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Data Management System for Dam Monitoring of Hydropower Projects

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Abstract: The assessment of dam safety and risk relies on a sophisticated monitoring and assessment of various parameters such as movement, pressure, temperature, water level, percolation etc. Our focus is the integration of such data in a state-of-the-art framework for data acquisition and storage, primary and secondary data validation procedures as well as alarming. Main objective of its implementation is to adapt the dam operator’s business processes and to enable a clear, efficient and safe execution of the monitoring activities. The primary validation layer aims at the individual validation of scalar time series by checking the data range, rate-of-change, persistent readings, among others. In a second step, the inner consistency of the data is addressed by the application of the well-established Hydrostatic-Season-Time (HST) Model. In this model-based validation, we fit the model into a moving window of historical data by a parameter identification. The deviation between simulated and observed parameters enables the detection of anomalies of the dam behaviour, which are the basis for the downstream alarming. We present the application of the framework to a reservoir system of 12 dams of various types of Enerjisa, a joint venture of Sabanci and E.On. The company distributes and supplies electricity serving 9 million accounts and with about 2.6 GW of installed generating capacity, of which 50% are renewables. The new dam monitoring solution is designed as modern information environment for office and field. It supplies all required information in dashboard style screens and easy to use field applications with fully automated background processes for data import and validation. This led to an optimization of Enerjisa’s business processes saving time and providing up-to-date information for the decision support.

Keywords: Dam Monitoring, infrastructure analytics, hydrostatic seasonal forecast.

1. Introduction

Enerjisa, a large Turkish hydropower producer, decided in 2015 to replace existing software for dam monitoring with a state-of-the-art data management system. The implementation by KISTERS started in the second half of 2015 for Menge Dam and continued with the roll-out of the system to the remaining 11 dams in the course of 2016 [Table 1]. Since 2017, the full-scale system is operated at Enerjisa’s computing centre in Ankara as an operational tool for operators in the headquarters and local staff on-site at the dams. The aim of the new system is to acquire measurement data from a total of about 1,500 sensors in the dams and its surroundings and to continuously and automatically store, process and evaluate it in real-time. The monitoring enables the fast and accurate detection of unusual dam behaviour in order to implement actions to secure the structural integrity of the dams.

An important aspect of the human machine interface of such a system is the structured and standardised presentation of all acquired and derived parameters. It relies on a joint design and implementation by Enerjisa and KISTERS. This enables the operators to address the dam behaviour at a glance and to consider stress acting on the dam swiftly. The real-time system state of the dams is displayed in a web dashboard while monitoring and evaluation tasks continue running automatically in the background. The intuitive interface based on cross sections and site plans of the dams allow the operators to navigate from the overview to the different levels of detail. While doing so, the current state is constantly compared to the long-term behaviour of the dam and can be shown simultaneously if required. The data is linked to information pertaining to limit values, alarms, and forecasts. This enables on-site staff to control operations in detail and provides them with a comprehensive overview at the central control centre [Figure 1].

Understanding long-term behaviour of the dams is an additional key component of the continuous analysis of the measured data. Statistical models allow for adequate description of available measurement data and for quantification of inherent interdependencies by means of statistical analysis. In this context, we pay particular attention to the time series assessment by regression analysis. It relies on the Hydrostatic-Season-Time Model (HST Model) to analyse the behaviour of dams (Ferry and Wilm, 1958). The model describes the correlation between the dam deformation, the reservoir water level, seasonal impacts and irreversible long-term deformations.
Table 1. Overview of hydropower projects and dams operated by Enerjisa.

<table>
<thead>
<tr>
<th>Dam</th>
<th>Construction</th>
<th>Height [m]</th>
<th>Length [m]</th>
<th>Storage volume [million m³]</th>
<th>Sensors</th>
<th>Readings</th>
<th>Survey Points</th>
<th>Power [MW]</th>
<th>Observed since</th>
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<tr>
<td>Menge</td>
<td>RCC</td>
<td>68</td>
<td>303</td>
<td>50.80</td>
<td>70</td>
<td>50</td>
<td>25</td>
<td>85</td>
<td>25/06/2012</td>
</tr>
<tr>
<td>Köprü</td>
<td>RCC</td>
<td>109</td>
<td>413</td>
<td>93.20</td>
<td>170</td>
<td>50</td>
<td>30</td>
<td>145</td>
<td>10/01/2011</td>
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<td>Kavşak</td>
<td>CFRD</td>
<td>95.4</td>
<td>40</td>
<td>-</td>
<td>460</td>
<td>50</td>
<td>100</td>
<td>182</td>
<td>19/06/2012</td>
</tr>
<tr>
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<td>23</td>
<td>n/a</td>
<td>20</td>
<td>30</td>
<td>8</td>
<td>16/02/2014</td>
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<td>Kandil</td>
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<td>347</td>
<td>438.68</td>
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<td>5</td>
<td>50</td>
<td>103</td>
<td>15/09/2011</td>
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<tr>
<td>Sarıgüzel</td>
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<td>464</td>
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<td>5</td>
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<td>45</td>
<td></td>
<td>11/11/2013</td>
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<tr>
<td>Arkun</td>
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<td>250</td>
<td>15</td>
<td>50</td>
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<td>27/05/2011</td>
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</table>

Figure 1. Web dashboard including Dam Monitoring Viewer (top left, interactive overview map on the position of the dams).
Model calculations of the HST Model are constantly being updated within the system considering continuously inflowing data. An alarm system identifies anomalies and notifies staff within the organisation as per the staff duty rosters and customisable distribution lists.

The following sections provide detailed information about the data acquisition and decision support components.

2. Data Acquisition

2.1. Online Data

The data acquisition at the dam sites rely on Campbell CR1000 data loggers. Each data logger has its own WEB interface and can administer over 100 measuring devices. Once every five minutes, the central information system calls via http the raw data from the loggers and stores it in the central database. Automatically acquired data includes reservoir water level, strain sensor, inclinometer, jointmeter, piezometer, strain gauges, settlement meter, pressure cells, tensiometer and seepage weirs.

2.2. Manual Collection

Data from measuring devices not currently accessible online is read by staff on their on-site inspections, is entered in a web interface, and is automatically transmitted to the central data management system. Manually collected sensor data include water levels, strain sensors, pendulum readings, inclinometer, jointmeter, piezometer, compasses, ground anchor, strain gauges, temperature and seepage weirs.

A standard smartphone or PC is used for visual inspections. Files (tables, images, videos etc.) are automatically copied from the device to an FTP server, sent to the database, and made available alongside other online data and manually collected measurements.

2.3. Automatic Data Validation and Analysis

The data management system distinguishes raw and production data. Raw data is stored as read-only and stays available in full resolution on a long-term basis. Data validation as well as all corrections and additions are executed based on the production dataset which at a later stage serves as the foundation for any evaluation, consolidation and modelling.

Data validation is a two-step process. The first step relies on the automatic validation by a number of data validation rules. Key rules check data loss, limit value violation and rate-of-change of the respective parameter. All rules are configured individually for all measurement points and can be linked to the alarm system. Furthermore, dedicated validation has been integrated by means of scripting. Inner consistency checks for individual measurement points as well as external consistency checks between different measurement points or the entire measurement network can be added by the operators during operations.

Following the automatic validation, manual data monitoring in graphs and tables is executed. The data management system provides expert staff with comprehensive tools to be able to monitor large amounts of data effectively. For appropriate and accurate data corrections, powerful and application-specific graphic tools are available [Figure 2].

Quality management functions document all automatic and manual data validations in real-time. Finally, detected anomalies by the automatic validation are logged as well as any changes to the data. This way, any data pool and its history remain traceable. Together with staff notes and remarks, this serves as a valuable foundation for long-term analyses and assessment of the results.
Figure 2. Manual validation of the data in the expert interface WISKI; this being jointmeter data at the Menge Dam.

3. Decision Support

3.1. Nearly-Real-Time Modelling

Global displacements in dams can be separated into hydrostatic (water level), seasonal (air and water temperature) and time (irreversible deformations). Understanding the long-term behaviour of a dam is essential to interpret the measured data in order to be able to distinguish the deformations caused by irreversible events and factors as the ageing of the dam in order to ensure its structural safety.

The Hydrostatic-Season-Time (HST) Model is a multivariate statistical model, which allows evaluating the long-term behaviour of a dam considering different measurement data types, based on a statistical polynomial regression provided by

\[
f (h,s,t) = c_1 h^4 + c_2 h^3 + c_3 h^2 + c_4 h^1 + c_5 \exp(t) + c_6 \exp(-t) + c_7 \cos(s) + c_8 \sin(s) + c_9 \sin^2(s) + c_{10} \cos(s) \sin(s) + c_{11}
\]

- **Hydrostatic** = \( c_1 h^4 + c_2 h^3 + c_3 h^2 + c_4 h^1 \) (2)
- **Time** = \( c_5 \exp(t) + c_6 \exp(-t) \) (3)
- **Season** = \( c_7 \cos(s) + c_8 \sin(s) + c_9 \sin^2(s) + c_{10} \cos(s) \sin(s) \) (4)
- **Residual** = \( c_{11} \) (5)

\[
c_1 h^4 + c_2 h^3 + c_3 h^2 + c_4 h^1 + c_5 \exp(t) + c_6 \exp(-t) + c_7 \cos(s) + c_8 \sin(s) + c_9 \sin^2(s) + c_{10} \cos(s) \sin(s) + c_{11}
\]

Hydrostatic \quad \text{Time} \quad \text{Season} \quad \text{Residual}

Where: \( h \) = reservoir water level, \( t \) = elapsed time, \( s = 2 \pi j / 365.25 \) (season varying between 0 and 2\(\pi\) from Jan.1 to Dec. 31, and \( j \) = the number of days since January 1.)
The HST Model describes the correlation (Eq. (1)) between the dam deformation, water level (Eq. (2)), irreversible long-term deformations (Eq. (3)) and thermic impacts (Eq. (4)).

![Figure 3. HST model interface for the modelling of building behaviour.](image)

The interface [Figure 3] allows for intuitive model operation. Any regression function can be added and calculation of regression coefficients can be launched both manually and automatically. A graph presents the results for an easier comparison, showing a simulated time series in contrast to the measured time series. The water level and a confidence interval support the user to swiftly identify where alarms have been triggered (as indicated in Figure 3). In addition, the list of alarms tab page includes a detailed description for each triggered alarm. The tables placed below the graph resume both regression parameters and statistical evaluations. Export of statistical evaluations is also possible.

Model calculations within the HST Model are constantly being updated in WISKI with continuously inflowing information. Model results are compared to measured data, with alarms being triggered and transmitted to the alarm system in the event of any anomalies.

### 3.2. Web Dashboard and Dam Monitoring Viewer

The real-time state of the dams is monitored using a Dam Monitoring Viewer [Figure 1]. This interactive web interface based on cross sections of the dam allows for easy monitoring thanks to intuitive navigation. Data, information and plots are displayed in maps, charts, graphs and tables fast. Data export in different file formats for further use is possible, too.

The tool is based on the KISTERS web portal framework. This is a web application based on portal technology which allows for comprehensive combination of small graphical components (widgets) with specific functions of the measurement data management. This data will then be combined to a solution tailored to the workflow and then can be accessed as a website using a browser. The solution is designed in an open and variable manner, to the effect that the Dam Monitoring Viewer can be adapted by users themselves in the event of modified demands to information or for new functions within the scope of future software releases. Additionally, the software allows different, configurable dashboards for different user groups and administers to them via user management. This way, each user can be provided with their very own workstation including their objects and data.

To operate the viewer, no specific software is required at the respective workstation. A web browser is sufficient for access from any computer, tablet or smartphone. When doing so, the appearance of the Dam Monitoring Viewer will be optimised automatically for the respective screen size. Key information is foregrounded and user guidance adapted (responsive design).
Within their security concept, Enerjisa decided to only access the Dam Monitor Viewer from within their internal network. Authorised users can be granted access via a VPN at any time. Access to the information via the internet by the interested general public is not provided at this time; it is, however, technically possible.

4. Conclusions

As storms, floods, and other large weather events can place those living near a dam at risk, proper monitoring of a dam is an important aspect of dam operation and maintenance. The described technologic solution allows a seamless integration of automatic and manual data acquisition offering evaluable benefits to plant owners and operators. Another important aspect is the significant role played by the validation of the collected data for the performance dam monitoring system. The integration of both processes, data validation and model-based assessment of dam movements, can timely reflect critical indicators of structural behaviour and support the analysis of the data and the alarms.

Data management system for dam monitoring allows the staff to monitor the dams according to an ‘over-the-loop’ concept, i.e. staff is not part of the automatic processing chain but supervises it. This conceptional enhancement increases process efficiency significantly.

5. References


