Advanced Solution Monitoring: Near Real-time Analysis

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Abstract

The monitoring software tool, called DAI (Data Analysis and Interpretation) is developed upon request of the EURATOM inspectorate. This monitoring tool does more than just supervision: it interprets the signals and verifies the consistency and coherency with predefined criteria and without intervening in the process. These criteria are based on the design characteristics of the recipients and transfer mechanism.

In the case of the solution process in a reprocessing plant, the signals are visualizing the solution properties (temperature, density) and tank levels. The change in tank level of the feeding tank is cross-checked against the corresponding change in tank level of the communicating process tank and the software verifies the coherency in total mass transferred. In particular the start of a transfer has to be recognized appropriately and that with the appropriate signal profile, that differs for siphon transfer and mechanical pumping.

In order to ensure that no nuclear material is diverted, a complete accountancy system is imposed that combines verifications with high accuracy of low frequency (in general annually), with those of high frequency but with lower accuracy. Mainly the latter one, also known under near-real time accountancy, enhances the quality of executing the procedures, because it allows the inspector to localize in time a leakage problem to the operators.

The monitoring tool DAI has been completely successfully validated at the Reprocessing plant of La Hague (UP2 and UP3) and is now in use by the inspectors. Also the IAEA has selected this DAI software tool to monitor the Tokai reprocessing plant in Japan.

1. Introduction

Application of intelligent signal processing allows a fully innovative way of process monitoring. A new method has been developed to monitor nuclear reprocessing. The novelty consists in the vast amount of signals which are captured in complete remote way and the very high data acquisition rate combined with a completely automatic data analysis which is crucial for extracting the relevant information from the large amount of data. Different types of signals can be treated: pressure, temperature, mass, neutron, and gamma signals. As an example the pressure data, collected with a high data acquisition rate in tanks containing dissolved nuclear fuel can give early warning of possible dip tube clogging if intelligent filtering, based on the physical understanding of bubble formation, is applied.

Process monitoring includes a two-fold task: firstly, a continuous survey of the health status of the instrumentation and process conditions and, secondly, a comprehensive real-time interpretation of the dynamic process functions. For a nuclear installation the first part is typically associated with the safety monitoring of the plant, whereas the second part, requiring a thorough understanding of the plants normal functioning and potential diversion paths, brings high value to nuclear safeguards. In process industry substantial attention has traditionally been given to the safety-related aspects, whereas the concern for safeguarding of precious product material is only recently raised. Norms for batch process control (an example being ISA-95 (2005), which addresses standards for enterprise-control system integration) are still under development. A particular aspect of the process control, namely the follow-up of cyclic solution processes, is addressed in this paper. Main innovative features are the analysis of the autocorrelation of the signals and the cross-correlation between different simultaneous signals.

For this process and solution monitoring, the TAME group of the NUSAF unit (JRC) developed a software tool, called DAI ("Data Analysis and Interpretation") that is continuously monitoring/tracking nuclear material flow through a reprocessing plant, while verifying by cross-correlation if the total mass transferred is arrived at its destination in the tank down stream.

2. Overview of the process monitoring system DAI

The JRC's software package for solution monitoring consists of five modules:

- Module1 :A data loader:
  as the measured data is stored in a large amount of files covering short time periods, a plant-specific CSV file reader is developed by JRC to load the data in the solution monitoring software package (data historian).
- Module 2: A data historian:
  it was opted to operate with a non-relational database to allow real-time registering of data with timestamp. In this case the Matrikon data historian is selected because it operates in a standard OPC system. Alternatively the PI data historian can be utilized for industrial applications provided that the PI system is standard present at the plant. The JRC opts to work with the low-cost Matrikon data historian for the medium scale applications.
- Module 3: The data analysis kernel: DAI:
  this kernel analyses and interprets the data collected from the process control sensors and actuators. The central task of the DAI kernel is the recognition of exploited process cycles with the objectives to survey in real time the correct operation of the production process, to diagnose abnormal situations and to evaluate the process performance indicators and inventory balances of the batch cycles in real time. Since the signals in the batch process have a certain repetitive form but are not mathematically periodical, the syntactic approach was chosen to analyse the signals' repetition for the active devices with a given cycle, represented in a synoptic.

The synoptic corresponds to the technical flow sheet and couples the plant design (inclusive instrumentation) to the acquired signals. These signals show repetitions of a cycle, that is a typical sequence of elementary or so-called "functional" behaviours.

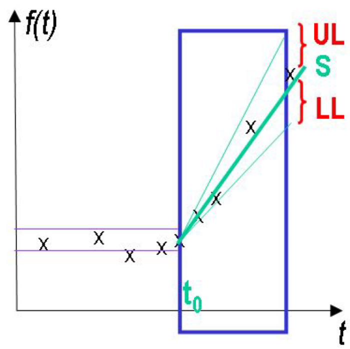

Fig.1: Filling detection

Functional behaviours of an active tank are typically, filling, plateau, emptying. The signal, composed of discretely acquired data points, is analysed from point to point with a sliding time window. In the example of a filling behaviour for a tank level, as shown in Fig. 1, the change in slope is checked against a set slope parameter S within a cone angle defined with upper and lower limit and the software automatically identifies the starting point t0 of filling. The software DAI detects each start of a functional behaviour as an important event in the cycle, based on criteria for the signal profile and reports back an alarm for each deviation from the expected behaviour. The analysis is interrupted for the alarmed cycle but continues with the next cycle by means of a resynchronization point. More information is given by Janssens-Maenhout et al (2003) and (2004) and details for the user are given in the manual (2005).

The DAI software verifies (1) flow incoherency with the prescribed goals by comparing the complementary signals for checking the mass exchange between the two linked active devices, and (2) the conformity with the predefined design by checking the completeness in the sequence of functional behaviours. A functional behaviour is characterized with specific parameters, such as mean slope, cone width (related to the angle uncertainty), duration limits etc. For effective, syntactical pattern recognition it is needed to set appropriate parameters based on expertise with the signal behaviour under regular working conditions.

The DAI kernel is constructed in such way that the modeling can easily be extended, by including additional libraries. Those .dll libraries have to respect a standard format, which is provided with the DAI software.

- Module 4: The calculation engine:
  the measured and registered data in original form need to be converted in real variables with physical meaning. The calculation engine calculates the mass/volume taking into account the calibration curves. The formula and calibration curves are given in via the scripts in the standard frame of the calculation engine.

- Module 5: The relational database with results.
  It was opted to write the results of the analysis by DAI in an Access Database, because this is the standard Microsoft Office tool for common and simple handling and/or representation of results. Alternatives are any ADO compliant databases such as the MySQL database for the treatment of the results. For the medium scale applications JRC utilizes the Access database.

The complete software package structure with the five modules are represented in Fig. 2. The different parts are configured via .xml files and the calculation is done via the Java Scripts. The different modules communicate with each other via the .dll libraries as indicated in Fig.3. It is necessary in the development of the software application to supply also all configuration files or .xml files.

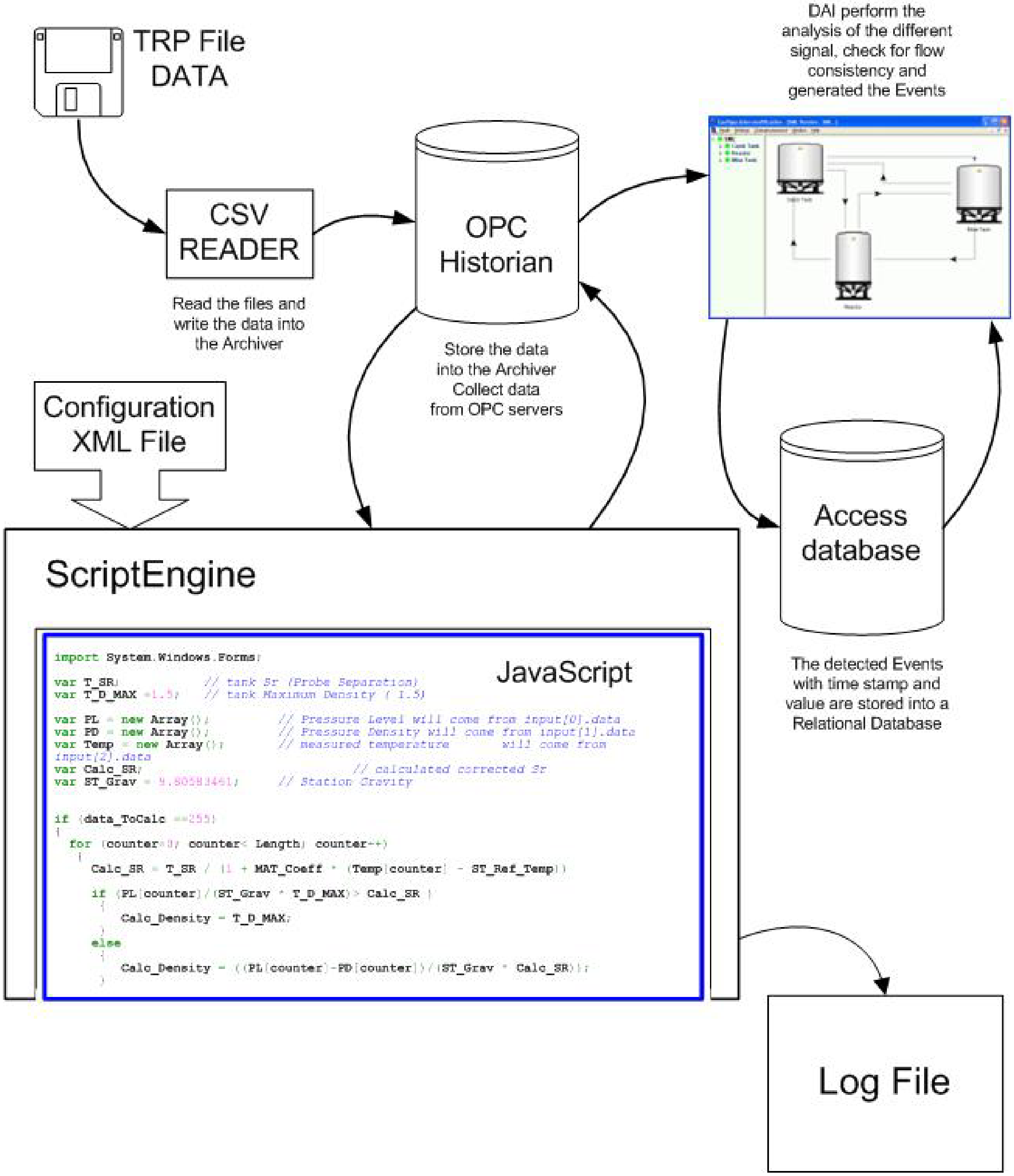

Fig. 2: The five modules in the JRC software package for solution monitoring

The complete software package is kept modular, and even the CSV file loader, DAI kernel and calculation engine have a generic and modular structure. It is possible to add any functional behaviour to the DAI kernel, as needed in the specific application, by means of a .dll library.

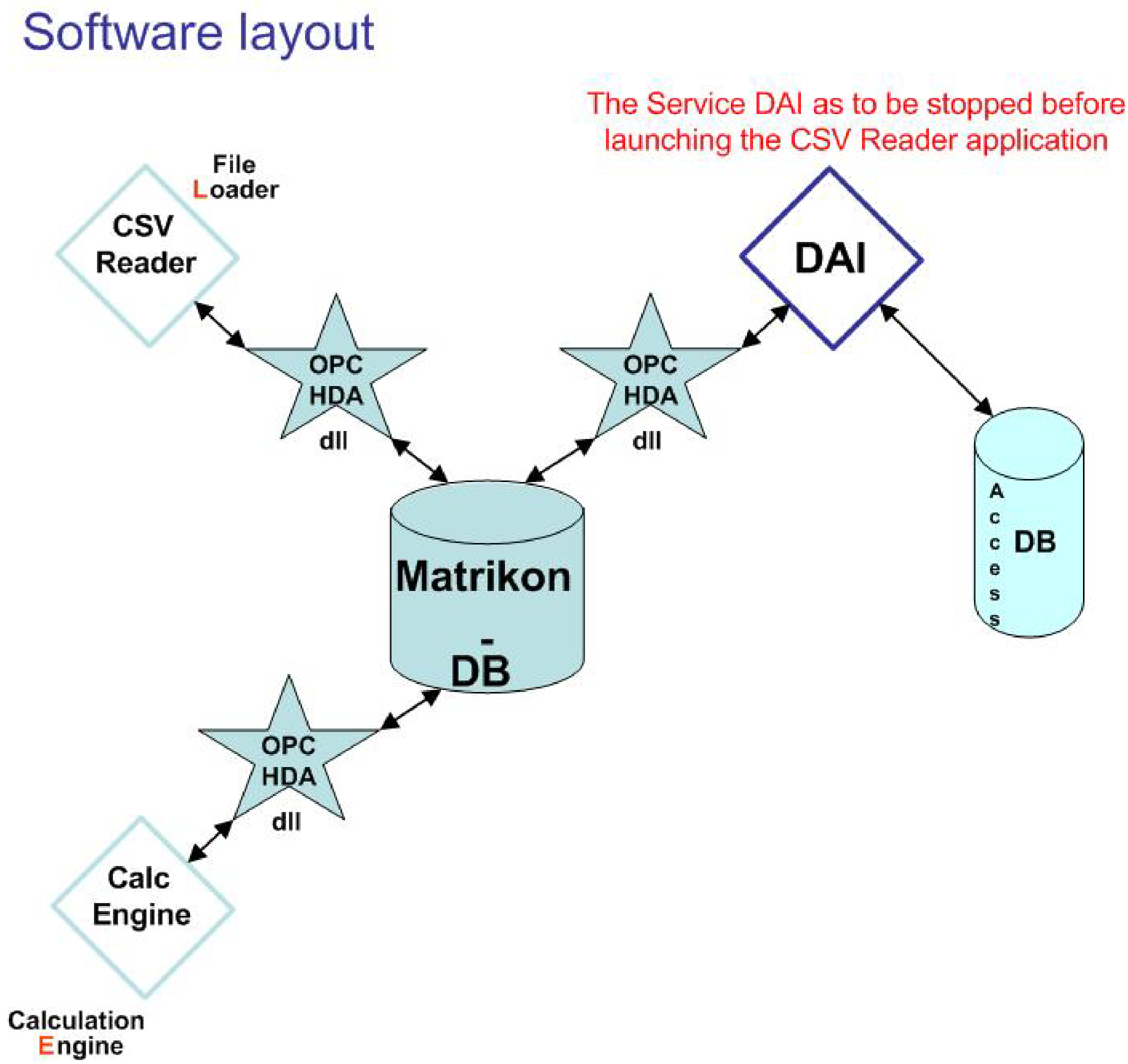

Fig. 3: Communication connections between the different modules in the software package

3. Applications, User Feedback and Needed Extensions

The monitoring tool DAI concept with a generic syntactic pattern recognition analysis kernel and plant-specific design parameters allows to apply the software to different plants. It can be applied to a batch process or a continuous process, by inserting the technical flow sheet with synoptics and establishing the appropriate set of parameters. The technical flow sheet is designed by selecting the appropriate active components and functional behaviours from a predefined list. For the parameter setting an auto-configuration module has been developed but adjustment based on analysis of signal by the user is needed. The output is a graphical representation of the signals in which automatically all important events are indicated. Anomalies identified by the software are highlighted with an alarm for further inspector investigation.

The tool was deployed and validated in a major European reprocessing plant, UP2 and UP3 from Cogema at the site of La Hague (France) as inspector tool. Fig. 4 illustrates a synoptic based on the technical flow design including an accountancy tank in the application for the La Hague reprocessing plant. Recently the EURATOM inspectorate at DG-TREN requested the implementation of a similar monitoring tool at the reprocessing plant of Sellafield (UK).

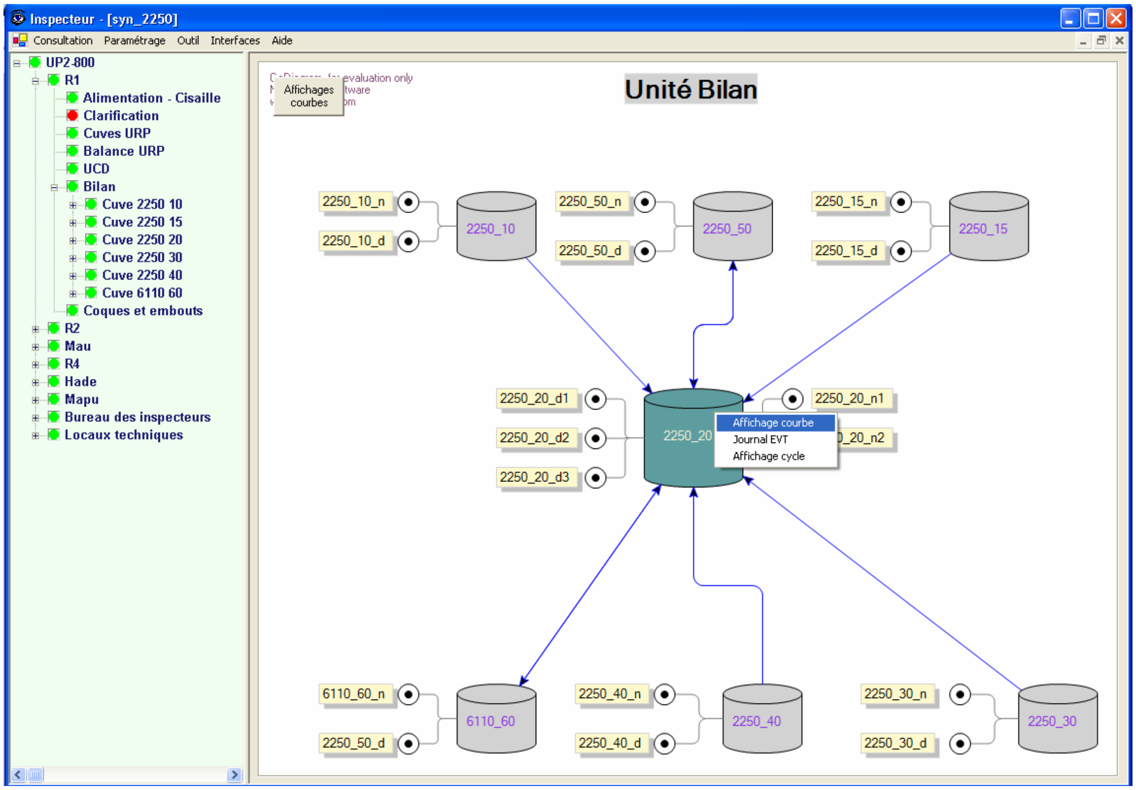

Fig 4: Example of a synoptic including an accountancy tank at a European Reprocessing Plant, that is coupled to the process signal sheet for automatic analysis and interpretation of the level and density signals

Further to this, JRC's software tool DAI was purchased by the Japanese inspectors of NMCC for the TETRA demonstration plant, in preparation of the solution monitoring at the Rokkasho Reprocessing Plant, starting up and aiming industrial production as UP2. Also the IAEA selected the DAI software for solution monitoring at the Tokai Reprocessing Plant in Japan and is interested in an application of the DAI software for the Rokkasho Reprocessing Plant. Moreover the IAEA (2005) recognised the scope and potential of JRC's monitoring principle and adapted software tool for enrichment facilities.

User feedback has indicated that it is needed to differentiate the different ways of liquid transfer. In reprocessing plants it is common to transfer liquids in a pneumatic way, to avoid problems with the maintenance of mechanical (contaminated) parts. Filling/ emptying by mechanical pump, or by siphon or by air-lift show different signal profiles. In particular the start of these behaviours is different and a better follow-up requires the careful treatment, appropriately adapted to the way of transfer. A new .dll library had to be setup to recognize the transfer by siphon as new functional behaviour with a special non-linear change in slope. Extra parameters are introduced for this new non-linear functional behaviour: "filling/emptying by siphon".

4. Refined recognition of different filling/emptying behaviours

A new functional behaviour (with new ID number, name and description) is defined by up to ten new parameters. Each parameter is expected to vary around a default value, specified using the database. The functional behaviour is detected by verifying the criteria on the defined parameters in addition to the general parameters (mean slope, upper/lower limit) with the parameter values, calculated based on the data points in the time window of analysis. The date and time allocation of the start of this new behaviour (the event positioning) is done with refined criteria in a second step. An example of the characterization of a new functional behaviour with new parameters included in the properties panel is given in Fig. 5.

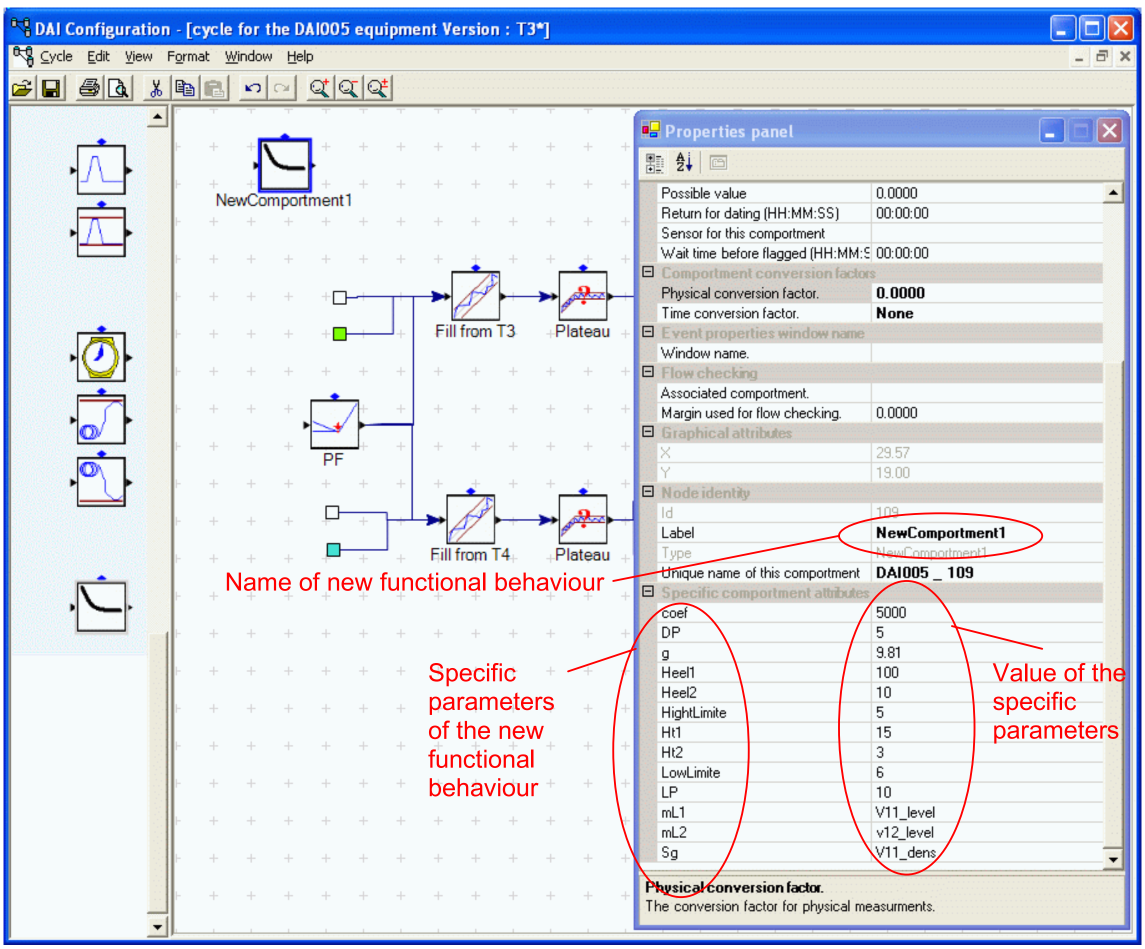

Fig. 5 : Example of NewComportment1 for the emptying by siphon with the user-defined additional parameters

Under a heuristic approach the emptying by siphon has been modeled with the following additional parameters:

- Diameter and length of the transfer tube: *Dp (m)* and *Lp (m)*
- Friction coefficient: *Coef* (dimensionless)
- Level difference between the 2 tanks: *Ld (m)* (to model different height positioning)

The mass of liquid transferred from the feeding tank is calculated with the density of the liquid at the temperature of the feeding tank, and so is calculated also the mass in the receiving tank. The coherency in mass transferred is checked by comparing the two calculated masses, while the difference in temperature of the tanks is taken into account. The change in mass in the feeding tank allows to determine a transfer mass flow rate that can be compared to the typical mass flow rate for transfer by siphon. Therefore a mean slope on the pressure of the level dip tube (kPa/hr) is determined by means of the following formula:

$$ms = 3600 \cdot \sqrt{\frac{2 \cdot Ld \cdot Dp \cdot g \cdot Sg}{Coef \cdot Lp}}$$

with: g the gravitational constant

Sg the specific gravity of the liquid

Comparison of the registered mean slope on the pressure signal of the dip tube in the feeding tank and the calculated one, allows detection whether the transfer is done by siphon or not.

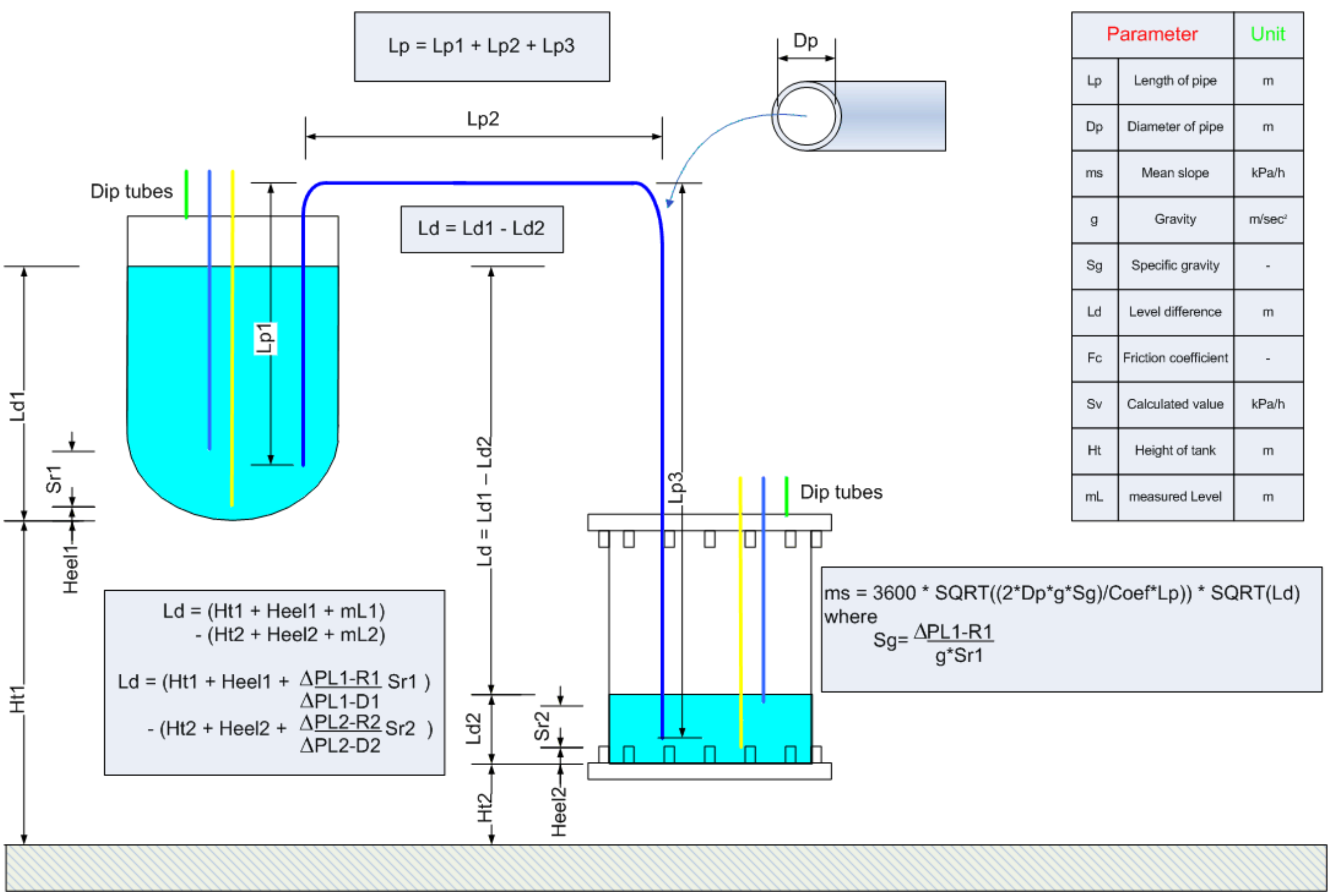

Fig. 6: mass flow rate by siphon transfer from tank on height Ht1 to tank on height Ht2

The new functional behaviour "Emptying by siphon" was implemented and successfully tested in the DAI software application for the TETRA Facility of the Japanese NMCC in

Tokai. Fig. 7 demonstrates the detection of all events, inclusive the start of “Emptying by siphon” (in green) on the level curve.

The database of patterns, that is representative with respect to the non-linear processes of interest, will also be analysed by means of multi objective genetic algorithms or fuzzy logic in order to determine the most relevant and/or sensitive parameters in the non-linear functional behaviour.

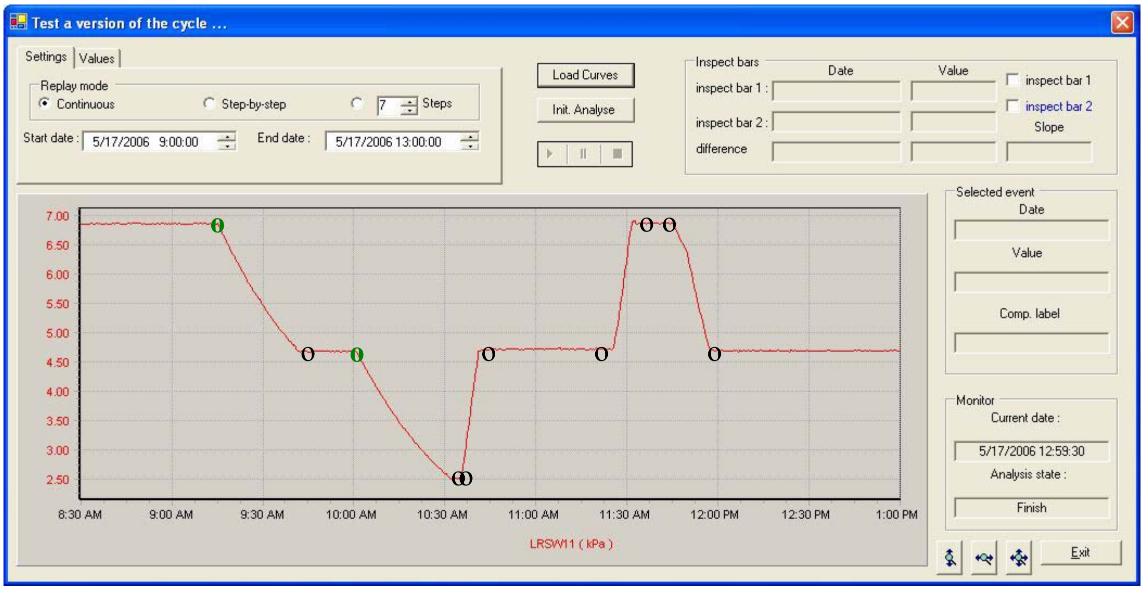

Fig. 7: Demonstration of detection of emptying by siphon with the DAI software

5. Conclusion

The JRC software DAI allows remote monitoring of the liquid flow through the process and detects on the tank level profile all transfers with specification of the type of transfer (mechanically or by siphon). The sensitivity of the DAI software on the interpretation of the non-linear level slope behaviour is successfully tested on real data from the TETRA facility and gave confidence in the automatic data analysis with artificial intelligence. Experience with abnormal phenomena regarding Solution Monitoring such as alarms (True or False alarms) are needed to further enhance the performance of the software, increasing the level of artifical intelligence with expertise.

An increased user pool and the continuous development for the DAI software to simplify the parameter setting guarantee the further quality of the software. This functional behaviour will be refined to distinguish also transfer by air-lift pumping. A further extension of the software is under development with other types of special functional behaviours: to identify the mixing of the liquid in the tank, and to evaluate if the loss of liquid in a tank is due to evaporation.

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