HARVESTING THE VALUE OF DATA:

A DATA ARCHITECTURAL SMART SOLUTIONS APPROACH FOR ENABLING DIGITAL WATER

Siddharth Seshan[a]

Dirk Vries[a]

Marcel Zandvoort[b]

Alex van der Helm[b]

Johann Poinapen[a]

[a]**KWR Water Research Institute** based in the Netherlands, is a leading international research institute operating at the heart of an engaging network of partners who collaborate to co–create science based, tailor–made solutions for local problems in the water–energy–food nexus. One of the research areas of KWR is Hydroinformatics, with specific expertise in developing and implementing smart water solutions and the Digital Water transition. KWR is currently supporting the Indian water sector by exploring opportunities to apply the knowledge and skills gained from the Fiwater4W and other smart water management projects to assist in shaping a water–wise India.

[b]**Waternet** is the only water company in the Netherlands that covers the whole water cycle. Waternet is responsible for all water related activities in and around Amsterdam, which include drinking water treatment and distribution, wastewater collection and treatment. We ensure that the surface water is kept at the right levels, the Amsterdam canals are clean and that the dykes are up to standard. These topics are important for everyone and we operate at the very heart of society.

Introduction

The development of smart water solutions for our water infrastructure is a rapidly advancing topic within the water sector. Over the past decade, more and more water utilities, research institutes, and the private sector are pursuing the development of solutions that enables the end–user to monitor, automate and identify the optimised control of key processes in water and wastewater infrastructures. These key and enabling technologies are being viewed as a necessity in order to tackle the extreme water challenges we face globally due to the harmful effects of climate change. Additionally, the rapid advancement in the fields of Internet of Things (IoT), advanced sensors, data analytics, Business Intelligence (BI), and Artificial Intelligence (AI) – has led to a major transition of the water sector and towards a more digitally enhanced and data–centric ecosystem.

This transition gives the opportunity for the water sector to be transformed and optimally benefit from the implementation of these upcoming technologies. Some key building blocks in the digitalisation of operational services in the water sector are seen to be the following:

- Increased deployment of instrumentation and sensors: Water utilities have increased their monitoring and measurement campaigns a great deal, thereby leading to lots of data signals now being available for key process parameters within the entire water cycle.
- Development of data–driven AI models to forecast and achieve optimal control: With the widespread use of Machine Learning techniques and Artificial Intelligence algorithms, the water sector can now benefit from such methods with the possession of large datasets. Data–driven models can be developed for the purpose of data quality control and replacing a failed sensor (soft sensors), forecasting key process variables, and supporting process technologists in making informed decisions to achieve (completely) automated process control.
- Upgrading of the water utilities' data architecture and ecosystem that supports an automated (near) real–time monitoring and control: The Process Automation (PA) and IT architecture may require renewal to achieve real–time optimized plant–wide control, as opposed to conventional control loops that rely on a single process. Additionally, some external data sources, such as weather–related datasets, can be crucial information for the control of a water system. Therefore, a standardised architecture that can enable the eradication of data silos that exist between varying data sources and sectors, would greatly facilitate interoperability between systems.

With the above–mentioned key building blocks, the value of water can be combined with the value of data and knowledge, thereby steering the water sector to the new age of digital water. Such an upgrade can result in sustainable and self–sufficient exploitation of water for consumption, through the use of innovative technologies. To achieve this, the water sector has begun its journey of transition, by implementing digitalisation and integration tools that will enhance the sector's stance in achieving resilient and optimised water services.

FIWARE– A Cross–Domain Smart Solutions Platform

As highlighted above, an imperative in the digital transformation of the water sector is a data and IT architecture that can support the next generation of internet services and enable cross–domain data exchange. Here, we focus on the application of real–time optimised control and automation using a next–generation data exchange platform. A data ecosystem solution that is currently gaining momentum in the European context is FIWARE (www.fiware.org). FIWARE is an open–source, smart solutions platform with an aim to support Small and Medium–sized Enterprises (SMEs) and developers in the creation of smart applications in multiple sectors. FIWARE's intention is to become one of the main open and sustainable ecosystems for Smart City initiatives that can achieve easy cross–domain data exchange and cooperation, thereby eradicating data silos that hinder the progress of the development of next–generation Internet services. Key aspects of FIWARE include its interoperable nature by design, the use of open (data) standards, and the ambition to achieve cross–domain cooperation.

FIWARE has made considerable progress in other sectors such as Energy, Transportation, or Telecommunication, with regards to the Smart Cities concept. However, in the water sector, progress in the development of smart applications using FIWARE has been made only recently. Therefore, through a directed call by the European Commission in 2018, five sister projects were initiated to introduce the concept of IoT compliant approaches for the water sector. The projects are Aqua3S (www.aqua3s.eu), Digital Water City (www.digital–water.city), NAIADES (www.naiades–project.eu), ScoreWater (www.scorewater.eu) and Fiware4Water (www.fiware4water.eu). The common component among the projects is to investigate and develop open–source FIWARE compatible applications for the water sector. The five projects combined compose a synergy group called Digital Water 2020.

Fiware4Water – A Study to Investigate the Use of FIWARE in the Digital Water Transition

The Fiware4Water project (www.fiware4water.eu) intends to link the water sector to FIWARE through the demonstration of its capabilities within different stages of the water cycle. The demonstration cases include smart applications for raw water supply, drinking water supply, wastewater treatment, and customer interaction. Within the project, the potential of its interoperability and standardised interfaces are being investigated for both water sector end–users (such as water utilities, citizens, consumers, and cities) and solution providers (private utilities, SMEs, and developers).

More importantly, the project aims to also demonstrate how linking FIWARE within the water sector can be nonintrusive and integrate well with legacy systems as depicted in Figure 1.

A FIWARE–based architecture can bring major benefits for the water domain – such as bringing water into cross–domain applications, using standardised interfaces, models, and methods for interoperability, revealing the power of data, and boosting innovation in the water domain. Fiware4Water tackles digital water challenges, by linking the physical

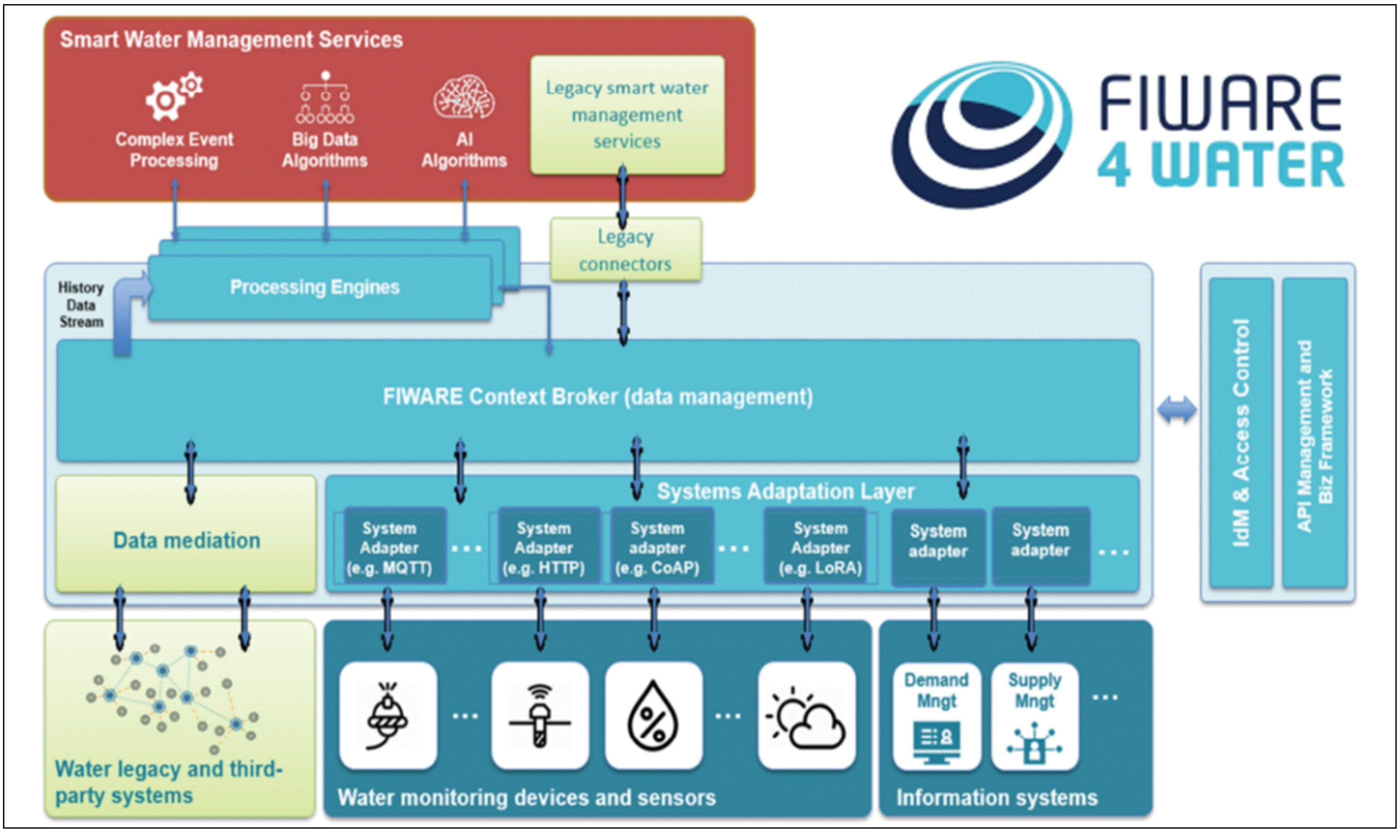

Figure 1: Fiware4Water structural concept with links to legacy systems (Source: fiware4water.eu)

and virtual worlds and providing technology enablers that simplify the generation of effective knowledge and deployment of personalised smart applications.

Case Study – Intelligent Control for Wastewater Treatment in the Netherlands

KWR Water Research Institute together with Waternet, the water utility for Amsterdam and surrounding areas, are working on a Fiware4Water demonstration project to achieve intelligent control of a wastewater treatment plant (WWTP). The Amsterdam West WWTP has a capacity of 1.1 Million population equivalent and serves the city of Amsterdam. The Process Automation of the WWTP along with the supporting IT architecture is in fast development in order to benefit from emerging digital transition and integration technologies. Additionally, Waternet is also investigating the upgrade of the control loops of the WWTP, by transitioning to a more plant–wide control using real–time data and external data sources that can feed process models.

To achieve plant–wide control and for testing smarting water applications, Waternet has transformed one treatment lane of the WWTP West into a research lane. Additional sensors measuring pertinent parameters have been deployed leading now to an increase in the available data signals. Data–driven control strategies can now be tested using newly developed AI models and data fusion techniques. The objectives of the research are to minimize nitrous oxide emissions (a strong greenhouse gas), energy use, and sludge production while maintaining the effluent water quality targets. This contributes to Waternet's overarching goal of achieving climate neutrality.

Smart Water Applications for Amsterdam West WWTP

With the development of smart water applications, automated plant–wide intelligent control can be pursued. The smart applications comprise of an AI–based data validation tool for data quality control, soft sensors that accurately predict key process variables, a digital twin AI model describing the process behavior and an AI control model that determines an optimal trajectory. All smart applications are being developed and tested in the designated research lane.

KWR Water Research Institute has developed an AI–based data validation framework for the Amsterdam West WWTP. A key aspect that must be considered prior to applying data–driven strategies and AI models is data quality. Typically within the context of treatment plant–wide data, the quality of data can be impacted by sensor faults, sensor calibration issues, fouling and obstruction of the sensors, and connectivity problems between sensors, actuators, and data management systems. This can lead to the hampering of advanced data–driven monitoring and control of (critical) water operations. As a result, data quality checks and corrections are needed. The data validation framework encompasses

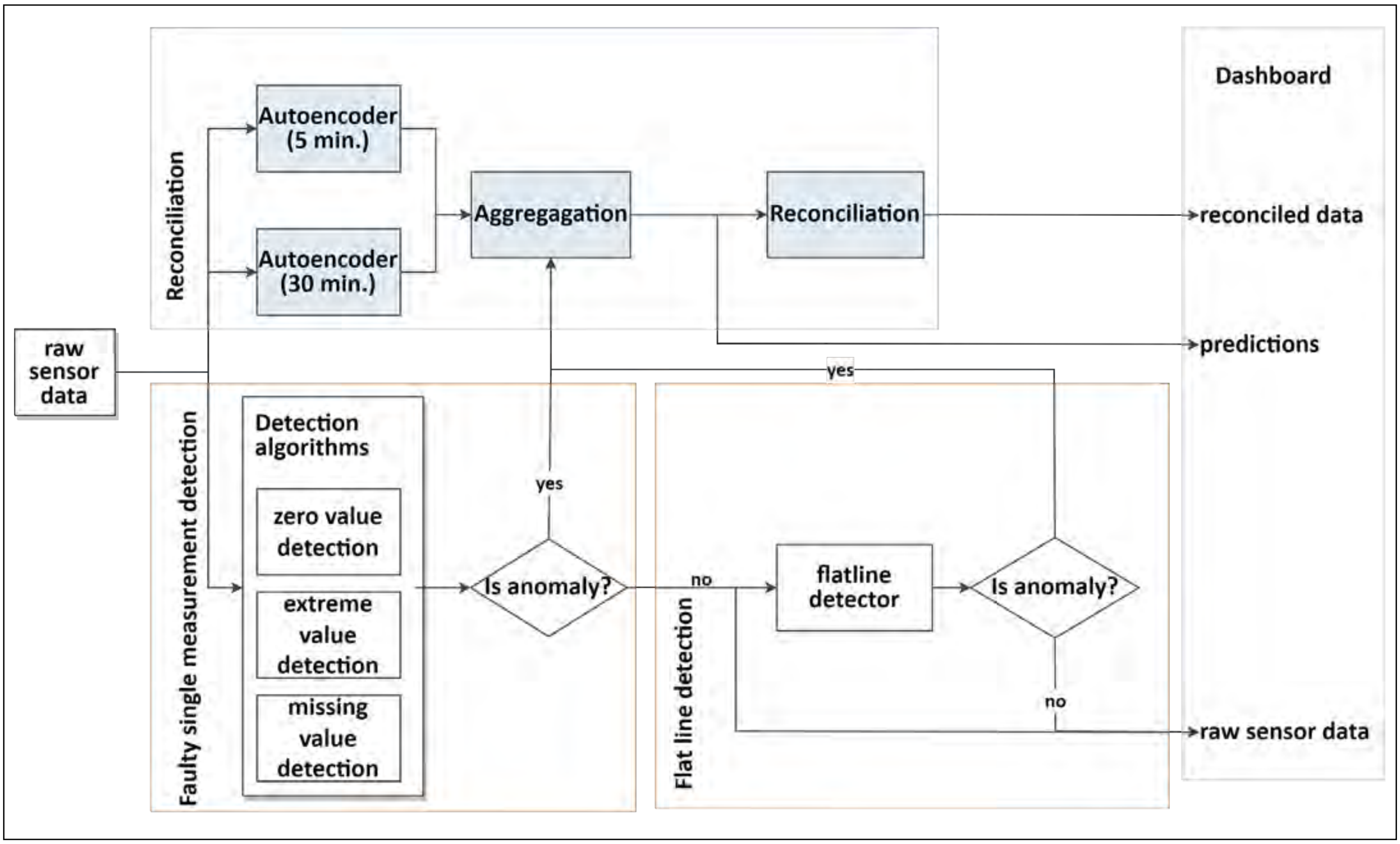

Figure 2: Scheme for AI–based data validation conducting sensor anomaly detection and reconciliation

an anomaly detector that uses (statistical) threshold techniques and a data reconciliation part that aggregates predictions from deep learning models whenever an anomaly is detected. The framework was tested on ammonium and nitrate data signals from an aerobic tank of a bioreactor unit in the research treatment lane of Amsterdam West WWTP.

Within the anomaly detection component, algorithms have been developed to automatically flag outliers through user–defined and statistical measures, i.e. threshold–based detections, extreme shifts/ jumps, and unfeasible flatline detection. For the data reconciliation, two recurrent neural networks based autoencoder models for each data signal, consisting of Long Short Term Memory (LSTM) and dense layers were trained and tested. The models were trained in order to be able to capture slow and fast dynamics of the signal using resampled data and different sequence sizes. Finally, the autoencoder model predictions were resampled and aggregated using exponential smoothing of the short–term constant autoencoder output to allow the long–time constant autoencoder to overtake the data reconciliation in medium–to–long forecasting horizons (1 hour or more). A schematic of the AI–based data validation framework can be seen in Figure 2.

The autoencoder models proved to have very high accuracy, as can be seen in Figure 3, wherein the case of the ammonium data signal, the autoencoder models' test performance has been shown when the raw data is resampled to every 5 minutes (short–term dynamics) and every 30 minutes (long–term dynamics). This allows for a good reconciliation performance considering the variability of the signal.

Finally, the near real–time validated data signals and the raw data signals can be relayed to a dashboard. The validated signals will be used as a screening of data that will subsequently be ingested by other AI–based data–driven models enabling monitoring and smart control of the WWP to minimize greenhouse gas emissions and energy consumption.

The Waternet team has already developed soft sensors to estimate key process variables of the WWTP. The first soft sensor replaces a number of inaccurate aeration flow sensor readings. The soft sensor is an AI tool that estimates the individual aeration flows to each of the seven aeration tanks, based on one accurate aeration flow sensor, the header pressure, and valve positions. This soft sensor is crucial to quantify the energy reduction possible through optimal control. The second soft sensor developed is the prediction of the influent flow of the treatment plant. Two AI models were trained and predictions performance was compared. The prediction horizon of the influent forecast model is 75 minutes with a sliding time horizon. Waternet has also developed a digital twin for the WWTP which describes the behavior of the treatment plant. This AI model estimates the state of more than 10 outputs, using an aggregation of over 30 input variables and has been linked to an

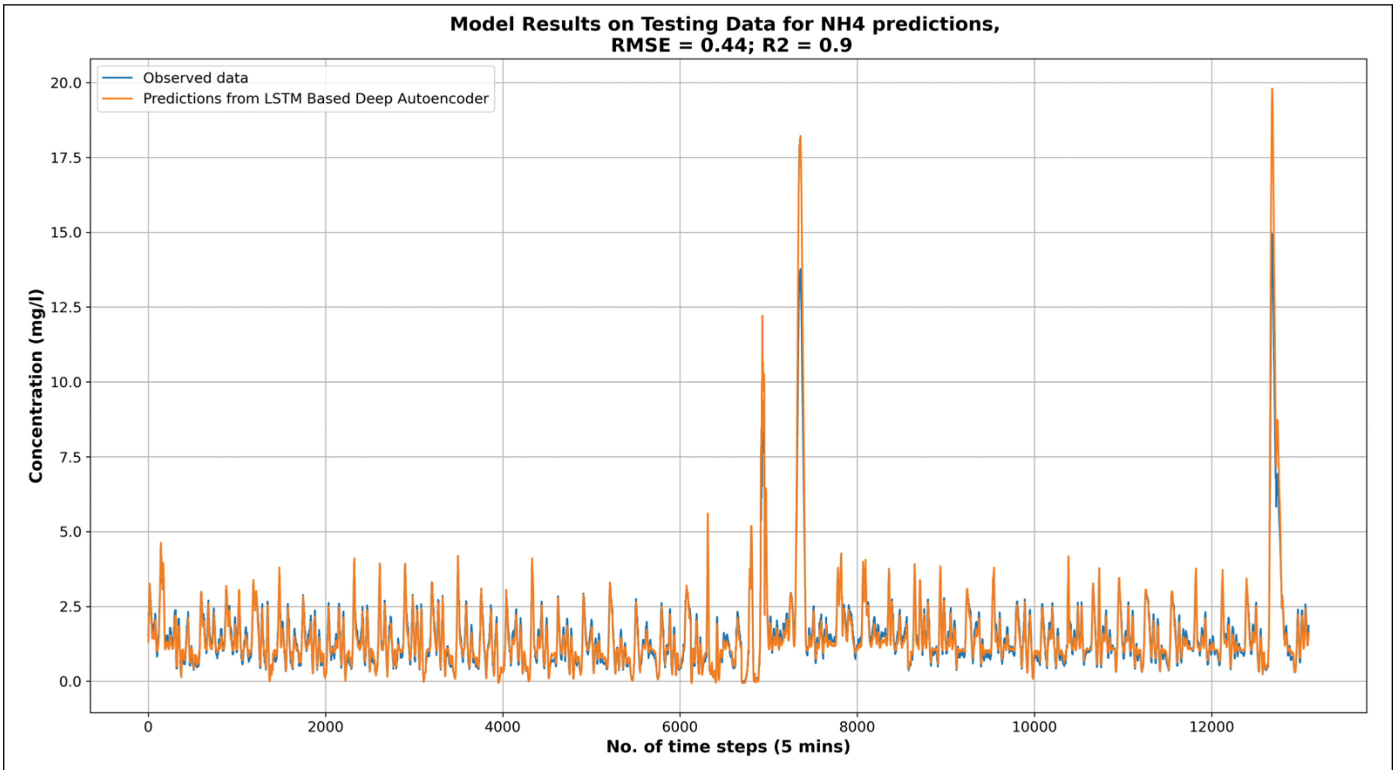

Figure 3A

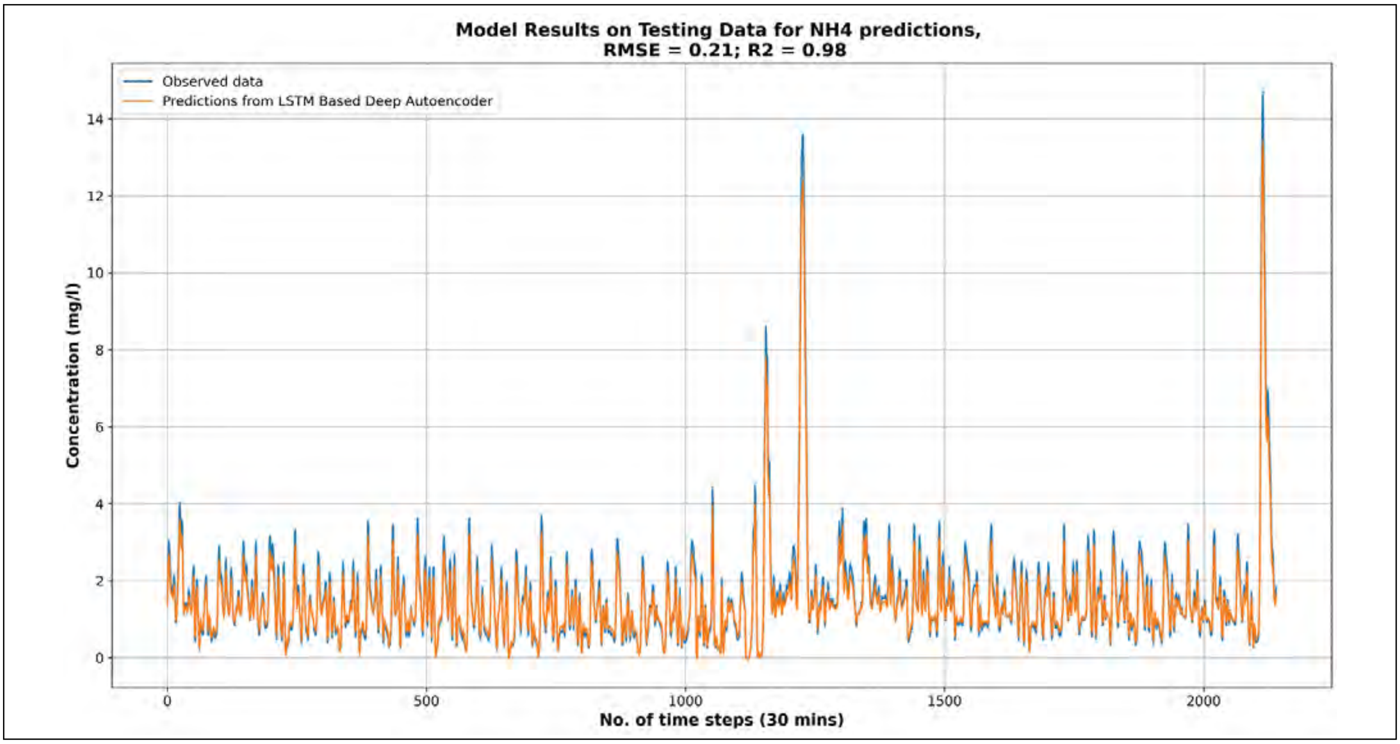

Figure 3B

Figure 3: Test results using raw data of the ammonium sensor (blue line) and the predictions of the autoencoder models in the case when data is sampled every 5 minutes (a) and every 30 minutes (b)

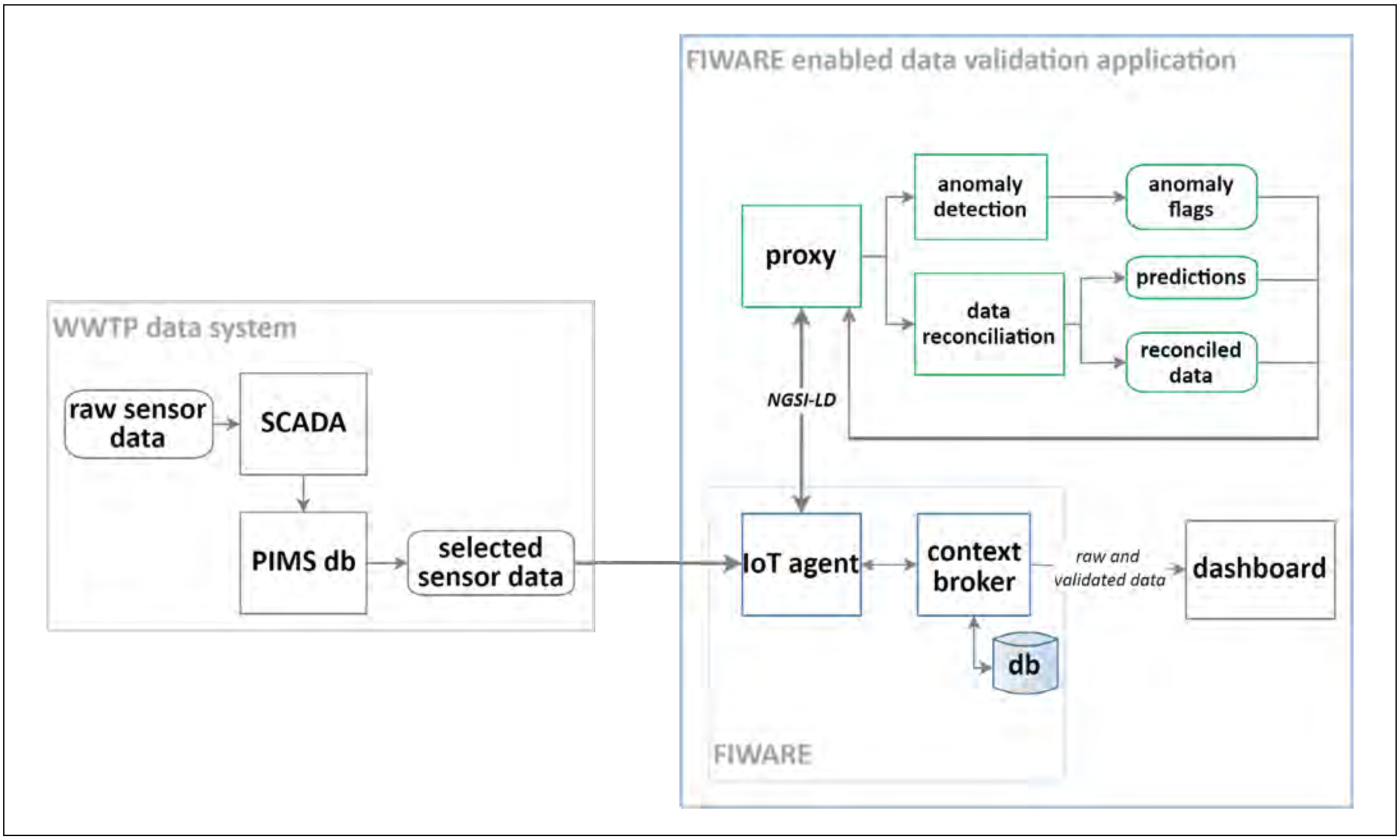

Figure 4: Simplified schematic overview of the data flows in the context of data validation within the architecture of the water utility

AI control model. The control model, which is based on reinforcement learning, determines the optimal control settings based on a reward system that includes energy use and nitrous oxide emissions. Once all remaining new sensors have been installed and sufficient data from the research lane have been collected to train the control model, the latter will be deployed and validated. Currently, the AI model has been successfully tested in other treatment lanes of the WWTP. The process automation system has also been modified, enabling the capability to use the setpoints determined by the AI control model.

Connecting Developed Smart Application with Fiware4Water Architecture

Through the Fiware4Water project, the smart applications developed for the case study will finally be integrated within a FIWARE architecture, while preserving the integrity and functioning of the legacy system. As an example to illustrate the integration of a smart application, Figure 4 provides a simplified schema that visualizes the connections between the legacy system, the AI–based data validation application, and FIWARE. The Distributed Control System directly communicates with the sensors installed in the research lane and the data can be accessed through the Process Information and Management System (PIMS). This legacy system can then communicate with the Fiware4Water architecture, which has now been integrated, tested, and deployed within a virtual test environment on–site. All communications within this architecture are conducted using interoperable (smart) data models and APIs. The real–time raw data and the validated signals from the data validation application are relayed via the proxy and FIWARE setup towards a dashboard.

Conclusion

With the water sector undergoing a digital transformation, the development of smart water applications is a need of the hour, thereby utilising enabling and upcoming technologies such as data–driven AI modelling, that can result in the upgrading of water utilities' IT and data architecture to achieve automated plant–wide control. Additionally, FIWARE can accelerate the transition of the water sector to optimally benefit from such key technologies and ensuring cross–domain cooperation (e.g. with energy). Today, many water utilities and authorities around the globe are benefitting greatly from such technologies and applications. India which faces formidable challenges in achieving water security and sustainability, due to its growing population and the impacts of climate variability, is ideally poised to harvest the value of data in the water sector. There are currently landmark programmes and schemes set up by the Government of India, namely the Namami Gange Programme, Smart Cities Mission, and other water–related schemes, where the development and implementation of a data architectural smart solutions approach for enabling digital water can help India to address its formidable water challenges. Accordingly, KWR Water

Research Institute is at the moment actively contributing to India's vision by collaborating, partnering, and co–creating knowledge with relevant Indian stakeholders. It is KWR's mission to share the combined relevant experience of the institute, the Dutch water sector, and partner's all over the European Union with our existing and new partners in India. Smart water applications are a key theme for such a collaboration, among many more. Currently, KWR is actively collaborating with Larsen & Toubro Water and Effluent Treatment IC as a knowledge partner where the two organizations are actively exchanging knowledge and are initiating capacity–building activities, thereby beginning a collaborative journey to collectively tackle India's water challenges.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821036

JAI MAA ASSOCIATES Engineers & Contractors providing services to Military Engineering Services for last two decades

Pre-Engineered Building & Infrastructure	Electro-mechanical utility services
Water & Wastewater Treatment Projects	Low Tension Electric Works
Sewage Disposal and Water Distribution Network	Incinerators

JAI MAA ASSOCIATES
ENGINEERS & CONTRACTORS

JAI MAA ASSOCIATES

Shop No. 33 Gopinath Bazar, Delhi Cantt - 110 010
M.: +91 98111 88819, Fax: +91 11 2568 2346, E.: jaimaaassociatesdelhi@gmail.com, jaimaa98@gmail.com, info@jaimaaassociates.in