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The Florence High-Speed Railway Hub: 4D monitoring – innovations in data acquisition and data management for tunnelling projects in sensitive urban areas

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ABSTRACT: Main construction work for the Florentine “Nodo di Firenze” high-speed railway hub started in 2010. The tunnel boring machine (TBM) transitions through extremely variable geological terrain and excavations along the entire length of the hub take place below water level. The 6.5 km long underground railway line is being built underneath the city’s critical infrastructure components and historic buildings. Due to the geological complexity of the area, settlements can be expected following tunnel excavation. Hence, this urban tunnelling project requires special supervisory measures. It was necessary to identify potential hazards at a very early stage and to mitigate their impact. The client required a comprehensive analysis of the monitoring data at short notice – especially during the tunnel advance stages, including online post-processing and the interpretation of all automated and manual measurements. These challenges were met by using the proven swissMon core technology for web-based deformation monitoring. This White Paper outlines how the workflow for manual measurements was optimised using the innovative tManual software. The software enables on-site personnel to safely upload validated measurements to swissMon from any location at any time. Illustrating the monitoring workflow, this White Paper focuses on the data management needed to provide data for online post-processing. The real-time monitoring data and the post-processing procedures that are described in a second paper enabled project engineers to make informed decisions.

1 Introduction

As a part of the new Italian and European high-speed rail network, a high-speed railway hub is currently under construction in Florence, including a new station and a city railway underpass featuring twin single tracks.

Tunnelling projects in urban areas require special supervisory measures to ensure compliance with safety requirements. Construction work in close proximity to critical existing infrastructures, including residential and commercial areas, can have a profound impact on building structures, human safety and commercial logistics, such as traffic flows. The complex subsoil conditions in Florence (extreme spatial variability of soils) as well as the building infrastructure and the historic heritage, said to be among the greatest in the world, represented a particular challenge.

To address this challenging monitoring task, the Italian “Associazione temporanea di Impresa” (ATI) consortium designed and implemented a comprehensive monitoring system using a wide variety of geodetic and geotechnical sensors in combination with a web-based monitoring platform. terra international ltd. provides the swissMon monitoring platform for real-time construction monitoring. SwissMon had already proven its worth for this type of project during the construction of the Zurich Cross-City Rail Link in Switzerland.

This paper provides an overview of the monitoring system used, highlighting innovations in data acquisition and data management needed to meet the project requirements. It places particular emphasis on the optimized workflow regarding the integration of manual measurements and virtual data calculated by the online post-processing software.

2 Project Overview

Italferr, a member of the government-owned Italian railway holding responsible for planning and controlling the completion of infrastructure and technological projects, started working on the Florence Hub in 2004. The Florence Hub is one of the major railway facilities on the high-speed / high capacity (HS/HC) Milan-Rome main line. Not only is the Florence Hub of nationwide importance, it also serves as a transportation hub for all major regional Tuscan railway lines and constitutes the core of the Metropolitan Regional Railway System (Italferr 2012).

Thanks to the work on the HS/HC high-speed train line a new through station at Belfiore will be added to the main S. M. Novella station to reduce scheduling conflicts between various transportation systems. In addition, the new line will provide a significant capacity increase for the existing railway line and will be used to develop regional and metropolitan traffic lines.

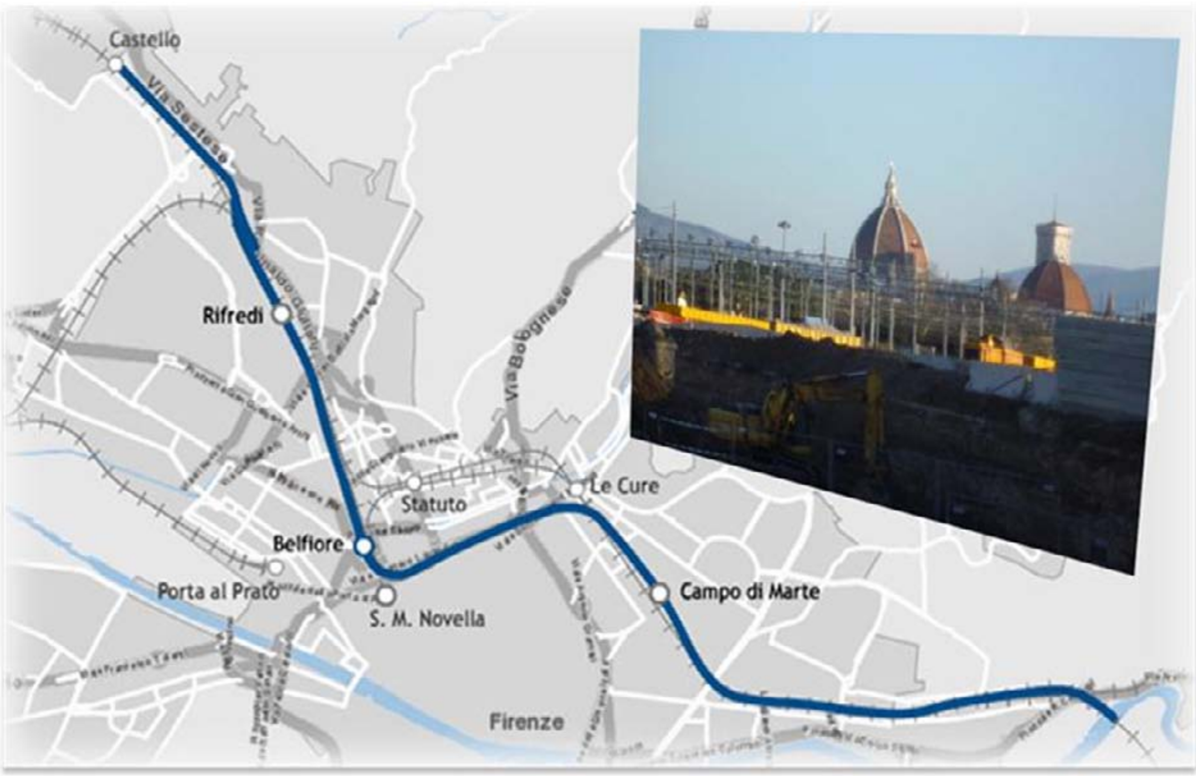

Figure 1. Nodo di Firenze – Florence HS Hub Project Overview (Italferr 2012)

Basically, the project is divided into two major sub-projects:

- The “Passante AV” tunnelling works
- The “Firenze Belfiore” underground station

The tunnelling work for “Passante AV” starts at the Campo di Marte station. From there, the tracks will run to the Belfiore underground station, located to the north of the city’s main station S. M. Novella. From Belfiore the tunnel proceeds north, reaching the northern entrance near Rifredi station (see Figure 1).

Each of the TBM-driven single-track tunnel sections is about 6.5 km long and will have a diameter of 9.4 m (circular section). The tunnels are excavated at depths from 10 m to 27 m and are scheduled to be put into service in 2015.

The new Belfiore station, designed by Norman Foster and engineered by Arup, will be 25 m below city level inside a 454 m long and 52 m wide box with reinforced concrete diaphragm walls. The station’s roof consists of a 450 m long cylindrically-shaped steel structure with a diagrid surface pattern. The roof will be built using a top-down construction method to comply with environmental requirements (Raschillà et al 2012). Construction work for the station is scheduled to be completed in 2016.

As pointed out by Raschillà et al (2012), the first half of the tunnel is expected to be the most critical part of the construction project. The TBM will proceed in an urban area, underpassing a bridge, the railway line to Milano and many structures, including hospitals, public buildings and famous monuments like the “Fortezza da Basso”, a Renaissance fortress built between 1534 and 1537.

Passive and active protection measures have been designed to protect existing buildings, bridges and rails. In particular, compensation grouting is planned in the southern part of the tunnel, where it is going to pass underneath buildings over a distance of 5 to 10 meters. Additional safeguards were established about 3 km north of the southern railway portal to protect the ancient Fortezza Da Basso.

More detailed information regarding the construction and the project management of the construction work for the Florence high-speed railway hub can be found in the paper presented by Raschillà, A. and Severi, M. at WTC 2012 session.

Figure 2. The South Entrance of the Campo di Marte prior to TBM Drilling

3 “Nodo di Firenze” Deformation Monitoring

3.1 Objectives

Tunnelling projects in urban areas require special supervisory measures. Supervision consists of:

- Observing the situation and keep it under systematic review
- Evidence preservation
- Avoiding damage to existing infrastructures, buildings or the environment
- Identifying potential hazards at a very early stage and mitigating their impact
- Optimising construction techniques

Fulfilling these objectives requires an integrated monitoring system that combines sensors and technologies from different areas of expertise, including geotechnical, geodetic, environmental (chemical) and geophysical methods.

Using available methods and technical options, the monitoring system addresses two essential goals:

1. Impact monitoring: Observation, alerts and evidence preservation. Results are used to allocate responsibilities, identify possible causes for claims or residual risks.

2. Design monitoring: Using important indicators to optimise methods and processes in accordance with EC7.

Today, monitoring systems handle huge amounts of data that need to be processed and visualised for different stakeholders or with regard to different objectives in near real-time. At the same time, monitoring systems automatically process data, compare measurements as well as (post-processed) derived thresholds and triggers to inform stakeholders in a timely manner about events or additionally required measures.

Web-based monitoring platforms are used in major state-of-the-art installations to master these challenges. The stable operation of such platforms is a prerequisite, irrespective of the number of measurements taken or the number of connected sensors.

3.2 Requirements

A comprehensive monitoring system using state-of-the-art sensors and digital data transmission that serves as a passive safeguard is being installed and operated in the entire railway hub construction area. Table 1 contains an overview of the sensors and the requirements for monitoring systems used in Florence.

Table 1. Monitoring System Requirements

Measurement Systems	
Automatic Measurements	Manual Measurements
27 total stations covering >3000 targets	2100 levelling points
400 hydrostatic levelling cells and inclinometers	2000 measuring points for manual 3D measurements
66 extensometers	59 vertical inclinometer measuring points
54 piezometers	28 convergence measurement points
75 load cells	Various ground water measurement points
60 fissurometers	
>1100 strain gauges	
Boundary Conditions	
Measurement interval: 10 to 120 minutes	Measurement interval:
Operating schedule: 24/7, 365 days a year	According to the monitoring plans
Project duration: 4 years	
Continuous online access to monitoring data	Online access to measurement data within 24 hours
Processing of >270’000 datasets per day	

In addition to the above requirements, the client requested online calculations to be derived from the measured values. Almost 150,000 manual and automatic measurements are performed and approximately 120,000 parameters are derived on a daily basis. Hence, about 270,000 parameters need to be checked daily for potential threshold exceedance.

To meet those requirements, the proven swissMon monitoring system developed by terra was used. Additional features were added to efficiently integrate manual readings and calculation methods into the system.

3.3 swissMon – 4D Monitoring

This section introduces swissMon, the web-based monitoring platform, deployed throughout the project to automatically record, analyse and display thousands of datasets that are generated both manually and automatically by geotechnical and geodetic sensors every day.

The system has been in operation since 2010 and will be used to monitor the entire alignment. Measurements, for example, convergence measurements, will be taken both underground and above ground, where approximately 150 buildings are scheduled for monitoring. Defined cross-sections will be measured before, during and after the TBM advance, depending on the TBM location.

The structure of swissMon is completely modular and therefore adapts to any project type and size. It includes interfaces for all relevant geodetic and geotechnical sensors. Due to its modern architecture, new sensors and features can easily be integrated as long as an interface is available.

The swissMon monitoring system consists of three basic units:

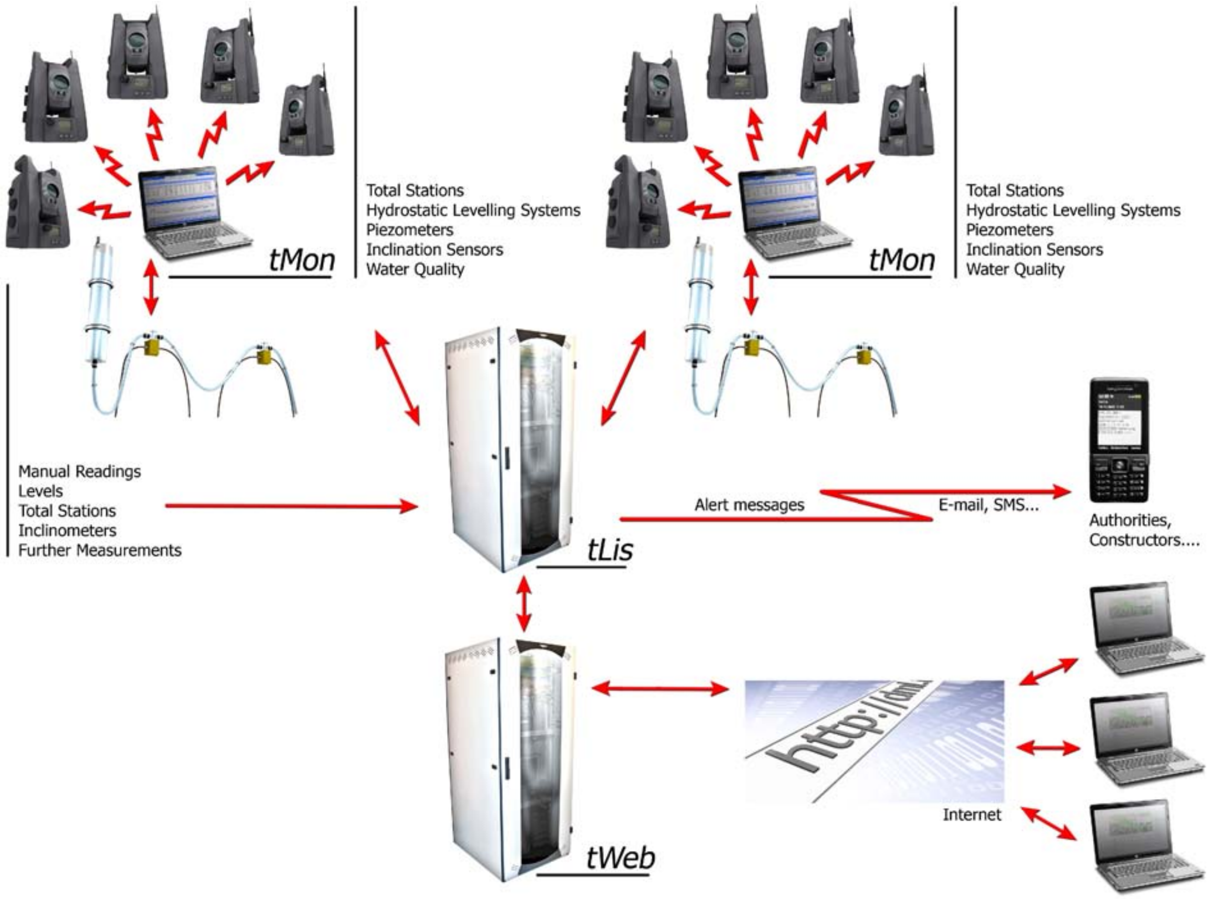

Figure 3. Modular Architecture of swissMon

Sensor Unit (tMon)

All on-site sensors that perform automatic measurements are connected to a node computer. The nodes are strategically placed near the sensors in order to reach as many of them as possible. The nodes take control of the sensors (see Figure 4), automatically executing measurements within defined intervals and analysing the field data. The validated datasets are temporarily stored on the tMon node and are regularly transmitted to the database unit via the Internet or an internal network connection. Internet connection can be established either by a main phone line or in special cases through a mobile telephone network with a high bandwidth. tMon already includes basic alert features and performs simple trigger tests to provide near real-time on-site alerts using sirens or flashing lights.

Database Unit (tLis)

This unit stores all recorded datasets. Datasets can also be updated with additional information and manually recorded datasets. This unit can perform complex triggering tests that can be customised according to project requirements. If a trigger level is exceeded, tLis can automatically transmit alarms to individuals or groups of people via email, SMS, facsimiles, pager calls or voice calls. It can also confirm, whether an alert message reached the intended recipients. The database unit runs on a server that is located outside the project boundaries. It is continuously backed up to ensure data security. It also features a watchdog functionality that automatically checks that all connected tMon nodes are still working.

Figure 4. Total Stations and Hydrostatic Levelling Systems at the Belfiore Site

Visualisation Unit (tWeb)

All data are presented to the online user in a numerical or graphical format. All stakeholders can access data anywhere at any time by using their preferred web browser on computers or mobile devices. Via their personal login, users have access to all necessary information for informed decision-making. tWeb includes the following features:

- Visualisation of data as time plots, profiles, cross-sections, surface plots, etc.
- Visualisation of trigger breaches.
- Storage of and access to project documents.
- Direct access to webcams on site.
- Quick search for single measuring points.
- Selecting of targets according to sections, subsections or trigger status.
- PDF or CSV download of all available data.
- Data protection through secure personalised logins.

In order for site engineers and site management staff to address the vast amount of data captured daily by a multitude of monitoring sensors (270’000 datasets for this project), tWeb is designed to provide information in a suitable and comprehensive way, allowing users to focus on critical tasks to be able to make decisions at the right time.

3.4 Efficient Integration of Manual Measurements

Previously, manual data was delivered to designated swissMon database administrators who directly entered them into the system using SQL queries & scripts.

In order to guarantee prompt availability and an efficient integration of manually measured data, the workflow was reduced following the implementation of the web-based application “tManual”. This tool has a graphical user interface. It is accessible via a web browser and thus location and platform independent. It can be accessed from a notebook computer, a tablet PC or from any smartphone that includes a web browser.

Managed through a user authentication system, swissMon can be accessed by all parties involved and offers different levels of functionality. The user (for example, on-site personnel) can simply define new targets with different trigger thresholds by editing field values and entering measurements into the database and by typing in values, pasting spread sheet columns or uploading text files.

In terms of quality assurance, incoming monitoring data can be checked with a limited set of features. For example, updated values can be compared with preceding values, selection lists or value ranges. After having been validated, new values are directly visible on the website, allowing users to perform an immediate visual plausibility check and providing a basis for fast decision-making.

The system offers personnel who are taking on-site measurements direct data access and significantly contributes to minimising the necessary time as well as upload errors, ensuring compliance with quality requirements.

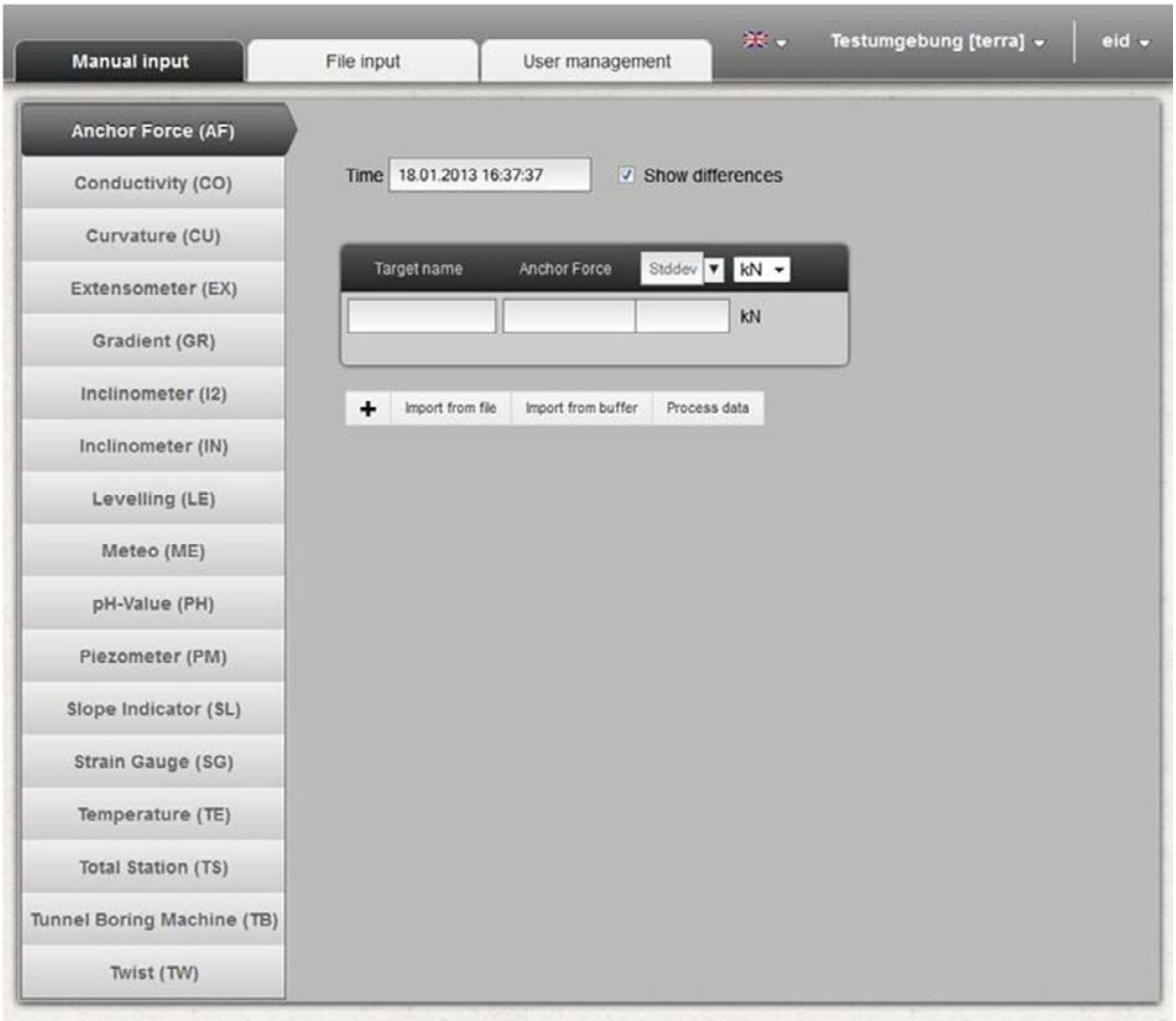

Figure 5. tManual Screenshot Showing a Sensor Array Ready for Online Manual Data Input

3.5 Online Post-Processing

In the past, geodetic and geotechnical monitoring systems used to be limited to providing validated datasets for direct measurements, and it was left to the customer to derive additional information to be used as a basis for decision-making. Today, the boundaries between providing datasets and deriving information from them have blurred and the functionality of modern deformation monitoring systems is gradually increasing.

Based on the requirements specified in the monitoring contract for the Florence Hub, the swissMon system underwent another innovative development phase: Online post-processing features were added to allow users to derive additional data from the recorded datasets. A tLis interface was added that automatically transmits selected validated measurements to external calculation modules. Using these modules individual parameters are calculated or complete datasets can be brought into a specialised context. The post-processing methods applied in Florence are outlined in a separate White Paper.

The post-processing results are automatically relayed to tLis as so-called “Calculated Values” (CV), where they are automatically stored and compared to predefined thresholds and triggers. In case of a trigger violation, tLis immediately starts transmitting alerts and integrates the process into the event and alarm management schedule.

With regard to the flexible integration of calculated values, tLis was enhanced by implementing dynamic sensor datasets. This feature enables users to create any required sensor type (i.e., volume loss, slope stability sensors, etc.) and to flexibly allocate a reading quantity and type (i.e., distance, settlement, stability ratio or failure probability, etc.).

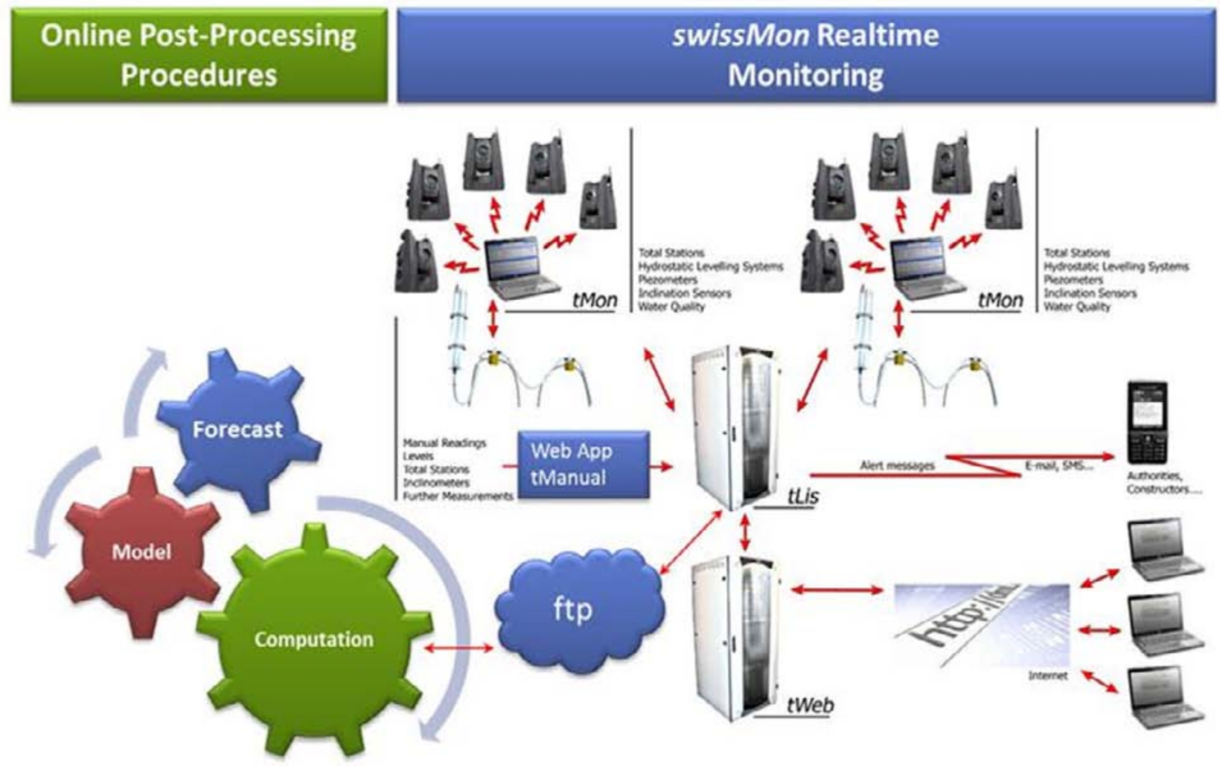

Figure 6. Enhanced swissMon Architecture Specifically Developed for the "Nodo di Firenze" Project

Online post-processing was deliberately excluded from swissMon to maintain a high degree of stability and availability that is typical of swissMon and to enable a flexible adaptation of post-processing procedures for any type of project.

Measured (real-time) data and calculated values (post-processed measured data) are clearly differentiated in the tWeb visualisation screens.

4 Conclusion

Due to the scope of the Florence railway hub deformation monitoring project different types of measurements need to be performed on a daily basis and thus efficient and automated data management is required. The swissMon monitoring platform is a powerful solution that executes complex monitoring tasks on a large scale. It provides access to a vast amount of manually and automatically recorded measurement data and to a variety of calculations.

tManual is an efficient, time-saving tool for post-processing a considerable amount of data captured using various methods and makes the data available on a single platform. tManual offers stakeholders who are involved in the monitoring process more flexibility in terms of responsibilities and greater independence by decentralizing the upload and verification process for manual measurements.

The integration of tManual and the corresponding post-processing procedures open up new possibilities, since they enable the use of practically unlimited data and sensor types in the fields of geotechnology, geodesy and beyond.

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