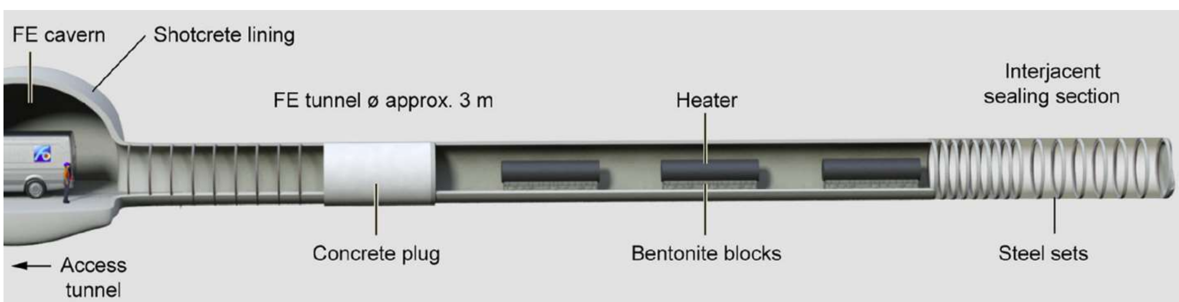

Figure 1: Visualisation of the general layout of the FE experiment and the 50 m long FE tunnel at the Mont Terri Rock Laboratory; sensors, bentonite backfill and rock bolts are not shown. Figure taken from [1].

The FE experiment is a long-term heating experiment currently 4 years in operation and monitoring is foreseen for more than 10 years. Long-term monitoring of boreholes started in 2011 and long-term monitoring of the complete experiment started in 2014. The heating phase of the FE experiment was initiated at the end of 2014. The measurement intervals of the different sensors vary between every 5 mins to every 4 hours. In addition, manual measurements and chemical analyses are periodically made.

The more than 1 million measurements recorded each day at the FE experiment quickly overwhelmed standard desktop software. We developed the OASIS – Overarching Scientific Information System to manage all the FE information (construction details, monitoring data, geophysical logs, chemistry data and documentation). The system consists of a high-speed client server database and web app that runs on computer with a modern internet browser. Review, evaluation, plotting, reporting and data export are fast even with the nearly 2 billion measurements recorded to date. The OASIS system is called the FE Information System (FEIS) in the FE experiment [2].

2. FEIS design

FEIS joins data sets from across different data acquisition systems allowing access to the data from all monitoring platforms. The system is "overarching" because it centralizes all information (data and documents) in one location.

FEIS consists of 3 main components:

1. Data-pipeline: Transforms the raw data coming into actionable and meaningful information. Automatically collects monitoring data from multiple contractors with different file formats and recording rates. Verifies and evaluates the data, assigns rich meta-data to the measurements, sends alarms when measurements exceed limits or go missing and makes the data available just minutes after being collected.

2. Database: Open source object relational PostgreSQL database with PostGIS and statistical R language extensions. The database extends GIS by modeling the project in 3D space. The statistical R language extension allows high-level statistical analyses to be done directly within the database. The database also includes a document content management system with complex and complete document search functionality, with keyword and full text searches that are independent of grammatical structure.

3. Web browser app: Charts and tables are fast, dynamic and interactive. Plots can be zoomed and scrolled, tables searched and sorted. Charts, tables and even drawings are created dynamically on-the-fly so any change in the project is immediately seen when the web page is refreshed.

FEIS represents the FE experiment in a virtual 3D space (Fig. 2) using custom spatial operators developed with the power of advanced PostgreSQL features such as operator overloading (these operations cannot be done so easily in other databases). The database uses geometric objects and custom linear algebra operators to work with the data and calculate spatial relationships between objects. Users can easily change between 2 sets of local coordinates (gallery meter, FE coordinates) and the official Swiss grid because the database translates coordinate systems. These features separate FEIS from conventional Graphical Information System (GIS) database systems which are primarily based on 2D mapped data.

Determining spatial relationships using a standard information database would involve complex mathematics and complex database queries. The project 3D model with custom spatial operators allow simple database queries which help to avoid errors. There is no need to store information like "sensor A is in borehole B" in FEIS. Instead FEIS simply calculates that sensor A is within borehole B. This makes FEIS very dynamic. When there is a change in the project (for example a sensor is moved) only the sensor coordinates need to be updated. FEIS calculates all spatial relationships at run time (on the fly). As a result, calculations, table data, plots and even drawings are automatically updated.

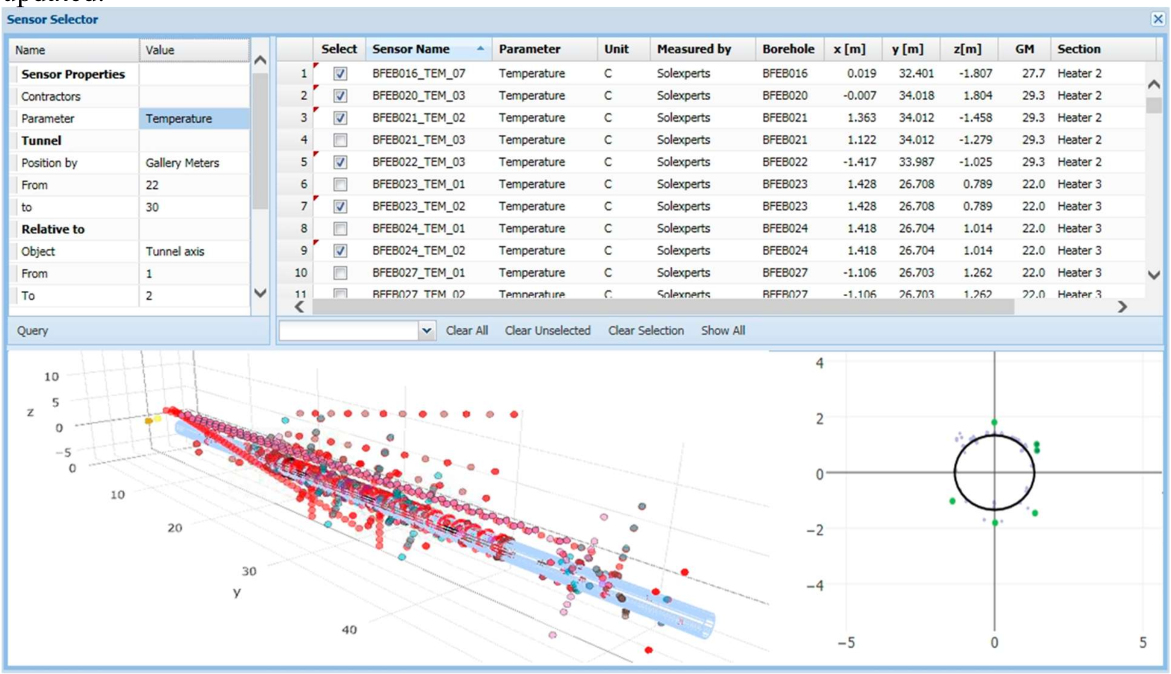

Figure 2: *Sensor selection window showing spatial and non-spatial selection fields with a sensor selection table with sortable columns.*

The web browser app is a single page Internet browser application providing easy, fast and efficient review, analysis and reporting. It runs in any modern internet browser. Manual measurements can be entered, chemical analysis spreadsheets uploaded and users can define mathematical expressions (calculations, functions and statistics) using sensor measurements as variables. Data are associated with rich meta-data making it easy to plot, report and calculate with only representative data. No data is deleted – the meta-data are simply marked as not valid. If the data are later determined to be representative then their meta-data is changed.

3. Data management with increased quality

Centralizing the project information promotes transparency, consistency and accountability. Problems of multiple versions, out-of-date documentation and data, inconsistent nomenclature, difficult to find documentation, etc. are significantly reduced.

Discrepancies in construction, nomenclature and monitoring details can easily be overlooked when data are stored in spreadsheets or multiple reports. Data quality can be difficult to evaluate. Relating data together allows investigators to correct inconsistencies so more spatially and temporally accurate information are available.

Spatially relating the 3D position of sensors, boreholes and other project components together corrects errors in survey coordinates easily missed by reviewing rows of coordinate values. The database brings structure and consistency to the project and normalizes monitoring and testing activities, which results in improved data management and stewardship. The system also improves findability, accessibility, interpretability, and reuse of the digital assets. Archives of the database and monitoring system data files collected by the data-pipeline are automatically produced, improving long-term care of the project's valuable digital assets. Relating data together is a benefit to the experiment. The web browser app allows password-controlled access to the project data documentation for all stakeholders.

4. 3D model and DTS measurements

The FE experiment's comprehensive monitoring program includes innovative DTS technologies. The DTS method provides a continuous temperature profile along several fiber optic cables that are routed in boreholes and along and round the tunnel wall. DTS has the advantage in long-term monitoring over conventional electrical "point-type" temperature because the temperature sensing involves only glass fiber and not delicate electronics. The DTS measurement unit (containing a laser and detection electronics) is outside of the sealed tunnel and can easily be replaced in case of defect.

The DTS system records measurements related to a fiber optic cable length. Using a process referred to as fingerprinting (heating the cable locally at know locations and noting the measured cable lengths where the responses are observed) the relationship between the DTS system cable length measurements and FE experiment coordinate system are determined.

FEIS calculates the physical 3D position within the FE experiment on-the-fly at run time using the project 3D model, custom spatial operators and the cable fingerprints. A large volume of DTS data is produced because several measurements are performed per day with sampling data recorded at intervals 0.05 – 1.0 m. FEIS stores the measurements in advanced data structures making it possible to report the DTS measurements with charts and tables within seconds.

FEIS reports the DTS measurements from three perspectives: as a profile showing temperatures within the tunnel at a given time; as a time-series showing the change in temperatures at a given point over-time; or as temperatures along the cable at a given time. Being able to view the DTS measurements from all three perspectives results in unique, detailed insights into the temporal and spatial variations of the temperature field in and around the heated FE tunnel.

The DTS measurements can be shown in FEIS as a 2D thermal map as well as a 3D thermal map spatially oriented around a cylinder representing the FE tunnel. Figure 3, below, shows a more detailed prototype 3D view of the experiment with a semi-transparent thermal map wrapped around the tunnel and static temperature sensors. Because the drawing is created by the database system the drawing is dynamically updated when data change.

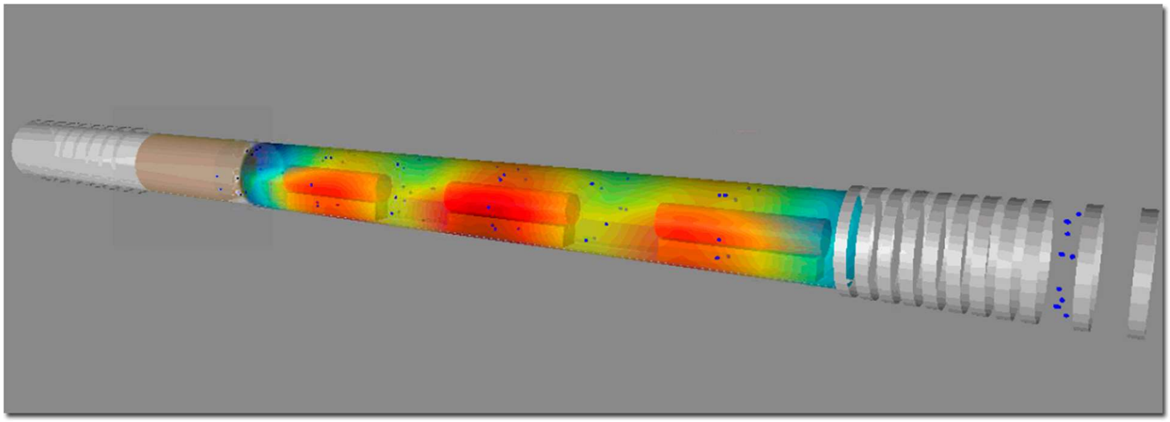

Figure 3. FEIS generated spatially correct 3D drawing of the FE tunnel with a semi-transparent thermal map and static temperature sensors (blue dots).

5. Improved DTS accuracy

Temperature measurement accuracies from DTS system were greatly improved by deriving values using the DTS raw Raman backscatter measurements (Stokes and anti-Stokes) with coefficients determined using a comprehensive calibration system. Two water baths covering the expected experiment temperature range were permanently installed near the FE tunnel and the fiber optic cables were routed through the baths. Conventional high precision temperature sensors automatically measure bath temperatures and the acquired data are collected and appended to FEIS by the FE data-pipeline allowing for calibration of the DTS system [3].

The location of step losses (abrupt decreases in light signal strength along each cable due to cable damage, splices or sharp cable bends) were determined using optical time domain reflectometry (OTDR). FEIS compensates the raw DTS measurements for step losses and determines bath temperatures corresponding to the time of each DTS measurement. Then, with the equations described by [4], FEIS calculates “dynamic” calibration coefficients for each cable measurement using the raw DTS measurements taken along the cable segments within the baths and the bath temperatures.

FEIS calculates temperatures on-the-fly using the raw DTS measurements and the dynamic coefficients each time the users request the data. The system is dynamic – if a new equation is used or parameters are changed then the temperature values are simply recalculated the next time the data are requested. The calculated temperatures are traceable because all parameters used to derive the values are stored with the measurement in the database. The process is based on optimized SQL procedures and is extremely fast. The resulting temperatures have an average measurement accuracy of 0.1 - 0.3°C depending on fiber optic cable type and DTS unit, Fig 4.

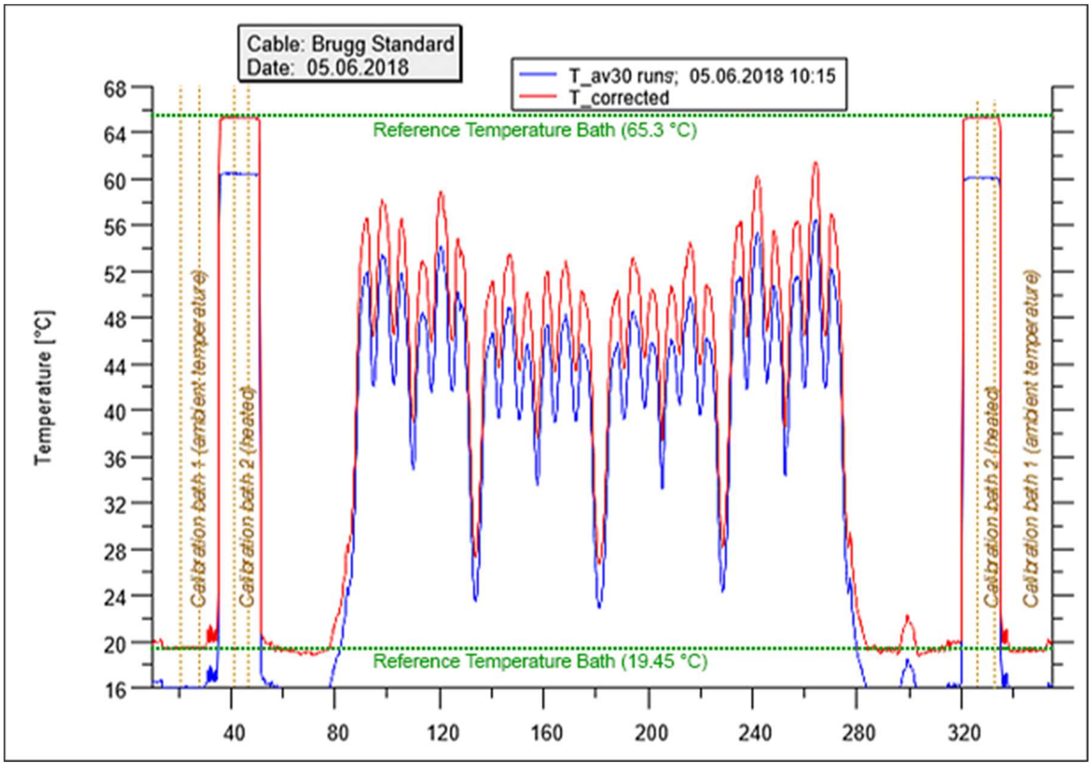

Figure 4. *DTS temperatures vs temperatures derived from the DTS raw Raman backscatter measurements (Stokes and anti-Stokes) with dynamic coefficients.*

6. Conclusion

Monitoring the FE experiment with more than 1 million measurements recorded daily led to the development of OASIS – Overarching Scientific Information System to manage all the FE information (construction details, monitoring data, geophysical logs, chemistry data and documentation). The FE experiment refers to the OASIS system as the FE Information System (FEIS). FEIS provides fast review, evaluation, plotting, reporting and data export, even with the nearly 2 billion measurements recorded to date.

FEIS represents the FE experiment in a virtual 3D space extending the system beyond conventional Graphical Information System (GIS) database systems which are primarily based on 2D mapped data. The DTS system records measurements related to a fiber optic cable length. FEIS calculates the physical 3D position on the measurements along the cable within the FE experiment on-the-fly at run time. Temperature measurement accuracies from DTS system were greatly improved by deriving values using the DTS raw Raman backscatter measurements (Stokes and anti-Stokes) with coefficients determined using a comprehensive calibration system.

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