LOTUS

LOW-COST INNOVATIVE TECHNOLOGY FOR WATER QUALITY MONITORING AND WATER RESOURCES MANAGEMENT FOR URBAN AND RURAL WATER SYSTEMS IN INDIA

Deliverable D 4.1

Technical requirement for the real time tools

Lead: IIT Bombay

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Abstract
This document captures the first version of the technical requirements of all real-time management tools involved in each use case, outlining all the models, their input and output requirements and how they are to be integrated with platform in an overall system arcitecture. It thus establishes the technical framework for the online tools at each of the Use Case studies in LOTUS.

Keywords
-

Disclaimer

The LOTUS Project

LOTUS is a project funded by DG Environment under the European Union Horizon 2020 Research and Innovation Programme and by the Indian Government. It brings together EU and Indian prominent organisations with the aim to co-create, co-design and co-develop innovative robust affordable low-cost sensing solutions for enhancing India's water and sanitation challenges in both rural and urban area.

The LOTUS solution is based on an innovative sensor and includes tailor-made decision support to exploit the capabilities of the sensor as well as a specific approach to co-creation. LOTUS aims to be co-designed and co-produced in India, and have a wide, diverse and lasting impact for the water sector in India due to intense collaborations with commercial and academic partners in India.

Based on the low-cost sensor platform, solutions for the early detection of water quality problems, decision support for countermeasures and optimal management of drinking and irrigation water systems, tailored on the functionalities of the new sensor, will be developed and integrated with the existing monitoring and control systems.

This sensor will be deployed in five different use cases: in a water-network, on ground-water, in irrigation, in an algae-based waste water treatment plant and in water tankers. The packaging of the sensor, as well as the online and offline software tools will be tailored for each of the use cases. These last will enable to test the sensors and improve them iteratively.

The project is based on co-creation, co-design and co-production between the different partners. Therefore, an important stakeholder engagement process will be implemented during the project lifetime and involve relevant stakeholders, including local authorities, water users and social communities, and will consider possible gender differences in the use and need of water. Broad outreach activities will take place both in India and in Europe, therefore contributing to LOTUS impact maximisation.

The further development and exploitation (beyond the project) of the novel sensor platform will be done in cooperation with the Indian partners. This will create a level playing field for European and Indian industries and SMEs working in the water quality area.

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Acronyms and Definitions

Acronyms	Defined as
API	Application programming interface
DMA	Distric metered area
GSM	Global System for Mobile Communications
QGIS	Quantum geographic information system
MILP	Mixed integer linear programming
NMPC	Nonlinear model predictive control
OPC	Open platform communication
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SQL	Structured query language
WDN	Water distribution network
WP	Work package

1 Executive Summary

This report captures the technical requirements of various modelling algorithms and tools for the optimal operation of water systems of each use case in real time, or near real time (i.e. response times between minutes to few hours). In this document, a list of real-time tools is first enlisted for each use case and then a collection of technical requirements for the execution and integration of real-time modelling and optimization tools with the LOTUS platform is presented, with specifics to each use case study.

The overall technical architecture presented in this document for each case study outlines the connections between tool input data requirements, modelling or solver requirements, output data requirements and any additional nodes for developing the application interface at the LOTUS platform. This framework will assist the teams in decisions on subsequent steps for implementation of the real time tools with the state-of-art platform where data will be collected, processed in real-time with the simulation/optimization tools and receives feedback for deciding optimal water systems management strategy.

In addition, this document also defines, if any, technical gaps that need to be bridged for integrating the real-time tools with the platform in each case study. This document is a first version of such technical requirements and will be kept updated, as and when need arise in any use case.

2 Overview

This document establishes the technical framework for the real time (online) tools for the LOTUS case studies. These real time tools for optimal operation of water systems as part of WP4, focuses on the development of modules for real-time data processing and real-time management of water systems, i.e. dynamically reacting to changing situations, demands, quality problems, failures, leakages, etc. while also ensuring the suitability of the tools with the use case instalments.

In this deliverable, several technical requirements are collected for the execution of such modelling, simulation and optimization tools on the integrated platform (from WP5) for each use case study. This will include (i) requirements for import (input data) and export (output results) of data to and from the tools, (ii) requirements of any numerical or optimization solvers used in the tools, and (iii) requirements for application interface with the integrated platform. If these requirements are not met directly for interfacing with the platform, decisions will be taken (based on the discussions in this document) to use available open-source software's or purchase the required licensed functionalities. Equal focus will be placed on water quality and quantity; for the former, a definition of relevant chemical species to be monitored within the case studies will be based on links to WP2 and WP6. Furthermore, a holistic approach will be used to address real-time optimal management that will take into account of all areas playing a role and affecting water management, including technical issues, projected deployment of sensors and characteristics of existing operating systems, as they are used at the Case Studies.

2.1 List of Real-time tools for all use cases

This section provides a brief description of various tools and functionalities for real-time operational management of each use case water systems, where LOTUS (sensors and tools) will be deployed.

2.1.1 Water Distribution Network Guwahati

1. ***Water quantity (pressure, flow) monitoring and anomaly detection in urban water distribution systems***

The main objective of this tool is real time detection of anomaly and early warning for quantitative (flow and pressure) disturbances in Guwahati piped water distribution network (WDN). These disturbances may occur after sudden physical damage to network components, for e.g. pipe bursts (natural, accidental or intentional), pipeline leakages, component malfunction (e.g. pumps, valves) etc. The detection will be based on pressure and flow sensors deployed in the network (existing or LOTUS deployed) and linked to the SCADA system. This functionality for real-time system operational management will involve models for event recognition (burst and leakage), leakage location identification and a holistic approach to leakage management by combining several types of alerts and approaches in a single Decision Support Platform to be developed in WP5.

2. ***Water quality monitoring and anomaly detection***

With the former tool focused on events related to water quantity, this tool will involve water quality monitoring in the Guwahati WDN and associated contamination anomaly detection functionalities. For this Guwahati WDN use case, this water quality monitoring tools will be based on and combined with the sensor placement module developed in WP3. The water quality parameters which will be considered in these tools will be based on report from WP3.

3. ***Real time mitigation measures for water quantity and quality alerts***

Once a valid contamination alert (based on flow/ pressure/ water quality disturbance) has been generated from earlier anomaly detection tools, these real-time mitigation support tools act to assist water utility operators in deciding and optimizing mitigation plans for clean water supply. This functionality will include a model developed by UNEXE to identify the locations of valves that need to be closed to isolate the burst pipe. This model needs the ID of the burst pipe and produces the IDs of the valves to be closed. Furher, these real time intervention measures will also cover tools and control strategy for optimal disinfectant dosage to ensure that disinfectant levels are high enough to minimize microbial contaminant re-growth, while minimizing disinfectant by products formation risk.

4. ***Real-time alerts to the public***

These tools will involve modules for alerting the public, using mobile phone applications (apps). It comprises the design and development of the apps, as well as the system/architecture of delivery to the public. The generic module will be adapted to the needs of each specific Use Cases, with specifically designed displays and screens, in the Indian language.

2.1.2 Tanker-based water distribution network

1. ***Short-term planning and operational management in real-time for tanker-based water distribution systems***

The objective of this tool is the real-time monitoring and management of tanker-based distribution systems. This includes, on the lower level, the monitoring of water quality based on data from LOTUS sensor deployed at water sources, tankers and consumption points, and on the systems level the planning of treatment plant operations, logistic optimization, and scheduling of tankers in adaption to the dynamic demand of costumers. It also includes an efficient water chlorination unit for mobile use on water tankers to maintain constant water quality in tanker-based distribution systems.

2.1.3 Irrigation Water distribution network

1. ***Real time optimal operation of irrigation systems based on quantity and quality monitoring***

The objective of the decision support tools is to assist in solutions for the optimal use of the available sources and of the optimal addition of fertilizer of water for irrigation. The goals are to provide a continuous flow of water of sufficient quality and to provide the right amount of fertilizer for optimum growth. Moreover, clogging of the irrigation systems must be reduced or avoided. This includes taking account of uncertainties (about the future inflow of water, in particular due to rainfall) for the informed decision-making to manage the storage and retrieval of water.

2.1.4 Groundwater and river water monitoring

1. ***Weather prediction tool for irrigation and ground and river water quality modelling use cases***

This tool will be concerned with time series based modelling of previous weather conditions to predict precipitation in the catchment areas of the river as well as other irrigation and ground water sources. Based on these prediction of the precipitation, in conjunction with other CFD/ hydrology-based models, the quality of the water stream will be predicted.

2.1.5 Algae based waste water treatment

1. ***Monitoring and control of algae-based waste-water treatment***

The information about the quality of the outflow of the experimental algae-based waste-water treatment plant will be used for model-based monitoring and control of the operation of the plant with the goal of long-term stability, meeting of water quality standards and assuring the usability of the algae. This will include the tools for investigation of observability of the process from different sensor information and a state estimator will be developed. Based on this information, strategies for the control of the algae based treatment will be designed and tested in simulations.

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3 Use case 1: Water Distribution Network of Guwahati

A drinking water distribution system should include all infrastructure needed to distribute treated water to service connections throughout the service area covered by the piped network. In this direction, online water quantity and quality monitoring in distribution systems involves the use of online sensors for real-time measurement of water quantity and quality at one or more locations in a distribution system. Further, with this sensor data, real-time tools are required by drinking water utilities to efficiently manage distribution system operations by detecting changes in water quantity and quality as they occur, and facilitate a timely and effective response. Specific details of technical requirements for deployment of all real-time tools involved in Guwahati WDN use case are discussed in this chapter.

3.1 Approach to address the use case

1. ***Water quantity (pressure, flow) monitoring and anomaly detection in urban water distribution systems***

This tool is built on following (fixed and mobile) sensor placement, burst detection and burst localisation models.

i. **Sensor placement**: Fixed sensors are established within a DMA to detect pipe bursts and to determine the rough area of the accident. A model developed by UNEXE is used for optimising the locations of the fixed sensors. To narrow down the potential locations of the burst, mobile sensors can be employed to collect real-time pressure data (over one to two hours) at predefined locations (optimised by a model developed by UNEXE). The extra monitoring data obtained by the mobile sensors will be used by a deep learning model (see details in 'burst localization') to determine the probability of burst happening at single pipes.
ii. **Burst detection**: It is based on real-time pressure data collected by the fixed sensors. SCADA data at the fixed sensors is fed into a detection model developed by UNEXE and the output is the probability of burst happening and the rough area (each sensor corresponds to a sub-area in a DMA) of it occurring.
iii. **Burst localization**: A deep learning model is being developed by UNEXE to produce the likelihood of burst happening at each pipe based on the mobile sensor data.

2. ***Water quality monitoring and anomaly detection***

The tool will include the following functionalities (flow chart describing the working of these tools is also shown below):

I. **Set point analysis**: The sensors placed in the network will be used to observe any violation in the quality standards of water being delivered. The range of the quality parameters at various monitoring locations will be estimated based on the location and EPANET simulation as shown in Figure 3.1.

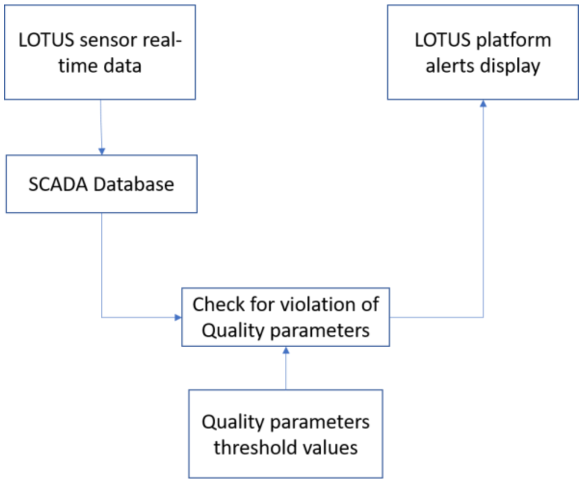

Figure 3.1: Schematic of Set-point analysis method for water quality anomoloy detection

II. **Advanced model analysis**: A model built on the basis of historical water quality and EPANET model data to consider the interactions between various quality parameters. This tool will include statistical and/or deep learning models to detect anomalies at the monitoring stations. A schematic of model structure is shown in Figure 3.2.

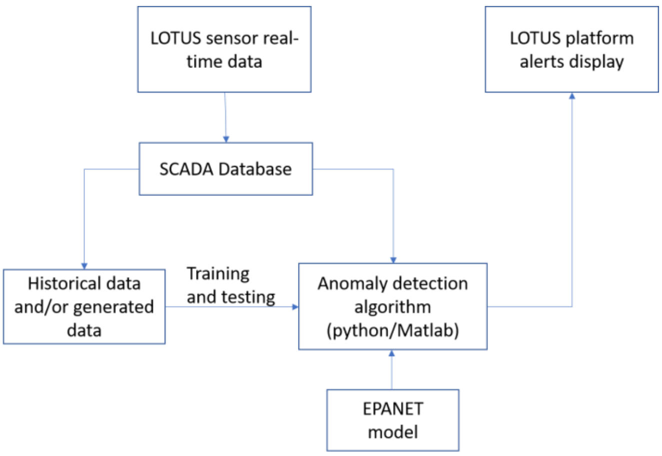

Figure 3.2: Schematic of ADvanced model- analysis method for water quality anomoloy detection

3. **Optimal Disinfectant Dosage for Chlorine residual control:**

Chlorine based disinfectants are most commonly used at treatment plants to ensures that pathogenic organisms be destroyed or inactivated before drinking water transports through distribution network. However, chlorine decay takes place in the pipe network, more so at the farther ends of the network. Therefore, adequate residual chlorine (under the regulatory minimum and maximum concentration levels) should be maintained (secondary disinfection) in the treated water to inhibit microbial (re)growth until the water is delivered to the consumers through the pipe distribution network. A two-point constrained zone control based optimization algorithm (developed by IITB) will be used in this tool for deciding optimal disinfectant dosage at several chlorine booster stations in the network. This approach comprises of clustering the large-scale network into several sub-systems and subsequently control the chlorine residuals at all nodes of the network in a coordinated decentralized fashion.

3.1.1 Description of Tools used in the approach

Water quantity *monitoring and anomaly detection:*

- **Pressure sensor placement**: A model (currently in Matlab but can be rewritten in Python) based on graph theory and greedy algorithm is being developed for optimization of the locations of the fixed sensors. The model (currently in Matlab but can be rewritten in Python) for determining locations of the mobile sensors is also based on graph theory. These two models can be run offline.
- **Pipe burst detection**: The SPC statistical model (in Python) is used for burst detection.
- **Pipe burst localisation**: A deep learning model is being developed, which is trained by the output from scenario analysis based on the EPANET model of Guwahati.
- **Valve operation**: A model based on graph theory will be used.

Water quality monitoring and anomaly detection: Quality contamination event detection based on (model to be discussed) combined analysis of online measured quality parameters, historical water quality data and future prediction based on EPANET simulations.

Optimal Disinfectant Dosage for Chlorine residual control: The tool uses EPANET and its multi-species extension of EPANET-MSX for distribution network hydraulic and water quality modelling respectively. EPANET is the open source simulator developed by US Environmental Protection Agency (EPA) for simulating water transport and quality in drinking WDN. Further, for the clustering and optimization purposes, the current version of algorithm uses MATLAB data analytic functions (principal component analysis and partial correlation analysis) and optimization toolbox.

3.2 Requirements for Input data to the tools

Water quantity *monitoring and anomaly detection:*

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- **Pressure sensor placement**: EPANET model input file (.txt) of WDN
- **Pipe burst detection**: real-time SCADA data
- **Pipe burst localisation**: output from the pipe burst detection module, extra monitoring data from mobile sensors
- **Valve operation**: confirmed location of burst

Water quality monitoring and anomaly detection

- **Set point parameters for monitoring**: EPANET model input file and water quality standards.
- **Advanced model analysis**: Historical water quality data (CANARY developed using 3 months data), EPANET model and real-time SCADA data.

Optimal Disinfectant Dosage for Chlorine residual control:

- EPANET input file (.txt) containing calibrated network model details and EPANET-MSX input file (.txt) containing water quality model.

3.3 Numerical/Optimization solver requirements of the tools

Water quantity *monitoring and anomaly detection:*

- **Pressure sensor placement**: EPANET model, Greedy algorithm
- **Pipe burst detection**: N/A
- **Pipe burst localisation**: EPANET model, deep learning algorithm
- **Valve operation**: N/A

Water quality monitoring and anomaly detection

- **Set point parameters for monitoring**: EPANET model.
- **Advanced model analysis**: EPANET model and others (MATLAB/python) based on the type of developed model.

Optimal Disinfectant Dosage for Chlorine residual control:

- The tool in current version uses *fmincon* solver of MATLAB for performing numerical optimization (i.e. iterative search method – “sequential quadratic programming”) in the algorithm. Other open source alternatives might be needed to look for.

3.4 Requirements of Application Interface with the Platform

Following are the specific details for interface of each modelling tool input and output requirements with the SCADA server and LOTUS cloud on the platform:

Water quantity monitoring and anomaly detection tools:

- **Mobile sensor placement**
- Modelling Tool basis: MATLAB
- Data Fetching from SCADA: N/A
- Interface with SCADA: Flat file communication from LOTUS CLOUD (It needs to be updated only when the EPANET input file is changed, e.g. addition/removal of pipes, change in nodal water demand).
- Frequency of data communication with SCADA: N/A
- Communication type between SCADA and Tool: N/A
- Use-case type: offline
- Output: Mobile sensor locations stored in LOTUS CLOUD

- **Pipe Burst Detection**
- Modelling Tool basis: Python
- Data Fetching from SCADA: every 5-15 min
- Interface with SCADA: Server and client based method for real-time communication required (OPC should suit).
- Frequency of data communication with SCADA: every 5-15 min
- Communication type between SCADA and Tool: uni-directional
- Use-case type: real-time communication
- Output: probability of burst having occurred based on measurement at each fixed pressure sensor. These values will be used for decision making through visualization tool of LOTUS CLOUD

- **Pipe Burst Localisation**
- Modelling Tool basis: Python+ EPANET
- Data Fetching from SCADA: Batch of data collected from mobile sensors measurement (not SCADA)
- Interface with SCADA: Server and client based method for real-time communication required (with wherever in LOTUS CLOUD the mobile sensor data is coming from).
- Frequency of data communication with SCADA: N/A
- Communication type between SCADA and Tool: N/A
- Use-case type: upon real-time detection of pipe burst

- Output: probabilities of burst occurring at every pipe within a sub-area. This should be shown through visualization tool of the Lotus Cloud.

Water quality monitoring and anomaly detection

- **Set-point Analysis**
- Modelling Tool basis: MATLAB + EPANET model
- Data Fetching from SCADA: Sampling in every 5 minutes
- Interface with SCADA: Both OPC and temporary database are applicable. OPC can be used for instantaneous data or the last input from the database (like SQL).
- Frequency of data communication with SCADA: every 5 minutes
- Communication type between SCADA and Tool: Two way
- Use-case type: Real-time
- Output: Quality of water in the network will be stored SCADA and displayed on tool

- **Advanced model analysis**
- Modelling Tool basis: PYTHON+MATLAB+EPANET
- Data Fetching from SCADA: Batch of last one hour
- Interface with SCADA : Either flat-file based communication or database set up for the tool.
- Frequency of data communication with SCADA: Every 15 minutes
- Communication type between SCADA and Tool: Two way
- Use-case type: Real-time
- Output: probability of water quality event in the network (if above certain number, will be sent for visualization tool on LOTUS CLOUD).

Optimal Disinfectant Dosage for Chlorine residual control:

- Modelling Tool basis: MATLAB + EPANET
- Data Fetching from SCADA: Batch type
- Interface with SCADA: OPC communication
- Frequency of data communication with SCADA: As and when some microbial contamination alert is generated.
- Communication type between SCADA and Tool: unidirectional communication from SCADA to MATLAB
- Use-case: real-time communication

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3.5 Interaction with SCADA & LOTUS Server

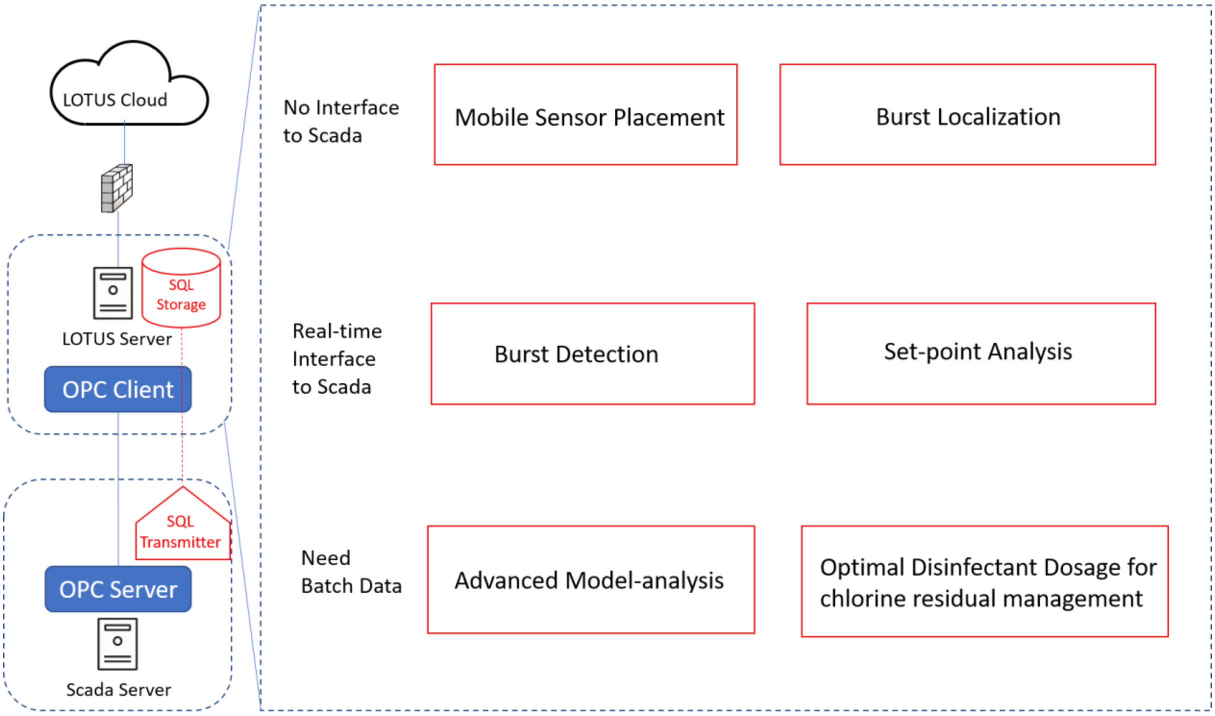

Figure 3.3: Structure for interaction of tools with SCADA and LOTUS server

3.6 Overall Architecture

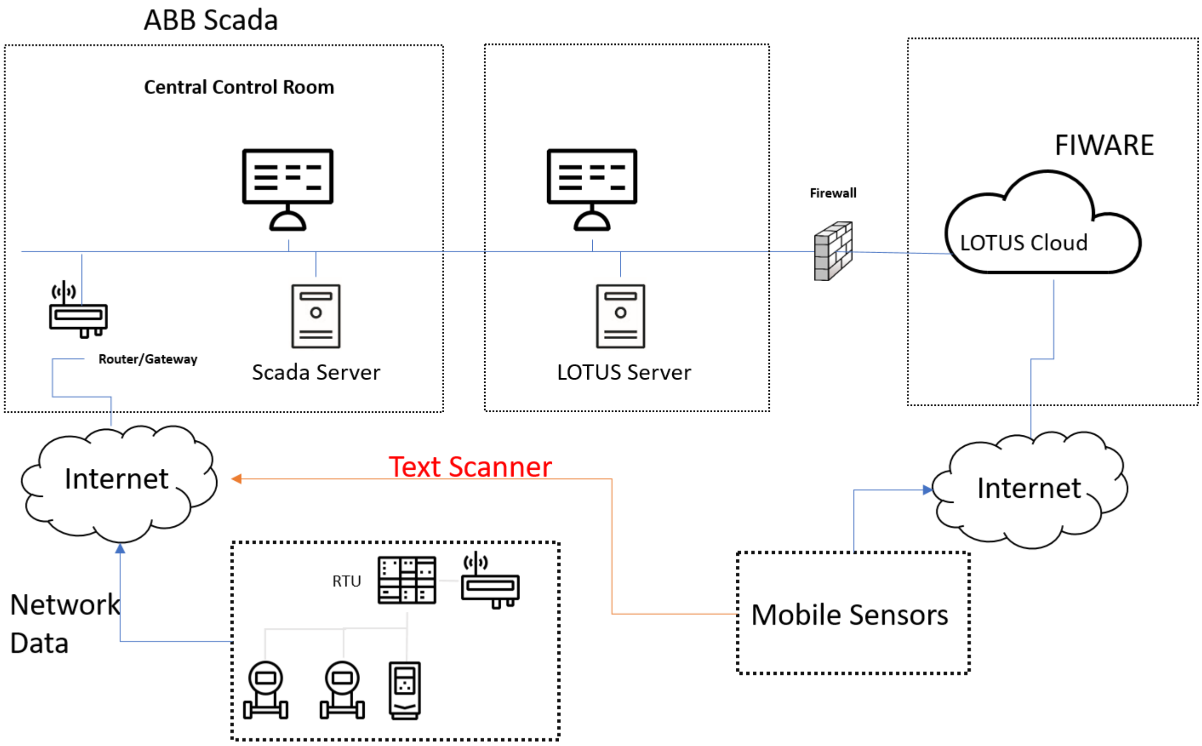

Figure 3.4: Schematic of System Architecture for Guwahati WDN

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4 Use case 2: Tanker-based water distribution network

The issue of increasing scarcity of water in many regions requires the development of new technological and scientific tools for efficient management of tanker based water distribution system. This chapter provides technical requirements for developing real-time tool to monitor and manage water quality and distribution of tanker water in urban areas.

4.1 Approach to address the use case

The lotus sensors deployed at the water sources and tankers will send the water quality parameters to the cloud database in real time wherefrom they will be accessed by the web/mobile application and displayed to the users for making well informed decisions regarding the use of water. The water quality parameter readings will also help in applying appropriate treatment to the water. The lotus sensors in tankers along with the water chlorination units will ensure constant water quality. The scheduling algorithm to be used will ensure successful management of water demand.

4.1.1 Description of the tools used in the Approach

Web and mobile app: Flask Framework (a python framework - used for developing backend API's), React Library (a javascript library for developing User Interfaces for web app), React Native (a javascript library for developing User Interfaces for mobile app), MySQL database management system (for storing data)

Scheduling tool: A scheduling algorithm developed (by IITB & IITG) in *FICO Xpress Optimizer* for MILP (mixed integer linear programming) problem of planning and scheduling tanker delivery and treatment-operations in tanker water distribution system. FICO is a commercial optimization solver having license requirements.

4.2 Requirements for Input data for the tools

Web and mobile app: The input data (like information related to users - distributors, drivers, customers, water sources, tankers, etc) will come from interaction of relevant users with the app. The data related to water quality (like TDS, pH, etc) will come from lotus sensors deployed at water sources and in tankers.

Scheduling tool: Text files (.txt) containing algorithm input data structures (described in D3.1 document) which are based on real-time data from customers/distributors.

4.3 Numerical/Optimization Solver requirements for the tools

Web and mobile app: N/A

Scheduling tool: MILP optimization problem solver (current version of algorithm uses Xpress MP solver of FICO optimizer)

4.4 Requirements for Output data from the tools

Web and mobile app: Water to be supplied by a distributor will have water quality parameters displayed in the app so that the customer can make well informed choice according to his need.

Scheduling tool: Text files (.txt) are generated containing results of the solved problem. These files can be further converted (by another software) to excel files for easy interpretation of the results for different requirements (drivers, distributors, treatment plant operators and customers).

4.5 Requirements of Application Interface with the Platform

Web and mobile app: N/A

Scheduling tool: Data input from real-time data and further execution of optimization solver. In addition, it will need http request and response for import of input data and export of output data respectively, to-and-fro API's in backend service.

4.6 Frequency of tools to be executed

Web and mobile app: App needs to be available 24x7

Scheduling tool: Can be run on hourly/daily/weekly basis

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4.7 Overall Architecture

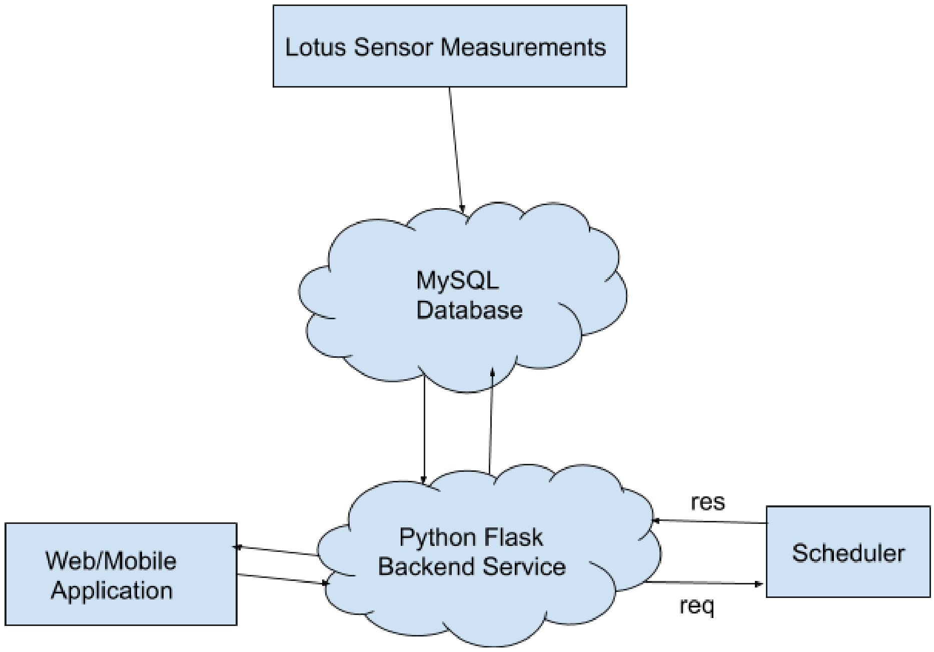

Figure 4.1: System architecture for real-time management of tanker-based water distribution system

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5 Use case 3: Irrigation water distribution network

The use of LOTUS sensor in drip and sprinkler irrigation systems offers the chance to bring a new level of automation to the mainly manually operated farming sector. The real-time measurement of relevant irrigation water quality parameters combined with weather data allows for the creation of tailored irrigation and fertigation instructions on daily basis. The goal of the real-time tool is to provide decision support for irrigation system operators with respect to both water quantity and water quality management. The water quantity management aims at guaranteeing sufficient soil moisture levels for the specific crops under minimal water consumption. The water quality management is concerned with adjusting the fertilizer dosage based on the chemical parameters of the source water to improve the availability of added plant nutricients, to prevent damaging the soil and to minimize the risk of clogging in the irrigation network. An alarm feature that triggers interventions by farm personnel in case of hazardous water parameters will be incorporated as well.

5.1 Approach to address the use case

The two main goals of optimizing the quantity and the quality of the water that reaches the crops are rather independent. The information on water quantity per irrigation event, crop type and age and recent and near future weather conditions are used to determine optimal irrigation instructions on a daily basis by means of model predictive control. The model generation is supported by data-based modelling techniques and machine learning. Based on current water quality measurements, data-based models and crop nutrient requirements, recommendations for the fertilizer and set-points for the dosage system can be calculated. An additional functionality will be sending alarms in case of water parameters reaching harmful values or leading to a high risk of clogging.

5.1.1 Description of the tools used in the Approach

do-mpc: An open source python library for the development of model predictive control applications created by TU Dortmund (www.do-mpc.com). It uses the open source tools CasADi (https://web.casadi.org/) and Ipopt (https://coin-or.github.io/Ipopt/) for solving optimization problems. do-mpc will be used for the model predictive control of irrigation water quantity.

PyTorch: An open source python library for machine learning (www.pytorch.org). PyTorch will be used for data-based modelling in both water quantity and water quality control subcases. The models are trained offline, PyTorch is not directly part of the real-time tool.

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5.2 Requirements for Input data for the tools

do-mpc: Models are written in python, measurement data can be read from databases, csv files or any other interface that the python programming language offers.

PyTorch: Training data for machine learning can be imported from any format that is accessible with the python programming language. This is done offline and not during the real-time application.

5.3 Numerical/Optimization Solver requirements for the tools

do-mpc: The open source tools CasADi and Ipopt are included with the do-mpc library, no additional solvers are required.

5.4 Requirements for Output data from the tools

do-mpc: Results of each step of the model predictive control run are stored in a database. Export to most file types and interfaces possible with python.

5.5 Requirements of Application Interface with the Platform

The application will use JAIN's communication platform.

The application must read the measurements and get weather data and write back the optimized irrigation and fertigation instructions. It must be possible to send out notifications to the mobile device of the person operating the irrigation system for both presentation of instructions and alarm notifications.

The Lotus platform from WP5 can be used for the collection of weather data from various sources and for the storage of weather and water quality data as well as results of the decision support routines. The cloud may be used to provide long-term data to the end users, e.g. via a web interface. This requires the possibility to export time series data to the LOTUS platform from the JAIN platform, e.g. using OPC as basis.

5.6 Frequency of tools to be executed

The model predictive control of irrigation water quantity is executed daily to generate a new set of irrigation instructions with updated measurements and weather data. The recommendations for fertilizer composition and dosage are calculated daily with the possibility for triggering recalculation for irrigation system subsections based on the most recent measurements shortly before they are irrigated. The alarm functionality requires more frequent execution about once every five minutes.

5.7 Overall Architecture

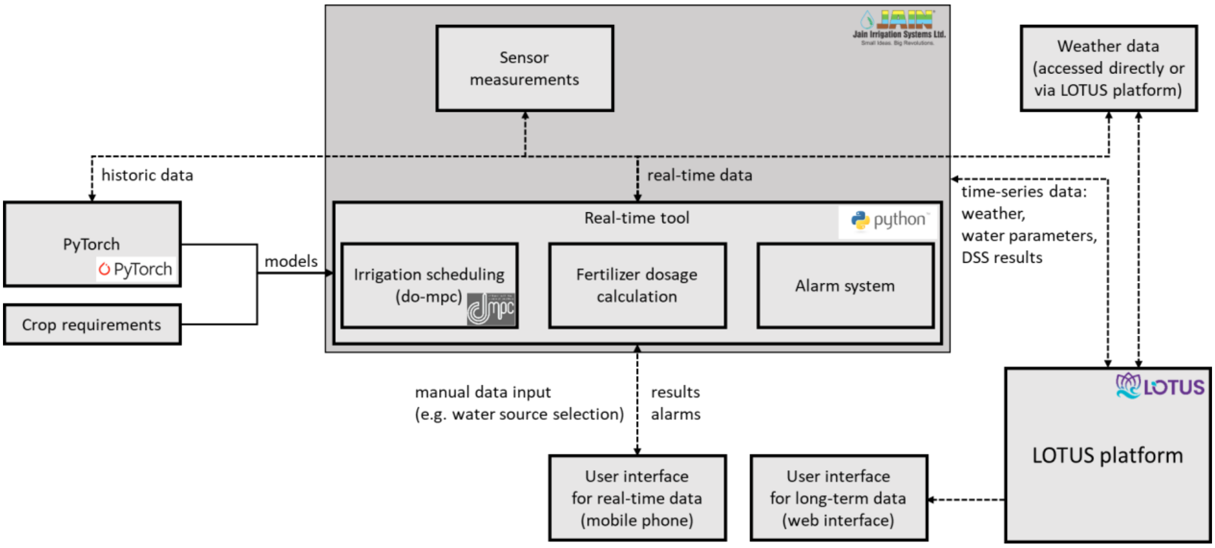

Figure 5.1: The overall architecture for the decision support tool for irrigation water management.

6 Use case 4: Ground water and river water monitoring

The goal of this use case is to assess the hydro-geochemistry pollution by real-time monitoring systems for groundwater (viz. arsenic & fluoride for Guwahati and toxic metal for Bangalore city, India) and surface water (viz. toxic metal for Ganga river near Varanasi city, India) sources.

6.1 Approach to address the use case

In the progress to achieve these use cases objectives, for groundwater quality monitoring a numerical contaminant transport modeling software QGIS and GMS will be adopted for Guwahati city whereas for Bangalore city groundwater quality will be manually monitored using LOTUS multiparameter field testing kit. Ganga river water samples will be collected using exiting water depth measuring mechanism and hydro-geochemistry will be measured on site using LOTUS multiparameter field testing kit.

6.1.1 Description of the tools used in the Approach

Description of the tools used for the groundwater quality monitoring at Guwahati city

A numerical transient state arsenic & fluoride contaminant transport model will be developed in QGIS and GMS software. To obtain the contaminant gradient model for the study area, the groundwater table model initially developed and further used for the contaminant transport model. Later their results will be used for groundwater quality continuous monitoring well (minimum 6) location finalization. The groundwater quality will be monitored once in week and data will be stored in the cloud for further action.

Description of the tools used for the groundwater quality monitoring at Bangalore city

For Bangalore city groundwater quality measurement, a blanket survey for typical groundwater parameters will be initially conducted manually, using LOTUS multiparameter field testing kit. Then based on the results, appropriate water filtration techniques will be suggested for the respective areas and data will be stored in the cloud for further action.

Description of the tools used for the Ganga river water quality monitoring at Varanasi city

Ganga river water quality will be monitored for typical water parameters at least of three different cross-sections of the river. The river water samples (at least three) will be collected from approximately 15m depth and samples will be analysed onsite using LOTUS multiparameter field testing kit and data will be stored in the cloud for further action.

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6.2 Requirements for Input data of the tools to groundwater and surface water quality monitoring

The basic requirement for groundwater monitoring input data are seasonal arsenic & fluoride groundwater concentration (along with other essential parameters), groundwater table (i.e. observation well data), lithology (at least for 1 km^2 well lithology) and meteorological data (at least from one nearer station) required for Guwahati city. Whereas for Bangalore city, groundwater quality of the entire city is essential for the representative area and aquifer depth. Seasonal hydro-geochemistry data of Ganga river water is required for designing and verifying the detection limit of respective parameters and its suitability for the multiparameter LOTUS kit.

6.3 Numerical/Optimization Solver requirements for the tools

Guwahati groundwater monitoring: Numerical contaminant transport model will be optimized based on inbuilt forward finite difference method for arsenic & fluoride concentration prediction for Guwahati city.

For Bangalore and Varanasi city: analysis the data and quantify in various units as per users requirement is needed.

6.4 Requirements for Output data from the tools

The output from the tool should provide a compatible file format with a specific time, date, and station name. The data should have compatibility with the processing system (viz. computer, laptop and mobile phone) connectivity.

6.5 Requirements of Application Interface with the Platform

Following requirements are needed from the application point of view from the interface with the platform:

1. Graphs with appropriate legends size and classification.

2. Two-dimensional contaminant concentration map (i.e. previous day, present-day and next day) for respective study area.

3. Can be enabled export to compatible text files.

4. This platform should have manually and automatic data entry option, graphical plotting and displaying the map (i.e. previous day, present-day and next day).

6.6 Frequency of tools to be executed

In the case of Guwahati groundwater quality monitoring, the frequency of tool execution can be limited to once in a week, and results can be displayed on a public platform. In Bangalore city, at the initial stage frequency of tool execution, can be maximum limited as 8 hours per day, and after complete survey and proper understanding of contaminant concentration in the respective area, it can be used once per week. For use of Ganga river quality monitoring, this tool should be executed continuously (except the high flood situation), a minimum of 8 hours per day (i.e. for 24 h) by dividing peak time into four slots (each slot of two hours).

6.7 Overall Architecture

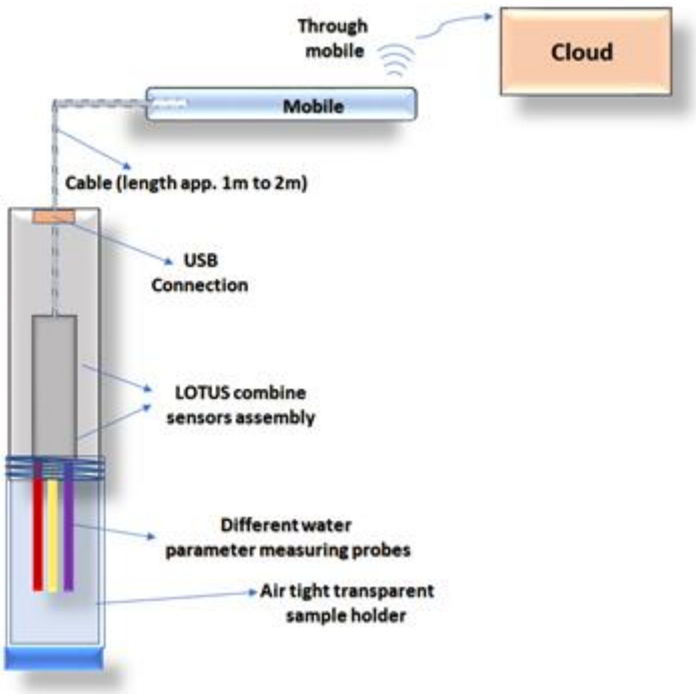

Figure 6.1: The overall architectural requirement needed for multiparameter field water testing kit

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7 Use case 5: Wastewater treatment

Two wastewater treatment processes are considered in this use case: an activated sludge wastewater treatment process (NIT Warangal) and an algal-based wastewater treatment process (NEERI, Chennai). In both cases, robust multi-stage Nonlinear Model Predictive Control (NMPC) will be implemented to satisfy the stringent effluent requirements while minimizing the operational cost by improving the overall efficiency of the process. NMPC is an online advanced control strategy that requires real-time measurement information (feedback) in order to be successful. The measurement information is used to estimate the current state of the plant using nonlinear state and parameter estimation techniques such as the extended Kalman filter, the unscented Kalman filter or moving horizon estimation. The estimated states are used to initialize the control scheme, which then solves an optimization problem to obtain the control inputs (manipulated variables in the plant). The control inputs are then communicated to the plant to achieve a desired response. This process continues in real-time as long as the process is active.

7.1 Approach to address the use case

The backbone of the approach is the model that will be built to predict the behaviour of the plant. The plant-model mismatch will be addressed in two ways:

1. Using multi-stage NMPC that can handle plant-model mismatch.
2. Adapting the model online using the measurement data.

For the successful application of robust NMPC online and adapting the model online requires timely update of measurement information from the sensor to the controller and from the controller to the plant. The controller is typically implemented on a personal computer that runs the NMPC and the estimation algorithms. Hence the communication time between the controller and the plant should in a range of 1 second to one minute. Additional sensors will be used in addition to LOTUS sensors to estimate the current state of the system.

7.1.1 Description of the tools used in the Approach

do-mpc: do-mpc is an open-source software platform for developing online NMPC solutions and estimation algorithms. The modular structure makes it efficient and easy to adapt to different user needs. do-mpc is a Python-based software (Python 3.X). For further details, refer www.do-mpc.com. A variant of the approach is also available in MATLAB.

7.2 Requirements for Input data for the tools

The measurement data from the LOTUS and the other sensors at the plant are the input for the control of the wastewater treatment process. It is possible to read data from open source databases such as MySQL, MongoDB, etc. The other option can be to use OPC communication/ other open source communication with python libraries. All the measurement data from the LOTUS and the other sensors should be available in the cloud. OPC communication or other open source communication with python libraries are recommended.

7.3 Numerical/Optimization Solver requirements for the tools

do-mpc software uses CasADi and Ipopt for efficient computation of numerical solutions. CasADi is an open source tool for algorithmic differentiation. Ipopt is an open source software for large scale nonlinear optimization problems. Further details of CasADi can be obtained from https://web.casadi.org/ and Ipopt can be obtained from https://coin-or.github.io/Ipopt/

7.4 Requirements for Output data from the tools

The results of do-mpc can be stored in a local database or can be communicated through open source tools with python libraries. The data must be transmitted to the actuators present at the plant, either directly or via a SCADA or small DCS system, as, e.g., SIEMENS S7. The output data should also be available in the cloud through one-way communication. That is, the data should not be editable through the cloud, but the cloud should be able to collect data. OPC communication or other open source communication with python libraries are recommended.

7.5 Requirements of Application Interface with the Platform

The requirement of application programming interfaces (APIs) depends on the type of communication/database used as defined in the other subsections. Additional APIs are not necessary.

7.6 Frequency of tools to be executed

The measurement data should be collected from the sensors and communicated to the database, and the control input data should be transmitted from the database to the actuators every fifteen minutes.

7.7 Overall Architecture

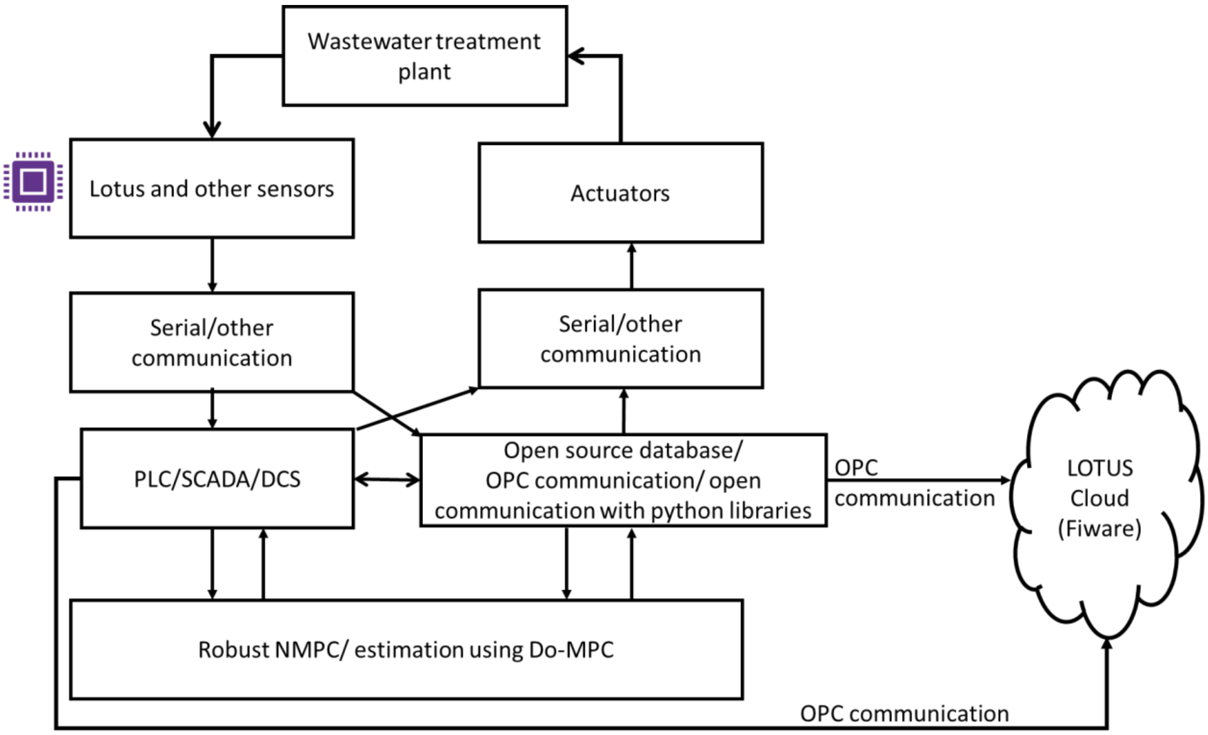

Figure 7.1: The overall architecture of the feedback control of wastewater treatment plant

Further details about the details of data acquisition and control for the plant at NIT Warangal

- Microcontroller based CPU card with 62 kBytes of nonvolatile Flash/EE program memory
- Integrates a high performance self-calibrating multichannel ADC, a dual DAC
- Four kBytes of nonvolatile Flash/EE data memory, 256 bytes RAM, and 2 kBytes of extended RAM are also integrated on-chip
- 8 Digital Input & 8 Digital Output
- Two-channel current to voltage converter
- Two-channel voltage to current converter
- RS232/USB Interface

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- In-Built IC regulated power supply
- Analog Input: 8 Channel, Resolution: 12 bit, Sampling Rate: 420ksps, Range : 0 to 5v
- Analog output : 2 Channel, Resolution : 12 bit, Range : 0 to 5v
- I/V and V/I converter
- No. of I/V: 2 Channel, Input range : (4-20)mA, Output Range : (0-5)V
- No. of V/I: 2 Channel, Input range : (0-5)V, Output Range : (4-20)mA

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8 Summary

The technical requirements of various real-time tools involved in each use case are thouoroghly discussed in this document. Each chapter in the document provides a brief overview of real-time monitoring and mnagament approach to address the use case, technical aspects of modelling and optimization algorithms involved in each tool and corresponding requirments for interface with the LOTUS platform.

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