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Development of an Internet of Things Based(IoT) Smart Distributed Water Pipeline Monitoring System For Effective Management in a Smart City Environment.

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Abstract: *Pipeline has been a cheap and major means of transporting range of refined goods and liquids across the world. Water pipelines has been a means of transporting water from the source or main supply to districts and to various households. Failures to these water pipelines exists in various forms which can be aging, mechanical pipeline vandalism and external forces due to environmental condition, which results from fatigues and cracks found in longitudinal welds of the pipeline, hence pipelines becomes brittle and prone to early failure resulting in leakage. Studies have shown that the occurrence of failures on pipelines are worth large sums of money as they look extremely difficult to ignore as they are means of conveying important commodities from the source to fork. The growth of urban areas across the Nigeria may necessitate the need for a more efficient pipeline leak detection technique for detecting failures or leaks in pipelines which can prove to be more efficient, reliable and safe option, as the traditional method of monitoring leaks in pipelines using visual/biological means of surrounding remote pipelines with trained dogs, experienced personnel and smart pigging techniques are not cost effective and unsustainable for continuous monitoring of leaks of distributed water supply networks. With the advancement of Internet of Things technology to a smart/real-time monitoring system can developed to monitor the supply of water showing the total consumption by the community and an system that notifies administrators if there is an incidence of leakage is developed in this work, accompanying this research works is a real-time data visualisation dashboard that collects and analyse data collected from IoT enabled devices connected to sensors, that shows variations in flow-rate at every interval of time. The result of this research project shows that my system has a high response time with worst case being 2s while several others are 1s. It also shows that user can receive prompt notification of failure in water pipelines.*

Keywords: *Data Acquisition, Remote Monitoring. Water Distribution, Pipeline IoT, Smart City*

INTRODUCTION

Pipeline adoption which originated in the 19th century in transporting a wide variety of materials including oil, crude oil, refined products, natural gases, condensate, process gases, as well as fresh and salt water (Rehman and March 2017).

The cconstruction of longer pipelines with larger diameters has increased the need for more intelligent monitoring and detection of leak and abnormalities on pipelines using Internet of Things, to easily monitor and localize the pipeline leakages in real-time. In many instances, due to the length of distance covered by the pipeline, it is difficult to inspect or monitor pipeline for abnormal conditions. With emergence of Smart City for efficient management of a city resources water distribution is a sub unit that need to need optimized, a smart city concept is shown in Fig. 1. One of the causes of failures in water pipeline systems is leakage, which is as a result of fatigue and cracks.

Fig. 1 Smart City Scenario

Tensile stress can cause stress tears which can reduce the effectiveness of cathodic corrosion protection system, resulting in corrosion of the pipeline. Cracks can also be caused by hydrogen indexing. In this case, atomic hydrogen diffuses into the metal grid of the pipe wall, forming molecular hydrogen. This can lead to pipe material becoming brittle and prone to early failure (Bolotina *et al.,* 2018). Mechanical pipeline vandalism can also cause leaks. For example, when cavities are rolled into material to extract materials from pipelines illegally. A smart city is an urban development that use Internet Communication Technology (ICT) and Internet of Things (IoT) to provide useful information to effectively manage resources and assets. A smart city is a municipality that uses ICT to increase operational efficiency, share information with the public and improve both the quality of government services and citizen welfare. The major driver smart city is the IoT shown in Fig. 2. Studies have shown that incidents of pipeline leakage are hard to entirely avoid as the sources of failures are diverse. However, in order to reduce the impacts of water pipeline leakage in metropolitan society, it is very paramount to monitor water pipelines for timely detection of leakage or even leak prediction, as early detection of leak will aid quick response to stop water discharge and proper pipeline maintenance.

Fig. 2 IoT Ecosystem

But why is it necessary to implement real-time pipeline monitoring and detection mechanisms in a smart City at all? They are the most efficient, reliable and safe option when compared to other means of pipeline monitoring mechanisms (Boaz *et al.,* 2018). In such scenarios, there's the need to minimise damage to people, the environment and property. For a city to be smart real-time monitoring and supervisory control must be ensured. Most water distribution leakage suffer neglect leading to wastage and loss of valuable asset. Over the years, visual/biological method of detecting leakage in pipeline in a number of growing urban areas in Nigeria using traditional process of surrounding remote pipelines with trained dogs, experienced personnel and smart pigging (Boaz *et al.,* 2018). This method usually utilises trained personnel who walk along the pipeline and search for anomalies condition in the pipeline's environment. Trained observers can recognize the leaks through visual observation or smelling the odour coming out from cracking point. Also trained dogs cannot be effective for a continuous monitoring of operations for more than 30 mins. Hence, there's a need to monitor pipelines for leakage in our growing urban areas in real-time and where authorized personnel can provide a prompt response should in the event of abnormalities in the pipeline.

Some authors have classified pipeline leakages into two categories: hardware and software-based methods (Turner, 1991; Murvay, 2012). In an attempt to group these methods technical nature further research efforts have been made (Geiger *et al.,* 2006) and (M. Pipeline leak detection, 2015) which led to the classification of available leakage detection systems into three major groups namely internal, non-technical and non-continuous and external methods (Boaz *et al.,* 2018). A recent study further sub-divided the different categories into 3 major categories based on the following namely: exterior, visual or biological, and interior or computational methods (Adegboye *et al.,* 2019). Exterior based methods and visual or biological methods of which detect leaking product outside the pipeline and include traditional procedures such as right way of inspection by line patrols that walk along the pipeline, looking for unusual patterns near the pipeline, as well as technologies like hydrocarbon sensing via fiber optic or dielectric cables (Adegboye *et al.,* 2019). However, these are quite expensive. After understanding the various methodologies used to detect pipeline leakages, their working principle, strength, and weaknesses. I factored out the cost and ease of implementation into place and decided to Adopted Mass-volume balance to detect leaks in pipes due to its strengths and also using Negative pressure wave in pipes to fill in for the weaknesses of Mass-volume Balance.

The Internet of Things (IoT) is a network of interrelated computing devices, mechanical and digital machines, physical objects (vehicles, machines, home appliances, and more) animals or people that are provided with unique identifiers and ability to transfer data over a network using sensors and APIs to connect and exchange data over the internet without requiring human-to-human or human-to- Internet of Things supports dozens of different IoT protocols. In view of this, many IoT experts have started to call for a global protocol standardization. Yet, being inherently fragmented, the IoT market will probably never be in actual need of an all-embracing standard.

Just as there are newer and newer applications and use cases cropping up within the IoT industry, fit-for-purpose IoT protocols for their deployment will continue to emerge along the way. Again, it should be emphasized that safe and effective device management is the keystone of a sustainable development of IoT networks worldwide. This is one of the reasons why describing and making sense of the various IoT protocols really matters. Therefore, what is really needed is the knowledge of one's own business needs and requirements, awareness of the advantages and drawbacks of the protocols offered by the market, and the ability to pick the one that best suits a given use case. Over the last two decades, the IoT kept expanding rapidly over the globe. Having worked its way to numerous industry branches such as manufacturing, healthcare, automotive, security, transportation and more, it has significantly empowered enterprises and brought them economic value. Internet of Things supports dozens of different IoT protocols. In view of this, many IoT experts have started to call for a global protocol standardization. Yet, being inherently fragmented, the IoT market will probably never be in actual need of an all-embracing standard. Just as there are newer and newer applications and use cases cropping up within the IoT industry, fit-for-purpose IoT protocols for their deployment will continue to emerge along the way. Again, it should be emphasized that safe and effective device management is the keystone of a sustainable development of IoT networks worldwide. This is one of the reasons why describing and making sense of the various IoT protocols really matters. Therefore, what is really needed is the knowledge of one's own business needs and requirements, awareness of the advantages and drawbacks of the protocols offered by the market, and the ability to pick the one that best suits a given use case. The IoT depends on a whole host of technologies – such as application programming interfaces (APIs) that connect devices to the Internet. Other key IoT technologies are Big Data management tools, predictive analytics, AI and machine learning, the cloud, and radio-frequency identification (RFID).

Intensive study has been conducted on different pipeline leakage detection methodologies. The selection of this related works is best understood within the context of pipeline Monitoring and leakage. This chapter summarises the related works of the authors of previous studies and tries to summarise and understand the limitations of their work. In a Study by (Karim and Alrasheedy, 2015) Compensated mass balance method was implemented to detect leakage using Supervisory Control and Data Acquisition (SCADA) Systems. The result obtained indicated that different pipeline operating conditions recognises the leakage condition from other abnormal operating conditions. Since the transient model of this method uses flow rate, pressure, temperature and density to calculate the pipeline packing rate, the compensated mass balance model can deal with different operational changes of the pipeline and detects leak easily. The limitation offered by this method is that it does not localise leakage communicating with each other hence for data collection and analysis. In the same Study by (Karim and Alrasheedy, 2015) pressure point analysis can also be helpful in detecting leakage in pipes, as sudden drop in pressure cause a disturbance in measuring pipeline leakage, as pipeline pressure falls too rapidly in the case of leak (Whaley, 1992). This leak can be detected by comparing pressure of pipeline at a single point and comparing it against the statistical pressure measurements. Dedicated software will determine if the behavior of these two signals contains an evidence of leak (Geiger *et al.,* 2006), when the pressure falls below a lower limit.

Pressure point analysis (PPA) method is a leak detection technique based upon the statistical properties of measured pressure at different points along the pipeline. A study by Bin *et al.,* (2011) hinted that leakage is determined through the comparison of the measured value against the running statistical trend of the previous measurements. If the statistical pressure of the new incoming data is considerably smaller than the previous value or smaller than a predefined threshold, it indicates a leakage event. This method is considered as one of the fastest ways of detecting the presence of leakage in a pipeline based on the fact that existence of leak always results in immediate pressure drop at the leakage point (Murvay and Silea, 2012; Arifin *et al.,* 2018). The PPA has been successfully applied in underwater environments, cold climate and sufficiently functioning under diverse flow conditions. Small leakage which cannot be easily detected by other methods can be detected using PPA.

However, it is difficult to determine leak location using this method (Wang *et al.,* 2017). The ease of usages and low cost of implementation are the major advantages of this method, but in a batch process where valves are opened and closed simultaneously, transient state may arise and create a period which may easily lead to a false alarm. In order to overcome this drawback, the operation changes must be defined so that detection of leakage can be restrained pending the steady state operation returns to the pipeline. Similarly, integrating this method with other techniques such as mass-volume balance improves its effectiveness. In a study the negative pressure wave has been widely employed in pipeline monitoring due to its fast response time and leak localisation ability (Yu *et al.,* 2009). However, it is only effective in massive instantaneous leaks and easily leads to false alarms due to the difficulty in differentiating between normal pressure wave and leakage. Similarly, precise determination of the leak location using time difference in pressure wave detection at the two ends of pipeline is another critical challenge of this method. In order to alleviate this shortcoming, several efforts have been devoted to improving leaks detection and localisation mechanisms using NPW (Ferrante *et al.,* 2007; Chen *et al.,* 2018). In the study of (Peng *et al.,* 2011), a negative pressure wave signal analysis system based on Haar wavelet transformation was proposed. The authors demonstrated an effective way of detecting signal variations in the pressure wave signal and established a systematic way of using wavelet de-noising schemes to overcome the noise attenuation destructive problem. The pressure wave signal created by small leakage can be easily mixed with noise and background interference. This makes accurate signal detection and thus the oil spillage detection process challenging.

An effective method of identifying small leakage signal using improved harmonic wavelet was proposed in (Yonghong, 2012). The proposed scheme was used to extract the pressure wave signal from the background noise, but the shortcoming of this approach is the decay rate of pressure wave signal in time domain. In order to address this issue, the authors adopted a window function to smooth harmonic wavelet. Different methods of addressing the effect of background interference from leakages signal have been proposed in the literature. An independent component analysis (ICA) technique for separation of characteristic signature of the pressure wave signal mixed with the background noise was reported in (Chen, Lian, & Yu, 2010). A similar study proposed an robust independent component analysis method for effectively separating mixed oil pipeline leak signals (Li *et al.,* 2016). The proposed method was based on statistics estimation and iterative estimation technique using information theory. An alternative method of detecting small leakage using a morphological filter has been presented in (Li *et al.,* 2009). The morphological filter was employed to filter background noise and retain the basic geometry features of the pressure signals time reversal pipeline leakage localisation approach using adjustable resolution mechanisms was proposed in (Liu *et al.,* 2018). The proposed scheme formulated a method of fine-tuning leak localisation resolution in the interval of time. The method seems to be effective to localise small leakage in pipes, hence this feature allows the filter to facilitate signals small and slow change detection.

Furthermore, in another study by (Li *et al.,* 2018) a liquid pipeline leakage monitoring method based on moving windows least square support vector machine algorithm (MWLS-SVM). In the study, the main idea behind of LS-SVM classification algorithm is to change nonlinear constraints in SVM to linear constraints and apply the sum of least square errors as the empirical loss function of the training set to improve the data. From Simulation of the experimental results, the liquid pipeline leakage data shows that the proposed method has higher accuracy than support vector machines and neural networks method. A robust mean of detecting leakage in the pipeline networks using mass imbalance technique was proposed in (Rougier, 2005). In this study, the activities of calibration and prediction were unified to infer the presence and characterisation of leakages. A similar study (Karim *et al.,* 2015) reports a mass balance compensation method for oil pipeline leak detection system. The difference in mass at the two ends against mass balance experiments. The obtained result showed that the proposed system can function in various pipelines networks under different operating conditions. The occurrence of leakage with a low rate of changes in pressure or flow rate can be detected using this method.

MATERIALS AND METHODS

The smart distributed water pipeline monitoring system consists of different parts integrated together. The parts consist of hardware and electronic components such as PVC pipes, valves, plumbing fixtures, reservoirs (buckets), NodeMCU ESP8266. The NodeMCU ESP8266 allows does the work of telemetry data collection from the flow sensors connected to various end of the pipe and sending the data to IoT platform which is ThingsBoard for real-time visualisation and analytics. Fig. 3 and Fig. 4 show the high-level overview of the smart water pipeline monitoring system and block diagram of the system respectively. As seen in Fig. 4 the network of pipes establish communication using and IoT Protocol called MQTT. It was designed for unreliable communication networks in order to respond to the problem of the growing number of small-sized cheap low-power objects. The ThingsBoard IoT platform provides for data collection, processing, visualization, and device management. It enables device connectivity via industry standard IoT protocols - MQTT, CoAP and HTTP and supports both cloud and on-premises deployments. ThingsBoard combines scalability, fault-tolerance and performance so one never lose data. Thingsboard provides for localisation and real-time alert system provides of failure of the to allow tenant administrator to promptly respond to leakages.

Leakage Detection Process

The smart water pipeline detection monitoring system, uses the mass-volume imbalance approach for leak detection is an operation that is based on the principle of mass conservation (Sheltami *et al.*, 2016). The principle states that a fluid that enters the pipe section remains inside the pipe except it exits from the pipeline section (Martins and Seleghim, 2010). In a normal cylindrical pipeline network, the inflow and outflow fluid can be metered. In the absence of leakage, the assumption is that the inflow and outflow measured at the two ends of the pipeline section must be balanced. However, the discrepancy between the measured mass-volume flows at the two ends of the pipeline indicate the presence of leakage. The inconsistency of the values in measurement can be determined using the principle of mass conservation given as follows:

$$\dot{M}_\iota(t) - \dot{M}_o(t) = \frac{dM_L}{dt} \tag{1}$$

where $\dot{M}_\iota(t)$ and $\dot{M}_o(t)$ represents the mass flow rate at the inlet (i) and outlet (o) respectively. The mass stored across the pipeline length is denoted by M_L, while L represent the length of the pipeline section. In a cylindrical pipeline system, the mass stored M_L for a pipeline of length L changes over time as a result of changes in fluid density (ρ) and cross-sectional area (A) satisfies equation below.

$$\frac{dM_L}{dt} = \frac{d}{dt}\int_0^L \rho(x)A(x)dx = \int_0^L \frac{d}{dt}\langle\rho(x)A(x)\rangle dx \tag{2}$$

Where $\rho(x)A(x)dx$ epresents the differential mass stored across the length of the pipeline (M_L) and ρ changes ın accordance to the relations; is measured with the coordinate position x, $0 \leq x \leq L$. If ρ and A is assumed to be constant

$\frac{dM_L}{dt}$ $\rho(x)A(x)dx$ = 0. Then the above equation as is as follows:

$$\dot{M}_i(t) - \dot{M}_o(t) = 0 \tag{3}$$

Similarly, assuming and are equal and constant for inlet and outlet mass flow, by introducing the flow with then;

$$\dot{V}_i(t) - \dot{V}_o(t) = 0 \tag{4}$$

The imbalance (R) between the inlet and outlet volume can be estimated and compared as given in the two equations below;

$$\dot{R}(t) \doteq \dot{V}_i(t) - \dot{V}_o(t)$$

$$R = \begin{cases} < R_{th} & in\ absence\ of\ leak \\ \geq R_{th} & if\ there\ is\ a\ leak \end{cases} \tag{5}$$

Where R_{th} is a threshold to evaluate the imbalance of the volume between inlet and outlet volume. This method has been commercialized and widely adopted in the oil and gas industry (M, Pipeline leak detection, 2015). Some of the existing flow meters in the industry include orifice plate, positive displacement, turbine and mass flow. Some scientific papers based on this method have been reported in literature (Fluid transients in systems, 1993) and (Karim *et al.*, 2015). In order to avoid false alarms with the with this system, the accuracy of the flow meter is ±10% was considered in the development my system.

System Design Consideration

The design of this system is principally based using IoT to for monitoring, and real-time visualisation and using mass-volume imbalance method for leak detection and alarm system. This is a hybrid setup that allows for localisation of leakage at various point of the pipeline., hence allows for optimal detection of leakage. The system block diagram, flow diagram, with all levels of design of data flow diagram are depicted in Fig. 3 and Fig. 4.

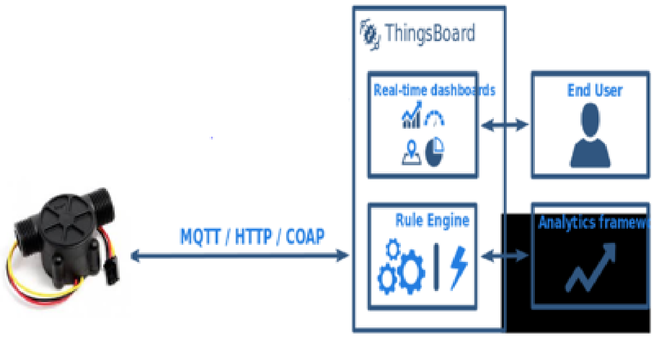

Fig. 3 Block Diagram of the of Smart Water Pipeline Monitoring System

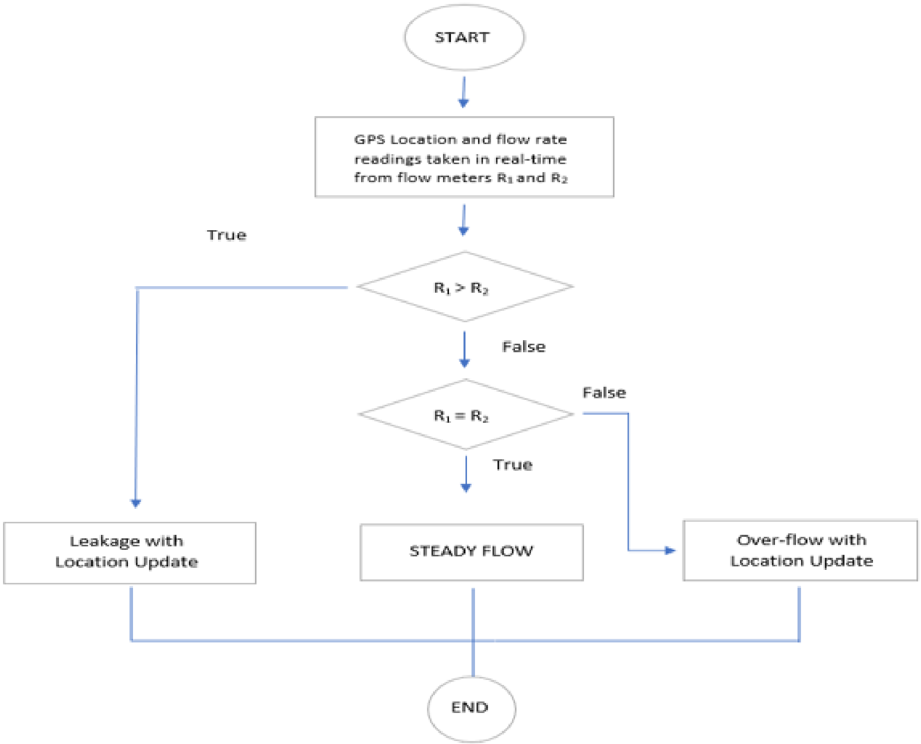

Fig. 4 Overview of the flow-chart of Pipeline Leakage Monitoring System

Hardware Design Considerations

The hardware design consideration of the system development revolves the following hardware components: YF-S201 Hall Effect Water Flow sensor, Lolin NodeMCU ESP8266 CP2102, PVC pipes, junction heads and Tap heads.

Lolin NodeMCU ESP8266 CP2102

NodeMCU is an open source IoT platform which includes firmware which runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. The term "NodeMCU" by default refers to the firmware rather than the development kits. The firmware uses the Lua scripting language. It is based on the eLua project, and built on the Espressif Non-OS SDK for ESP8266 (NodeMCU, 2017). The ESP8266 is a Wi-Fi SoC integrated with a Tensilica Xtensa LX106 core, widely used in IoT applications. NodeMCU started on 13 Oct 2014, when Hong committed the first file of nodemcu-firmware to GitHub. Two months later, the project expanded to include an open-hardware platform when developer Huang R committed the gerber file of an ESP8266 board, named devkit v0.9. Later that month, Tuan PM ported MQTT client library from Contiki to the ESP8266 SoC platform, and committed to NodeMCU project, then NodeMCU was able to support the MQTT IoT protocol, using Lua to access the MQTT broker. Another important update was made on 30 Jan 2015, when Devsaurus ported the u8glib to NodeMCU project, enabling NodeMCU to easily drive LCD, Screen, OLED, even VGA displays (NodeMCU, 2017). In summer 2015 the creators abandoned the firmware project and a group of independent contributors took over. By summer 2016 the NodeMCU included more than 40 different modules. Due to resource constraints users need to select the modules relevant for their project and build a firmware tailored to their needs.

PVC Pipes, Valves, Plumbing Fixtures, Tanks (Bucket)

The connection of PVC pipes, valves, plumbing fixtures with direct connection with the reservoirs is used to convey fluids from one end of the pipe to the other. They form of a network of pipes that supply to various districts or towns. Hardware implementation was done on PVC pipe which is a solid liquid that is used to convey cold liquid i.e. water from one end of the pipe to another.

Software Design Considerations

The software development will make use of all available packages and libraries of available of Nodemcu ESP8266 which will send telemetry to the cloud in real-time. It is assumed the Nodemcu device will make use of Arduino libraries and available for the system to send data to the cloud in real-time. The following subsections explains the whole software considerations in the project.

Arduino IDE, Libraries and Packages

Arduino IDE is an Integrated Development Environment, enables programmers to consolidate the different aspects of writing a computer program for Arduino. The programs written on the IDE is called a Sketch and ends with ino extension. Generally, IDEs increase programmer productivity by combining common activities of writing software into a single application: editing source code, building executables, and debugging. Sketches are saved, compiled and uploaded on uploaded on Nodemcu. Generally, the IDE allows us to do more with Arduino than just making websites interactive. ESP8266 core brings support for the ESP8266 chip to the Arduino environment. It allows one to write sketches, using familiar Arduino functions and libraries, and run them directly on ESP8266, with no external microcontroller required. ESP8266 Arduino core comes with libraries to communicate over WiFi using TCP and UDP, set up HTTP, mDNS, SSDP, and DNS servers, do OTA updates, use a file system in flash memory, and work with SD cards, servos, SPI and I2C peripherals.

ThingsBoard

ThingsBoard is an open-source IoT platform for data collection, processing, visualization, and device management. It enables device connectivity via industry standard IoT protocols - MQTT, CoAP and HTTP and supports both cloud and on-premises deployments. ThingsBoard combines scalability, fault-tolerance and performance so one never lose data.
Essential Features offered by Thingsboard:

i. Provision and manage devices and assets: Thingsboard Provision, monitor and control IoT entities in secure way using rich server-side APIs. Define relations between devices, assets, customers or any other entities.
ii. Process and React: Define data processing rule chains. Transform and normalize device data. Raise alarms on incoming telemetry events, attribute updates, device inactivity and user actions.
iii. Microservices: Construct your ThingsBoard cluster and get maximum scalability and fault-tolerance with new microservices architecture. ThingsBoard also supports both cloud and on-premises deployments.

RESULT AND DISCUSSION

The result of the system is simulation result that is based on the implementation of water distributed water supply in a pipeline distribution network. The result also includes the implementation of the project which monitors the flow of water and is send to and IoT platform for visualisation and analytics. Notice that at junction 1, there is a local demand of 0.15 cfs, but the tank is supplying 4 cfs. Node 1 is where water enters the system. Therefore, the total demand is negative and has a value of 0.15 – 4 = 3.85 cfs. The bottom of the tank is located at 400 ft and has an initial level of 10 ft above the tank bottom. The data corresponding to the tank is shown in Fig. 5.

Tank TA1

Property	Value
*Tank ID	TA1
X-Coordinate	-972.22
Y-Coordinate	9166.67
Description	
Tag	
*Elevation	400
*Initial Level	10
*Minimum Level	0
*Maximum Level	20
*Diameter	50
Minimum Volume	
Volume Curve	
Mixing Model	Mixed
Mixing Fraction	
Reaction Coeff.	
Initial Quality	
Source Quality	
Net Inflow	#N/A
Elevation	#N/A
Pressure	#N/A
Quality	#N/A

Fig. 5 Data corresponding to the tank (TA1)

Modelling of Water Supply Network Using EPANET

Simulating a 50 ft. diameter tank located in a city to supply drinking water for a small community. The tank is 20 ft. high and is located 400 ft. above the city. The tank supplies water with a constant flow of 4 cfs. (cubic feet per second) during the day. All the nodes in the network are located at 0 ft. elevation. All the pipes have a roughness coefficient C = 100. Using Hazen-Williams formula, minor losses are neglected. The Hazen–Williams equation is an empirical relationship which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction (Hazen–Williams equation, 2019). It is used in the design of water pipe systems such as fire sprinkler systems, water supply networks, and irrigation systems. Also, it does not account for the temperature or viscosity of water. Also the length of pipes that connect different junctions together are equal in size in 50 ft. except that the length of pipe from Junction 10 (JU10) and junction 11 (JU11) is 100 ft.The water demand during the day at each junction is same throughout as shown in Fig. 7.

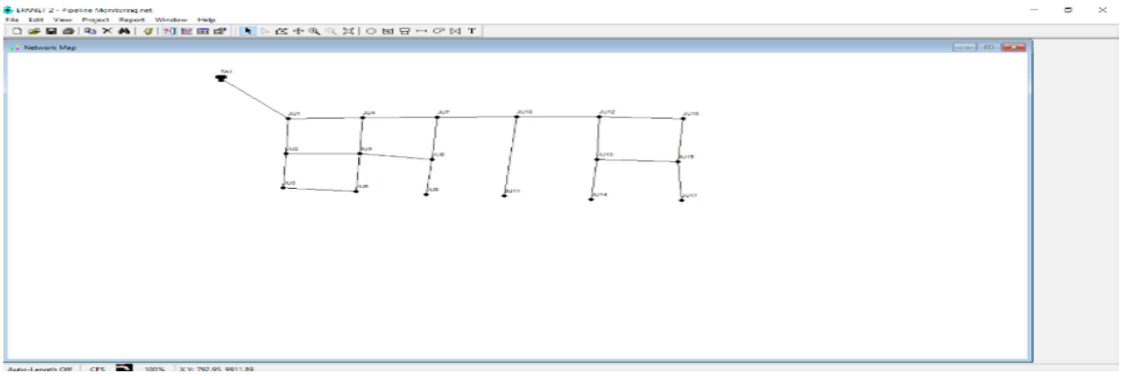

Fig. 6 Network Distribution Pipeline Network Using EPANET

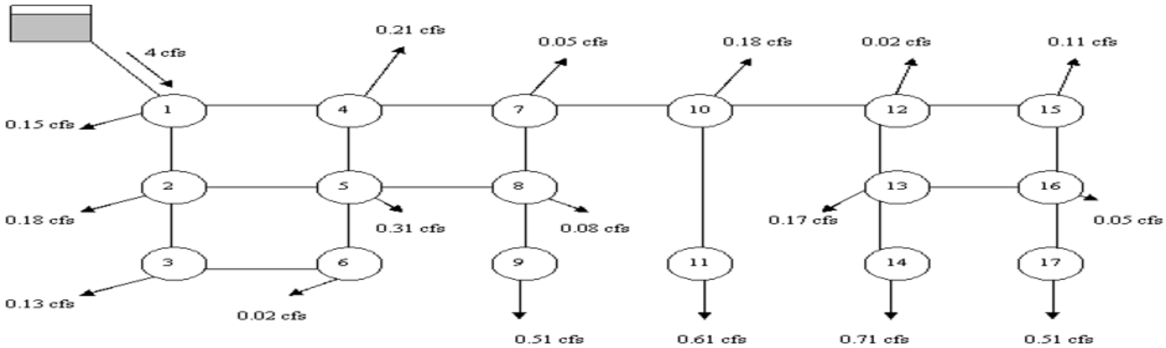

Fig. 7 Water demand at various junctions of the Network

Notice that at junction 1, there is a local demand of 0.15 cfs, but the tank is supplying 4 cfs. Node 1 is where water enters the system. Therefore, the total demand is negative and has a value of 0.15 – 4 = 3.85 cfs. The bottom of the tank is located at 400 ft and has an initial level of 10 ft above the tank bottom. The data corresponding to the tank. Table-1 shows Flow, velocity, Unit head loss and Friction factor based on the network shown in the pipeline distribution network and Table-2 shows the various demand pattern and pressure at various junctions of the pipe distribution network.

Table-1 Table of Flow, velocity, Unit head loss and Friction factor

EPANET 2 - Pipeline Monitoring.net - [Network Table - Links]

Link ID	Flow CFS	Velocity fps	Unit Headloss ft/Kft	Friction Factor	Reaction Rate mg/L/d	Quality	Status
Pipe PI1	0.00	0.00	0.00	0.000	0.00	0.00	Open
Pipe PI2	0.96	2.74	6.21	0.035	0.00	0.00	Open
Pipe PI3	0.33	0.95	0.87	0.041	0.00	0.00	Open
Pipe PI4	2.89	3.68	6.68	0.032	0.00	0.00	Open
Pipe PI5	0.45	1.28	1.51	0.040	0.00	0.00	Open
Pipe PI6	0.20	0.58	0.35	0.045	0.00	0.00	Open
Pipe PI7	0.36	1.04	1.04	0.041	0.00	0.00	Open
Pipe PI8	-0.18	0.52	0.29	0.045	0.00	0.00	Open
Pipe PI9	2.32	2.95	4.43	0.033	0.00	0.00	Open
Pipe PI10	0.68	1.95	3.31	0.037	0.00	0.00	Open
Pipe PI11	-0.09	0.26	0.08	0.050	0.00	0.00	Open
Pipe PI12	0.51	1.46	1.94	0.039	0.00	0.00	Open
Pipe PI13	2.36	3.00	4.58	0.033	0.00	0.00	Open
Pipe PI14	0.61	1.12	0.91	0.039	0.00	0.00	Open
Pipe PI15	1.57	2.00	2.15	0.035	0.00	0.00	Open
Pipe PI16	1.02	1.30	0.97	0.037	0.00	0.00	Open
Pipe PI17	0.71	0.90	0.50	0.039	0.00	0.00	Open
Pipe PI18	0.53	0.97	0.70	0.040	0.00	0.00	Open
Pipe PI19	0.14	0.40	0.18	0.047	0.00	0.00	Open
Pipe PI20	0.42	0.77	0.45	0.041	0.00	0.00	Open
Pipe PI21	0.51	0.94	0.65	0.040	0.00	0.00	Open

Auto-Length Off | CFS | 100% | X,Y: 14412.84, 9174.31

Table-2 Table of demand Pattern, Pressure at Various Junctions

Network Table - Nodes

Node ID	Demand CFS	Head ft	Pressure psi	Quality
Junc JU1	-3.85	410.00	177.65	0.00
Junc JU2	0.18	409.69	177.52	0.00
Junc JU3	0.13	409.65	177.50	0.00
Junc JU4	0.21	409.67	177.51	0.00
Junc JU5	0.31	409.61	177.49	0.00
Junc JU6	0.02	409.63	177.49	0.00
Junc JU7	0.05	409.44	177.41	0.00
Junc JU8	0.08	409.45	177.41	0.00
Junc JU9	0.51	409.35	177.37	0.00
Junc JU10	0.18	409.22	177.31	0.00
Junc JU11	0.61	409.12	177.27	0.00
Junc JU12	0.02	409.11	177.27	0.00
Junc JU13	0.17	409.06	177.25	0.00
Junc JU14	0.71	409.03	177.23	0.00
Junc JU15	0.11	409.07	177.25	0.00
Junc JU16	0.05	409.05	177.24	0.00
Junc JU17	0.51	409.02	177.23	0.00
Tank TA1	0.00	410.00	4.33	0.00

Hardware Modelling of the System

The hardware setup contains the main supply that that supplies water to different districts. The setup on shows a district. The flow rate and total consumption from a district is measured from the flow setup. The connected district has which supplies water to neighbouring towns has is monitored for leakage and total consumption by the community. The readings are sent to the cloud for in real-time for real-time monitoring of leakage and flow-rate. Pipeline localisation is provided to detect a leaking pipeline in real-time. The Graphic User Interface GUI shown in Fig. 8-Fig. 10 are interface that monitor status of the system with Geographical Location Capabilities also incorporation Dynamic Graph Plotter.

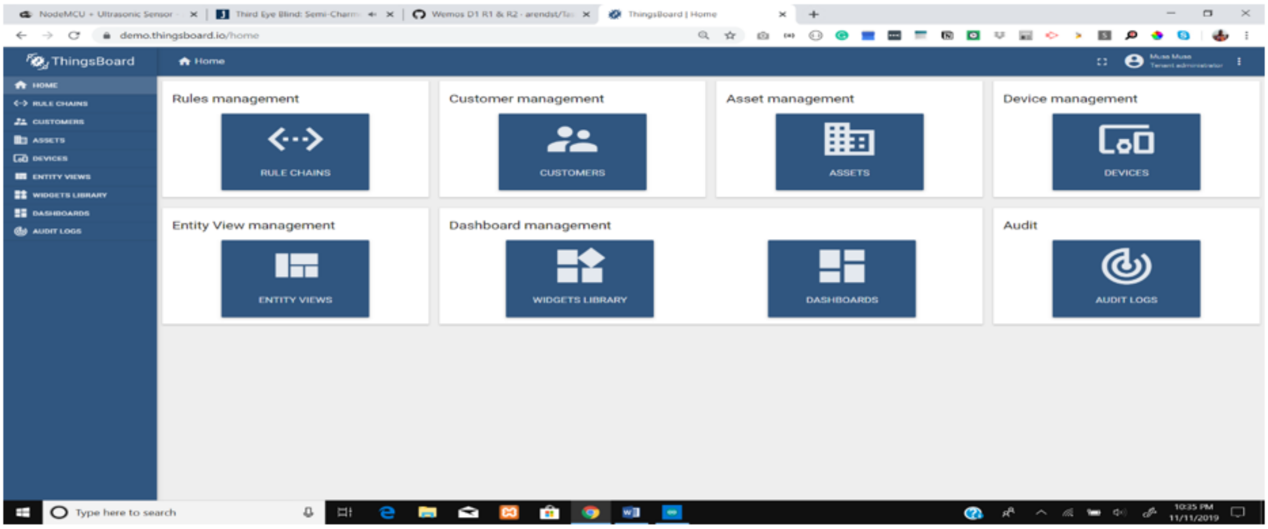

Fig. 8 Main Analytics Dashboard (Tenant Administrator) Interface

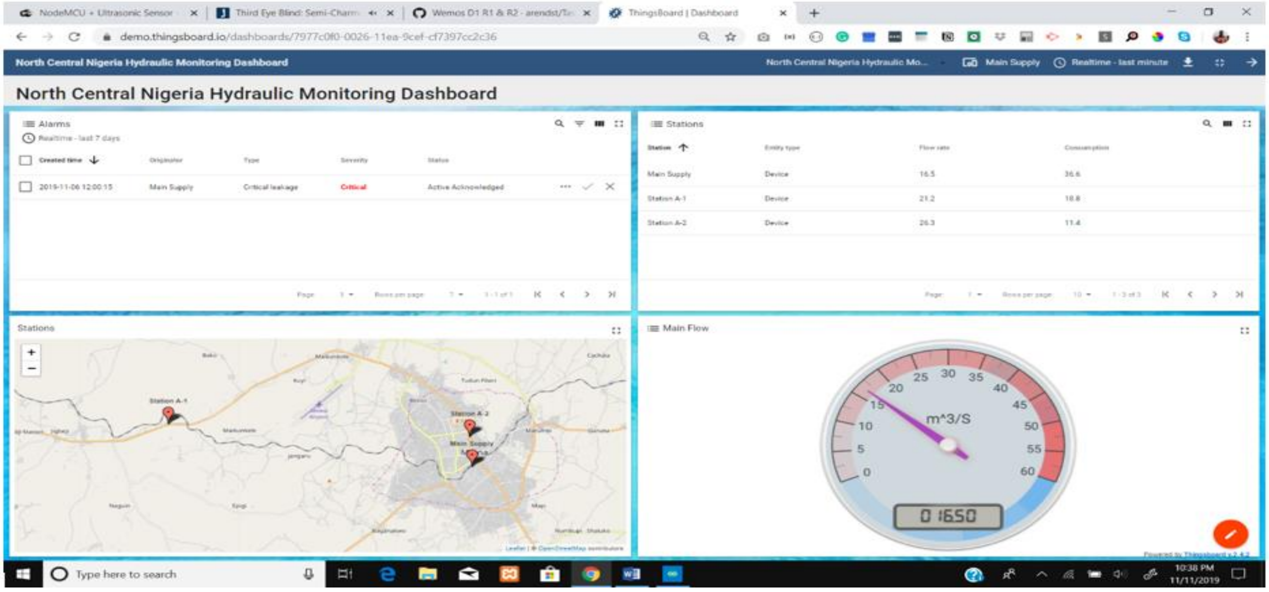

Fig. 9 Main Analytics Dashboard (Tenant Administrator) Interface

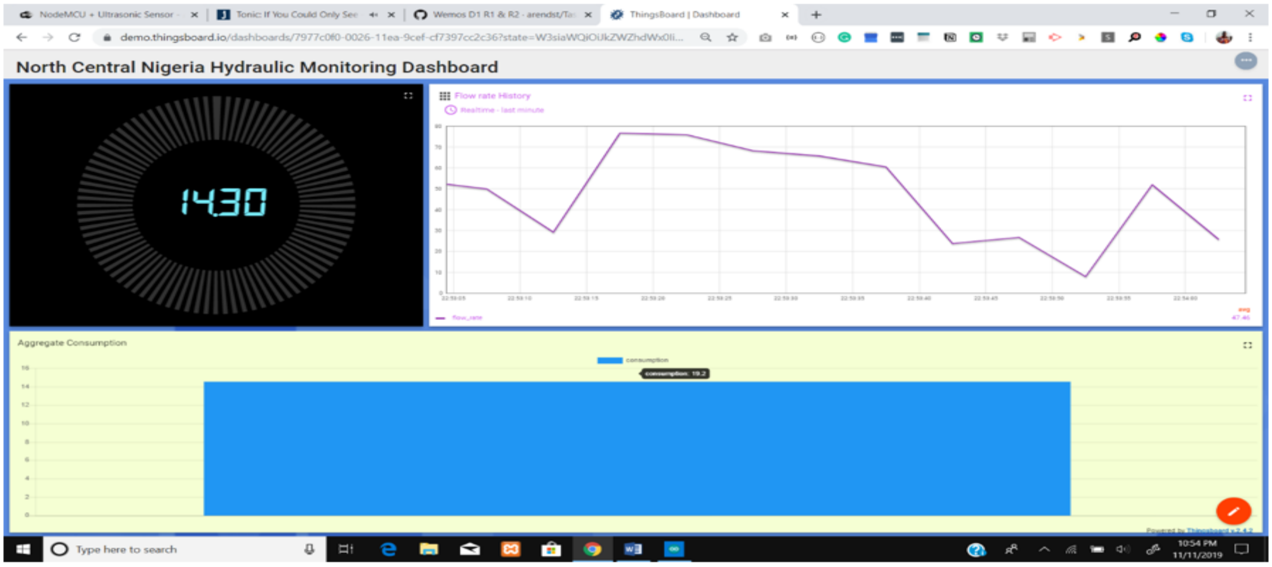

Fig. 10 Drilldown view to the flow of water in a district

Performance Evaluation Results

The performance metrics considered are the flow rate and system response time. Flow rate is computed using the mathematical relationship $M = \rho v A$ for mass flowrate where ρ is the density of water, v is the volume and A is the area of the distribution pipe. The mass flow rate was measured at different time intervals using the flow sensor and at different times. The result is shown in Table-3 and the flow rate graph in Fig. 11.

Table-3 System Flow rate measured at different time intervals

Time interval(s)	Flow Rate(liter/min) First attempt	Flow Rate(liter/min) Second attempt
5	7.1	6.66
10	6.88	6.44
15	6.88	6.44
20	6.88	6.22
25	6.66	6.44

From Table-3, the range is 0.44 which implies that the flow rate is stable. Once there is a leakage, the flow rate will no longer be stable and such information is instantly sent to the right authorities.

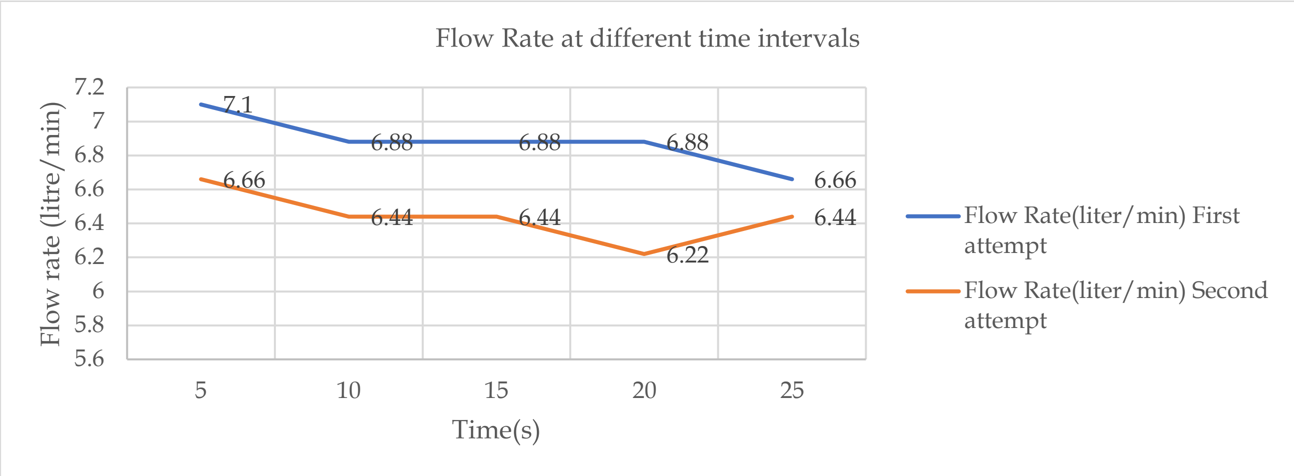

Fig. 11 Graph of flow rate at different attempts

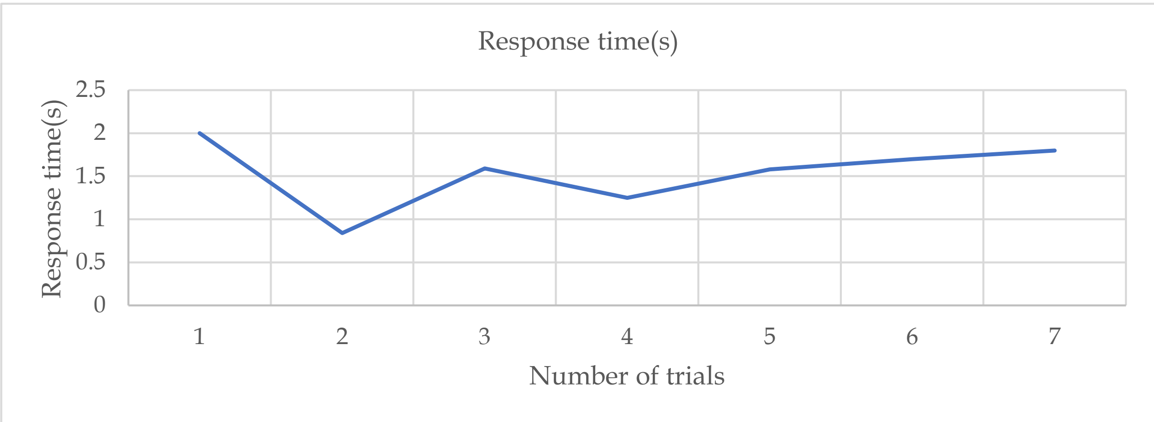

Fig. 12 Response time graph for an "OK" network

Also, for a network range of 48-54 with signal strength of -83dBm to -79dBm with a general remark "Good", the highest response time was 1.25s and the lowest 0.44s. Table-4 shows the response time for a good network scenario while Fig. 13 shows the graph of the response time.

Table-4 Response time for a good network scenario

No. of trials	1	2	3	4	5	6	7
Response time(s)	1.25	1.00	0.94	0.71	0.64	1.18	0.58

Summarily, for both scenarios of low and good network, it can be deduced that the system exhibits high response time with the worst case been 2s and the several others below 1s. This implies that a user receives a prompt notification as soon as there is water flow.

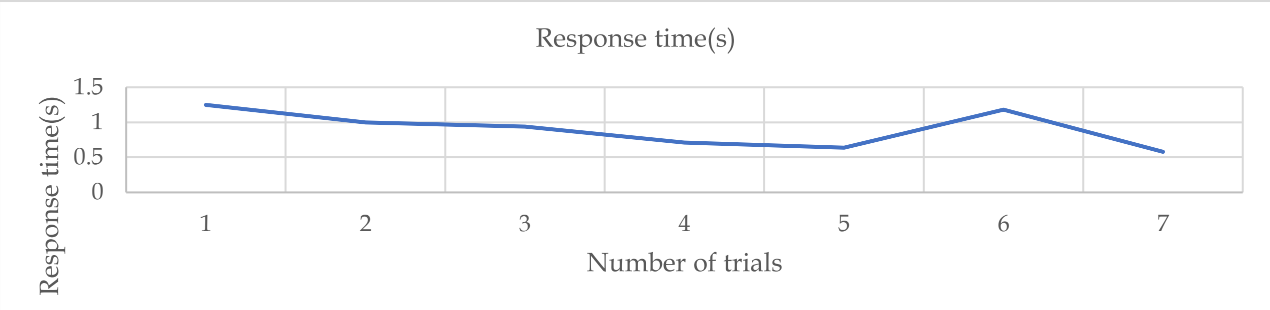

Fig. 13 Response time graph for an "Good" network.

CONCLUSION

The practical implementation of this system, coupled with the analytic dashboard and notification system has made it possible to show real-time visualisation and thus provide localisation and monitoring. One of the causes of leakage in a system is fatigue and cracks, which occurs as a result of material fatigue and are often found in longitudinal welds. This may be a rather difficult situation to prevent but this system is able to detect such leakages and instantly send notifications to the right authorities indicating the location of the leakage and the flow rate at that station for adequate maintenance measures to be carried out.

CONFLICT OF INTEREST

The authors declare no competing interest.

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