International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 09 | Sep 2018 www.irjet.net p-ISSN: 2395-0072

REFlex Water – A Tool for Smart Water Management

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Abstract - *The water management is a fundamental question to ecosystems and human beings. Due this diversity of public and private institutions involved in resource hydric management, it is difficult to manage these systems through conventional business processes based on predetermined flows. In this context, declarative processes can offer the flexibility necessary to represent the complex forms of interaction and respond appropriately to changes and unforeseen situations that may occur. This paper proposes of a water management tool, called REFlex Water, based on the modeling of declarative business processes to assist managers in water management and decision making. The Platform combines complex event processing and technologies of internet of things coordinate with a management system of declarative business processes. Also, we provide an architecture for interaction between the subsystems enabling that are manageable and interoperable between themselves. Results are presented to demonstrate the feasibility of the proposed approach, and they indicate that failures should not be neglected.*

Key Words: **reflex, internet of things, declarative process, reflex water, water supply systems, water management**.

1. INTRODUCTION

Water resources available to cater the world population are likely to remain immutable over the years. In this context, the efficient management of water has great impact on various aspects of human life such as food production, health, comfort, and power generation. Water management is the activity responsible for optimizing the use of water resources. It involves planning and controlling the storage, distribution, and reuse of water. The quality of service is a critical factor, which is directly related, for instance, to bad resource utilization that may prevent organizations from achieving their goals [1].

The water industry operates in a scenario with complex interaction between sectors with conflicting interests, such as socio-economic versus environmental systems. Representing this diversity through conventional processes (e.g. BPMN [2] and other workflow notations), based on fixed and predetermined flows of activities, is a huge challenge. This is true even for process managers with extensive experience in the water sector. In this scenario, declarative processes can provide the necessary flexibility to represent the complex forms of interaction required for efficient water management.

Traditional business process specifications rely on an imperative paradigm, wherein every action is prohibited unless explicitly stated otherwise. As a counterpoint, Pesic [3] proposed the declarative paradigm for business process, which allows the execution of every action except when it's explicitly prohibited in the process specification. Defenders of the declarative paradigm claim that it can produce more flexible processes.

Water management systems include a set of rules, which define the policy to be followed by water managements. However, in the context of IoT-based systems, it may be difficult to anticipate all scenarios and establish how managers should do in each situation. Therefore, such systems usually rely on the experience of managers to decide what must be done in the presence of a given warning signal. In other words, managers are free to act, provided they follow the predefined policies. In this context, declarative processes seems to be the natural choice to specify the management policies and control the managers operations. Such business process paradigm offers the desired freedom of action while preventing the execution of activities that violate management policies.

In this perspective, the main contribution of this paper is to fill this gap and innovate with an architecture oriented to declarative processes built with the objective of providing, through rules, the proactive management of water policies and treatment of contextual information in the physical environment of the supply system.

We propose in this paper, a water management tool, called REFlex Water, that uses declarative business processes to specify the management policies and to control the actions of water managers and technology internet of things. Experimental tests were conducted that evaluated the platform's ability to respond to requests through of the metrics, response time and number of transactions per second demonstrate the ability of the proposed approach and they indicate that failures should not be neglected.

The remainder of this work is organised as follow. Section 2 presents related work and Section 3 introduces basic concepts. Section 4 presents the proposed tool and its operation. Finally, Section 5 presents the case study, and Section 6 concludes this work.

2. RELATED WORK

The Internet of Things (IoT) is a pervasive and ubiquitous dynamic network infrastructure that allows the interaction between things/objects and people [5].

A literature review on the use of IoT technologies for water management indicates that this theme has gained increasing attention. However, most research papers are actually pure engineering works. They focus on the IoT infrastructure itself to demonstrate and evaluate some implementation alternatives. Other works address innovative strategies for analysing the massive amount of data generated by the sensors. They want to identify patterns (e.g. water losses) through big data technologies. Unfortunately, in real scenarios, the analysis must produce results in real time. Otherwise, it may be too late to take the necessary measures to avoid disasters or other incidents. To confirm these facts, we present below a summary of the main works related to our theme of study:

- Anjana et al. [6], presented an IoT design for real-time water flow metering and quality monitoring that avoids the traditional manual process. The investigation addresses new challenges in the water sector: ease of billing; fair billing; data analysis of supply versus consumption; as well as monitoring water quality indicators using pH and ORP sensors;
- Kulkarni and Farnham [7] conducted case studies addressing problems, such as leakage management, demand management, and asset management in scenarios involving two utilities in Europe. The studies aimed at evaluating the impact of wireless connectivity on the global performance of IoT solutions for water management;
- Koo et al. [8] proposes a schematic development of IoT application for Big Data collection through a huge number of water clients. The data mining is defined to identify the important indicators from the water system such as: pressure; flow; illegitimate water consumption; location and quantity of water breaks and losses;
- Navarro-Hellín et al. [9] developed an architecture to manage the water supply in an irrigation system. The architecture includes wireless nodes equipped with GPRS connectivity. Each wireless node makes use of solar energy to get autonomy. It installs sensors for measuring a wide range of parameters of the soil, plant, and atmosphere. These data is then sent and stored in a remote database, allowing further analysis;
- Kartakis et al. [10] developed an tool for monitoring, controlling and simulation smart water networks. The studies performed on the water distribution network allows evaluating and identification dynamic events (e.g. leakages) and energy optimization. Besides, the results assist managers in decision making.

3. BASIC CONCEPTS

This section presents the basic concepts adopted and discusses the adopted Water Supply System for building the REFlex Water framework.

3.1 Declarative Process

The companies structured on the basis of their processes allow an effective restructuring [11]. The purpose is to achieve improvements in time, quality, cost reduction and customer satisfaction, giving opportunities to the organization to have more dynamism, flexibility and ability to change. Dynamics process management systems emerge as a necessity to allow dynamic changes in workflow management systems. In response to the demand for dynamic management of business processes, a new generation of adaptive workflow management systems is developed, the flexible processes [4]. Among the flexible approaches we have the declarative processes.

The main concept of declarative modeling is that the process behavior is defined by constraints. In this approach, a business process model is formed by two elements: states (activities) and constraints (business rules) [12]. Such rules define permissions, obligations and prohibitions about the activities of the process. Therefore, any activity that is not prohibited can be performed.

Thus, there may be several execution possibilities for the same activity. However, the decision about which activity to perform is free choice, providing greater decision-making power and greater flexibility for those who participate in the process. Thus, the execution of an activity can only be authorized by business rule. In this case, the execution of the process is conducted by constraints: everything that does not violate a constraints is enabled for execution and at the end of execution all constraints must be satisfied [13]. In addition, the greater the number of restrictions, the lesser will be the amount of execution options.

3.2 Water Supply Systems

A water supply systems can be defined as “a set of construction, equipments and installations which are destined the produce and distribution water to use collectively”.

This system is characterized by the water captation of nature, treatment of its quality to the drinking standard, transport and distribution to the population in quantity compatible with their needs [14].

Basically a supply system is composed of the elements:

- **Fountain**, source where is withdrawal water used to supply of region;
- **Captation**, refers to structural set and of machinery installed to water extraction of the fountain;

- **Adduction**, is the network of pipes that form the path that water will go move between the units of the system;
- **Treatment**, process responsible for the transformation physical, chemical and biological of the water that the makes appropriate to the consumption;
- **Reservation**, your finality is accumulate water in reservoirs that will be utilized to meet existing demand;
- **Distribution network**, a network made up of pipes that carry water continuously to all consumers.

The adoption of a water supply systems generates environmental impacts. The treatment phase, for example, is one of the most aggressive to the environment by using chemicals. In this sense, it should incorporate strategies (e.g. Management of Demand and Supply) to control environment impacts during the life cycle of the water inside supply system [14].

The studies that deal with the evaluation of the impacts are usually performed using the Life Cycle Analysis. The objective is to measure in each phase of the water supply system the impact generated [14].

The Fig. 1 shows a representation of the life cycle of the water from a water supply system. However, there are contexts in which some phases may not be present.

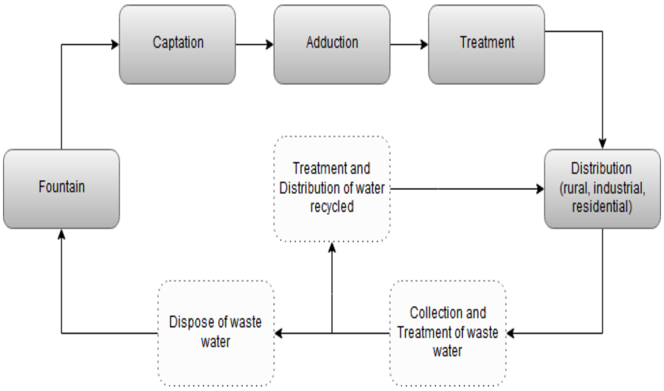

Fig -1: Life Cycle of the water

Therefore, the strategies created for the water supply system need to incorporate the uncertainties present in water supply, as well as, control and mitigate the environment impacts resulting from the implementation of actions and of climate change.

3.3 Complex Event Process

Complex Event Process (CEP) is an emerging technology for finding relationships between simple and independent series of events from different sources, using previously defined rules [15]. In addition to being an active field of research, CEP already plays an important role in many areas of application such as logistics, energy management, finance and manufacturing processes [16]. The CEP provides a natural decoupling between basic events with a strong relationship to the semantics of the underlying technology (e.g. readings from sensors) and complex events closer to the application semantics [16].

Complex event processing technology can be used, among many other things, to enrich existing enterprise processes by introducing rules that will allow you to capture relevant information from different stages of your process [15]. Furthermore, the CEP too can be used to predict unexpected situations [15]. For example, we can say that, due to a global alert of an increased water pressure in pipes, it can be used to interpret a set of events and identify patterns relevant to the water management system (e.g. leakages, breakages of equipment) and report these patterns in the form of alerts to the Water Manager.

4. PROPOSED TOOL

This section presents the water management tool called REFlex Water. Initially we describe an overview of the system, then introducing the architecture and detail the operation of each layer.

4.1 REFlex Water Architecture

The REFlex Water architecture described in Fig. 2 is formed by five layers (from bottom to up): Declarative Process Modeling, Device, Devices Manager, Middleware IoT and Application. At the Devices Manager layer, there is an interface that manages the DEVICE layer devices that collect Physical Infrastructure data. Physical Infrastructure represents the actual physical infrastructure of the water supply and distribution system. However, it can also be represented by a simulator that models these systems to perform simulations of hydraulic behavior in the laboratory.

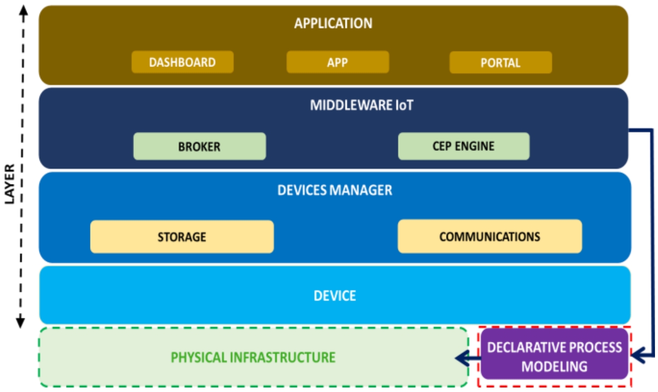

Fig -2: REFlex Water architecture

The layers of the proposed architecture and its main elements are described below:

a) **Declarative Process Modeling –** at this layer the REFLex rule engine is responsible for verifying rules and controlling the execution of declarative processes;

b) **Device –** is the second layer of the architecture responsible for collecting data that are generated from the sensor network installed in the Water Supply System. Devices may be of various types (e.g. Raspberry Pi, ZigBee, Arduino), but must have communication attachments to the internet (e.g. Ethernet or Wi-fi). This data is sent to the next layer by means of messages that follow the JSON data transmission pattern. The formatting of this message occurs through software installed on the device (e.g. Arduino) that receives data collected from the sensor network and sends it to the Devices Manager layer;

c) **Devices Manager –** is the layer responsible for the control and management of sensors in the Water Supply System and for integration with the IoT Middleware layer. Management is done through a web interface. This layer is composed of two components:

- **Communications** – component that enables the connectivity between the DEVICE layer and the DEVICES MANAGER layer through a communication protocol (e.g. MQTT, HTTP/HTTPS);
- **Storage** – this component is the dedicated location for storing data collected on the first layer. In addition, it allows for homogeneous access of data by the system client.

d) **Middleware IoT –** this layer is responsible for the orchestration of the framework that connects the IT infrastructure to the client applications by sending and receiving messages. It consists of two components:

- **Message Broker** – component responsible for managing the message queue that enables the receipt and sending of data messages between client systems;
- **CEP Engine –** in this component, as requests are received, they record events and identify behaviors of interest through the processing of previously defined CEP rules.

e) **Applications –** in this layer are present the features for service provisioning. We offer a tool that allows the development of different types of final application, for instance, Dashboard, Mobile and Web Application to control and management of Water Supply System.

4.2 REFlex Water Functioning

The Fig. 3 presents an abstract view of the REFlex Water tool. The dynamic behavior of REFlex Water can be described by means of a sequence of actions:

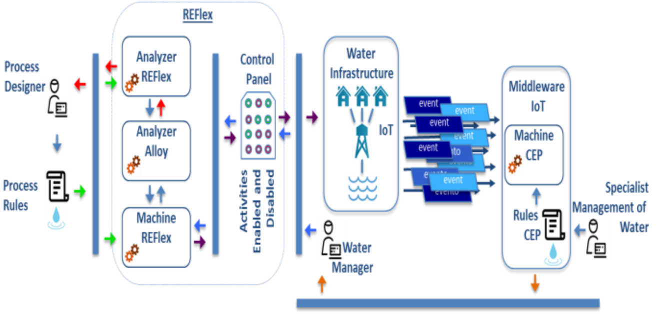

Fig -3: REFlex Water Framework

ACT#1: The Process Designer specifies the Process Rules that regulates the behavior of the water management system;
ACT#2: The REFlex Analyzer identifies possible lexical, syntactic, and semantic errors in the Process Rules;
ACT#3: REFlex asks the Alloy Analyzer to explore the state machine representing the Process Rules, looking for execution paths that can produce conflicts (e.g. *deadlocks* or *livelocks*);
ACT#4: The Alloy Analyzer reports eventual conflicts to the REFlex Analyzer, which passes the information to the Process Designer;
ACT#5: After the analysis phase, REFlex launch the process execution;
ACT#6: The Control Panel displays the process state, which is defined by the set of activity states (*enabled*, *disabled*, *suspended*, or *blocked*);
ACT#7: The Water Manager analyzes the Control Panel and chooses one enabled activity to execute;
ACT#8: After the activity execution, the REFlex Engine analyzes the effect of this event on the process state and update the Control Panel;
ACT#9: The REFlex Engine inserts new rules to avoid paths that can generate conflict whenever necessary during the process execution (the Alloy Analyzer is used to aid in this activity);
ACT#10: State changes in the Control Panel is reported to the Water Infrastructure so that the physical elements are configured to respect the process;
ACT#11: A CEP (Complex Event Processing) Engine interprets, in real-time, a large number of events to identify patterns relevant to the water management system (*leaks*, *equipment breakdown*, *reservoir level shifting*, etc.) and emit warning messages to the Water Manager;
ACT#12: Such warnings may affect the Water Manager decisions on what activity must execute.

The Water Infrastructure is the real physical infrastructure, with reservoirs, lift stations, distribution networks, water meters, etc. It has a large number of sensors, each responsible for reporting a certain type of event. In addition, the specification of CEP Rules requires an expert in the water management field to determine which event patterns are relevant to the water system.

5. EXPERIMENTAL CASE STUDY

This case study presents of the RESTful API provided by REFLEX Water. We simulate the sending of requests through JMeter tool [17] to demonstrate the practical feasibility of the API. The hypothetical network of Anytown [18] is adopted as the basic water infrastructure since it is a benchmark used in several studies [19, 20, 21, 22] for hydraulic simulations.

5.1 ANYTOWN scenario

This section presents conceived scenario the hypothetical *Anytown* network that represents the physical infrastructure of the system of supply and distribution of water Fig. 4, that consists in: 2 reservoirs that are the sources of water abstraction aided by 2 pumps, 1 distribution network that has 16 nodes, 34 tubes (stretches) and 1 distribution tank.

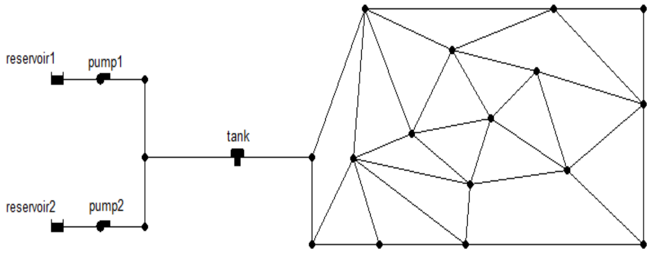

Fig -4: Hypothetical *Anytown* network

For the this scenario, the points of interest of monitoring are: pumps, reservoirs, nodes and tank.

Performance scenarios: This experiment sought to exploit the ability of the RESTful API provided by REFlex Water. Considering the data that travels in the platform in real time, we adopted the JMeter tool to load test functional behavior and measure performance. We simulated virtual users in the JMeter to send requests to the platform, which has received and processed these requests.

Table 1 shows the parameters used in both tests. The submitted requests were of the type GET and the connection path used:

/reflexwater/input/list.json?node=[node_id]&apikey=[apikey].

Virtual Users in the JMeter represent the platform users who monitor (pumps, reservoirs, nodes and tank) with sensors that collect and send data. The duration in both tests was 30 minutes.

Table -1: Configuration of parameters adopted in Test

parameter	value
Virtual users	42
Ramp-up (sec)	3
Loop count	infinite
Connect timeout (ms)	10000
Response timeout (ms)	10000; 7000

The response time metric allows us to identify when the application is underperforming, that is, its response time for users starts to increase. Chart 1 depicts the average response time that the platform takes to receive a request, process and deliver the response to the virtual user. For tests 1 and 2, the connect timeout was 10000ms.

As observed, the mean response time of Test 1 was 809.36ms and for Test 2, 814.16ms. For validation purposes, with the values estimated during the simulation of tests 1 and 2, a paired t-test [23] was performed considering the 95% confidence interval the mean response time of Test 1 was [793.9 ; 824.9] and Test 2 [798.48 ; 829.83]. Since 0 ϵ [-26.838 ; 17.252], there is no evidence to reject the equivalence hypothesis between the response times of test 1 and test 2. Indeed, no impact in response time is detected, in the sense that the platform cannot handle with the demand of virtual users.

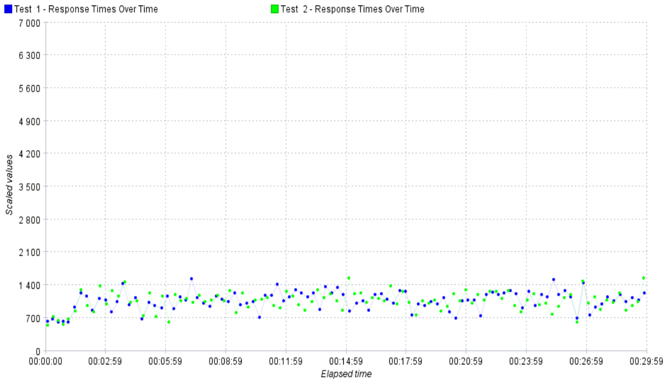

Chart -1: Response Times Results of the Tests 1 and 2

Chart 2 depicts transaction per seconds values demonstrating the success and failure behavior of the requests in tests 1 and 2. The response timeout configured for test 1 was 10000ms and for the test 2, 7000ms. The average number of transactions processed per second for the tests 1 and 2 was approximately 15.8 transactions/second.

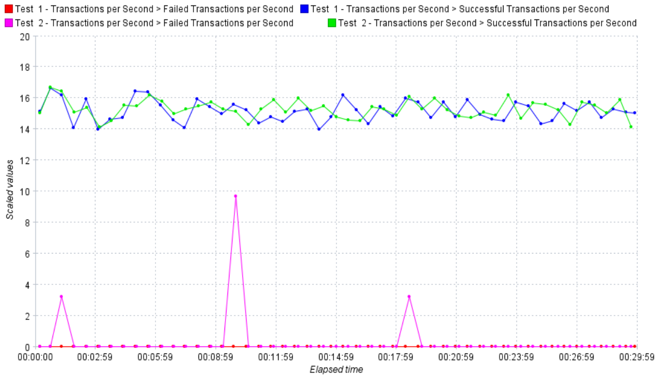

Chart -2: Transactions Per Second Results of the Tests 1 and 2

Assuming the 7000ms response timeout, failures affect the throughput less, but the results demonstrate that failures should not be neglected as they considerably affect performance compared to flawless results. This is visualized in periods 00:08:59 and 00:17:59 when the number of transactions per second reaches 14 transactions processed and the number of transactions that fail in Teste 2 reaches 10 and 3.3 respectively. On the other hand, when the response time limit was 10000ms, the failures did not affect the throughput.

6. CONCLUSIONS

This paper presents the proposed of a water management tool, called REFlex Water, based on the modeling of declarative business processes to assist managers in water management and decision making. The REFlex Water combines internet of things technologies and complex event processing, coordinated with a declarative business process management system. Many papers addressed the first technology. This project innovates by integrating these three technologies into a single water management tool. Moreover, we provide an architecture for interaction between subsystems allowing then to be manageable and interoperable with each other. The proposal, through of architecture supports a wide range of services in context of smart cities such as intelligent water management. In addition the initial results indicates that in the tests performed in the API provided by REFlex Water presented satisfactory result.

ACKNOWLEDGEMENT

This work was partly supported by the Brazilian Research Council(CNPq).

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