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Development of a Secured IoT Based Pipeline Product Distribution Monitoring System Using Blockchain Technology For Smart City Development

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Abstract: *A serious drop in ensuring the pipeline product quality in the distribution system is a factor that affects public health and wellbeing. The conventional methods of analyzing the Pipeline product quality require much time and labour. So there is a need to monitor and protect the pipeline product with a real time quality monitoring system to make active measurements to reduce contamination. The growth of the technology had helped in developing efficient methods to solve many serious issues in real-time. Internet of things (IoT) has achieved a great focus due to its faster processing and intelligence. One of the methods through which they achieve this is by ensuring that the parameter of the fluid (such as temperature, pressure, PH etc) are been monitored constantly via a website. This design therefore helps to maintain the quality of the products. The design also attempt to resolve the issue of data theft through the application of block chain technology. In this paper, we present the development of a secure IoT based pipeline product distribution system using blockchain technology. This system helps in monitoring the ensuring that the parameter of the fluid such as temperature, pressure, PH are intact. The hash algorithm based blockchain technology approach helps to secure the system database and accomplished monitoring of the pipeline product. It prevents an individual concerned from remote database information altering or unscrupulous parties' intrusion. Also, it manages the archives and linking of the subsequent records through the developed secure distributed database system (blockchain)and it also sends a notification SMS when it detects an intruder trying to vandalize the system.*

Keywords: Blockchain, IoT, Pipeline, Wireless Sensor Network

INTRODUCTION

Pipelines have been utilized as routes in most sectors to transport fluids of all kinds. In the oil and gas industry, pipelines are the primary means of transferring fluid to various processing locations (Box and Park, 2011). In most circumstances, fluid parameters like temperature, viscosity, and pressure must be determined in order to confirm that the standard is satisfied. Another issue with using pipelines as fluid transport conduits is the frequency with which vandals target pipelines, particularly those carrying petroleum. Many millions of dollars have been wasted in Nigeria as a result of vandalism, which has resulted in the loss of life and property in the majority of cases (Okoli *et al.,* 2013) However, this design was put in place to prevent the imperfections that can occur when using pipes to transport liquids. The use of vibration sensors, which detect vibration around the pipeline and provide a signal to the microcontroller sub-system, which executes the necessary command, is one method of identifying vandals (Ajao *et al.,* 2021).

The introduction of several types of sensors, such as pressure sensors, temperature sensors, and PH sensors, has also made it easier to estimate parameters such as fluid pressure, temperature, and PH froma reference value (Chaware, 2021). The internet of things (IoT) cleared the path for these data to be view by users via a server. This provides a way for the data from these sensors to be watched from anywhere in the globe, and required action can be done when deviations occur. This architecture also makes use of block chain technology, which helps to protect from being stolen by hackers. Block chain technology is a method of storing data in a way that makes it difficult to alter, hack, or deceive the system (Witanto and Lee, 2021). A smart city is an urban development using Information and Communication Technology (ICT) and Internet of Things (IoT) to provide useful information to effectively manage resources and assets. The concept is shown in Fig. 1. Smart city involves data collected from citizens and mechanical devices, that are processed and analyzed to monitor and manage traffic and transport systems, power plants, water supply networks, waste disposal, etc.

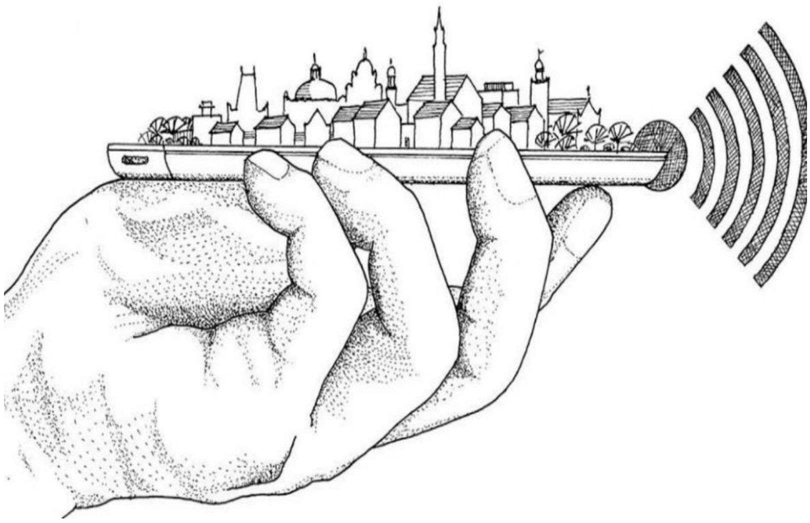


Fig. 1 Smart City Concept (Dawn News, 2021)

Fig. 2 Pipeline Distribution System (What is a Smart City, 2021)

The regular occurrence of pipeline vandalism, which has resulted in the scarcity of gasoline on multiple occasions, loss of life, and a reduction in revenue collected, is one of the difficulties that this design attempts to address. Most organizations or sectors that have already carved out a niche in society, such as Coca-Cola, would constantly want to ensure that Their product's quality is upheld at all costs. One of the ways they accomplish this is by constantly monitoring fluid parameters such as temperature, pressure, and PH (power of hydrogen). As a result, this design aids in the preservation of product quality. Through the use of block chain technology, the design also attempts to address the issue of data theft. This work is aimed at developing a secured IoT based pipeline product distribution system using block chain technology. The objectives are as follows:

i. To develop an IoT based Pipelined Product Distribution System
ii. To develop a secured data privacy and integrity system using Block chain technology
iii. To develop the pipeline distribution system integrating objectives I and II.
iv. To evaluate the performance of the system using accuracy and response time.

This section provides a review of the works on different Pipeline distribution systems used for distribution of pipeline products and the techniques are evaluated in this study, these techniques include; IoT and Blockchain. This section also presents and critically explains the adopted techniques involved to improve the pipeline distribution system (Agajo et al., 2017). Over the past few years, we have consistently heard the term 'Block chain technology,' probably regarding cryptocurrencies like Bitcoin. It seems like Block chain is a platitude but in a hypothetical sense, as there is no real meaning that the layman can understand easily. It is imperative to understand what Block chain is, the technology used, how it works, and how it's becoming vital in the digital world. Block chain technology is a structure that stores transactional records, also known as the block of the public in several databases, known as the "chain," in a network connected through peer-to-peer nodes. Typically, this storage is referred to as a 'digital ledger' .Every transaction in this ledger is authorized by the digital signature of the owner, which authenticates the transaction and safeguards it from tampering. Hence, the information the digital ledger contains is highly secure (Dogo *et al.,* 2019). In simpler words, the digital ledger is like a Google spreadsheet shared among numerous computers in a network, in which, the transactional records are stored based on actual purchases. The fascinating angle is that anybody can see the data, but they can't corrupt it. Blockchain is an emerging technology with many advantages in an increasingly digital world it is highly secured. It uses a digital signature feature to conduct fraud-free transactions making it impossible to corrupt or change the data of an individual by the other users without a specific digital signature(Id and Tapas, 2018).

Suresh *et al.* (2017) proposed an implementation of smart water distribution metering approach especially suited to third- work countries with limited investments in infrastructure and burgeoning populations and amoeboid expansions to urban habitats. This prototype system relies on the use of simple Internet of Things (IoT) approach for Water- metering in conjunction with a custom built Smartphone App. Metering data communication and update to CRBM, logging of complaints, dynamic checks for water leakages at consumer-end and Utility monitoring of hourly consumption from individual or group of meters for suspected leakages / tampering, etc. are potential advantages using this approach. This paper describes a novel Smart meter implementation architecture that permits both online and offline methods especially for areas with poor / unreliable cellular network coverage (Priya *et al.*, 2018). The paper discusses the recent development in the field of in-pipe real time contamination detection system. In addition, a contamination detection system is developed based on the emerging Internet of Things technology. The system samples the water at regular time intervals supplied through pipelines to the consumers/public. The real time data are analyzed using fuzzy synthetic evaluation and uploaded over the internet/cloud. When contamination is detected in the water, the system sends an alarm/alert to the consumers regarding the water quality parameters and prevents the further flow of water in the contaminated region in the pipe using a solenoid valve. The other region which supplies quality water to the consumers in the water distribution network remains flowing. The results demonstrated that the developed system is capable of analyzing the water quality parameters in real time and can successfully process, transmit data to the cloud and intimate the users about the contamination in the particular region

Herath, (2019) developed system focuses on micro factors that occur in household water usage, which leads up to a significant impact collectively. Waste of water is primarily due to the careless usage, leakages, and the overflow of the overhead tanks in households. "Smart Water Buddy" is a system that monitors water usage with IoT devices and uses machine learning to identify water leaks and abnormal usages, which helps to optimize the usage. The Smart Water Buddy system contributed to the conservation of domestic water usage efficiently and smartly. Because of the Open-source IoT Architecture, Smart Water Buddy system can be introduced to the market at a lower price while other Smart Water Management solutions have a higher price since they have used properties technologies and frameworks.

Table-1 Meta-data analysis showing related works

S/N	Authors Name	Year of Publication	Title	Strengths	Weakness
1	Abdelhafidth *et al.*	2018	Fluid Distribution Monitoring System.	The System Uses IOT Services Which Improve the Monitoring Process and Allow a Real Time Management and Data Processing System	The IoT produce lots of data with the system not having a means to store and manage those data scalable
2	Elleuchi *et al*.	2019	Water Pipeline Monitoring and Leak Detection using soil moisture Sensors: IoT based solution	It is a solution provided to monitor water pipeline and detect Leak using soil moisture sensors based on IoT technologies	It is difficult to pin point the actual location of leakage and it takes a bit of time for it to detect the change in soil mixture
3	Priya *et al.*	2018	IoT based Automation of Real Time In-Pipe Contamination Detection System in Drinking Water	The system is capable of analyzing the water quality parameters in real time and can successfully process, transmit data to the cloud and intimate the users about the contamination in the particular region	The system data is prone to attack or hack as there is no security measure securing the data sent which may lead to doubts about the data sent.
4	Isuru Sachitha Herath	2019	Smart Water Buddy: IoT based Intelligent Domestic Water Management System	It is a system that monitors water usage with IoT devices and uses machine learning to identify water leaks and abnormal usages, which helps to optimize the usage	Anomaly detection model of Smart Water Buddy is developed focusing on domestic water usage management making it not applicable in managing large scale water grids.

MATERIALS AND METHODS

This section describes the procedures which was used in the development of the proposed system (a secured IoT based pipeline product distribution system using block chain technology). It provides the detailed steps in block diagram, circuit diagram, flow design and flow chart. This research adopts the use of a blockchain based webapp as a security measure for the pipeline distribution system. The above listed technique is employed to improve the Safety and integrity of data from hackers and it also provides privacy to its user.

Software Requirements

The developed system made use of the following software:
i. Operating System
ii Mongo DB Database
iii. Node-JS
iv. C++

Hardware Requirements

The developed system made use of the following hardware:

i. Power Supply
ii. Microcontroller (Arduino)
iii. Liquid Crystal Display
iv. Temperature Sensor
v. Vibration Sensor
vi. Flow Rate Sensor
vii. GSM Module*
viii. System Design

Block Diagram

Fig. 4 depicts the data flow diagram of the Pipeline Product distribution system. The block diagram of the IoT based pipeline product distribution system using block chain technology is shown in Fig. 3.A flow diagram in Fig. 3 is presented as flow chart for IoT based pipeline product distribution system using block chain technology.

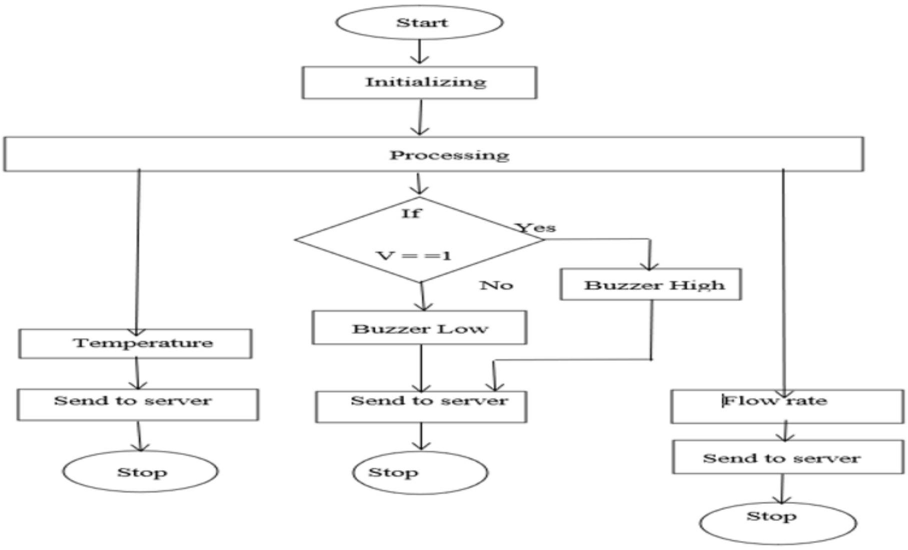
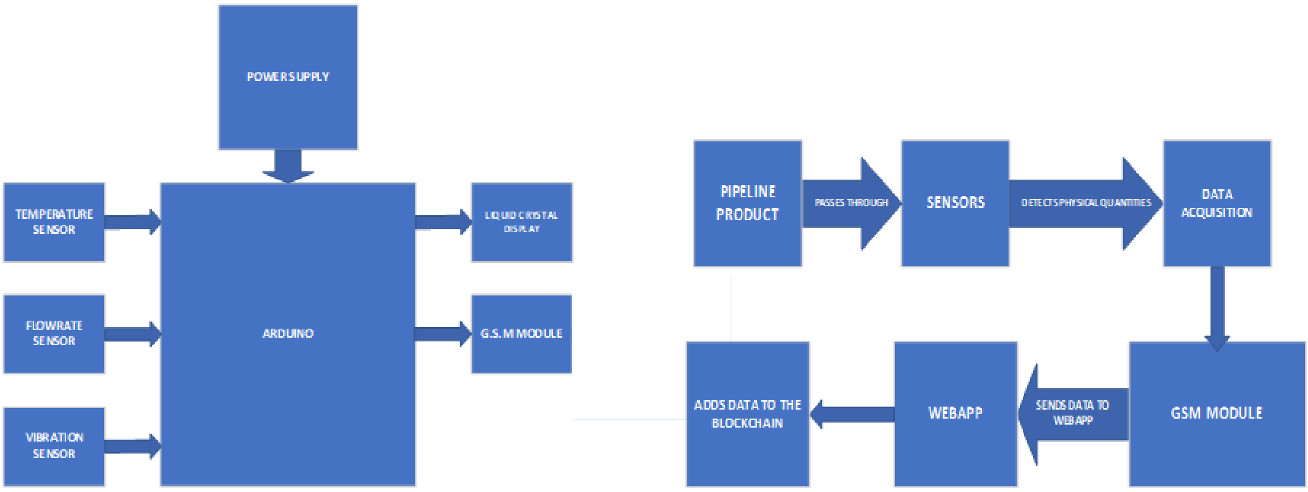


Fig. 3 Flow chart for IOT based pipeline product distribution system using block chain technology



a. System block diagram

b. Data Flow diagram of the developed System

Fig. 4 Data flow diagram of the pipeline product distribution system

Working Principles

The Electronic components adopted in the development of this project are, Arduino, LCD, Sensors (Temperature sensor, Vibration sensor, Flowrate sensor), GSM module, Switch button, power supply. The Sensors, the push button and the power supply all acts as the input to the microcontroller (Arduino) while the LCD and GSM module acts as the output for the system, the API (application interface) acts as both input and output in Pipeline Distribution system. Once data are being gotten from the sensors into the Arduino controller, the data are being sent through the GSM Module to the Webapp, which is then encrypted and added to the block chain and converted to a transaction hash. The system made use of three basic components in the embedded system design as under listed:

- Arduino Uno
- LCD
- GSM Module
- Sensors

RESULTS AND DISCUSSION

Software Simulation Results

The Block chain based Webapp was developed using Mongo DB database and node JS programming language demonstrating the final stages undergone in the final result of the pipeline distribution system, after the sensors of the system was used as a means to get data of the pipeline product as input. Appendix 1 shows the image of the login page of the webapp of the system. Appendix 2 shows the transactions that has occurred in the pipeline distribution system with its transaction Identification number as well as the value of each of its data. Appendix 3 shows in details an example of a particular transaction block in the block chain with its full details (its transaction ID, the data values (i.e., the value of temperature, flowrate and vibration), the broadcaster public key, the previous block hash, the signature hash and the timestamp.)

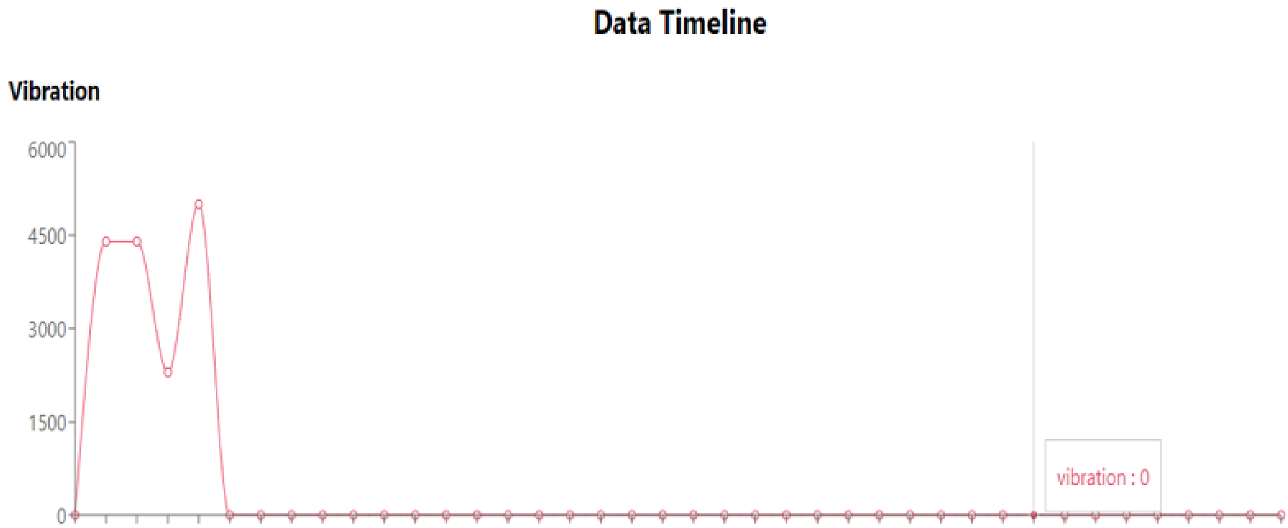


Fig. 5 Vibration data timeline characteristic curve

Fig. 6 and Fig. 7 shows the characteristic curve of each property (flowrate, vibration and temperature) of the pipeline product from each of the transaction carried out in the pipeline product distribution system.

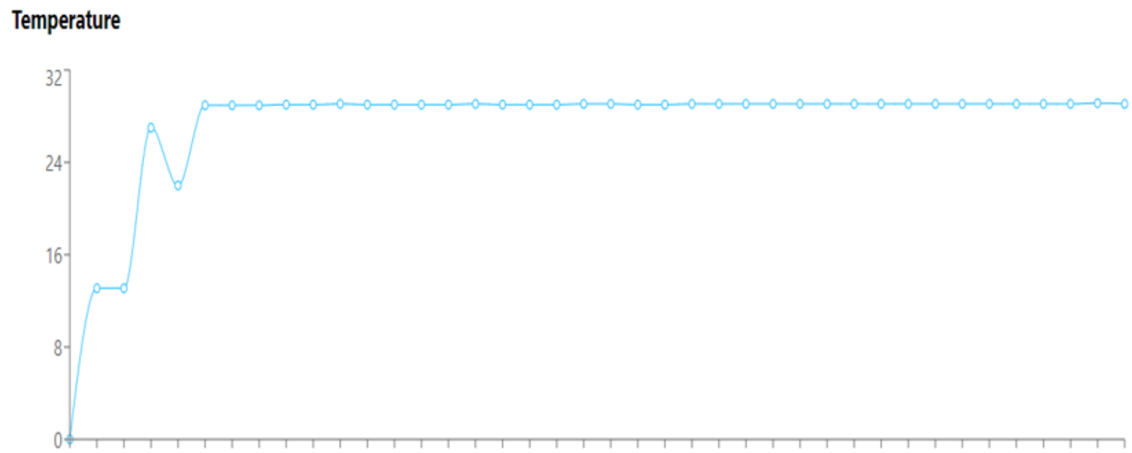


Fig. 6 Temperature data timeline characteristic curve

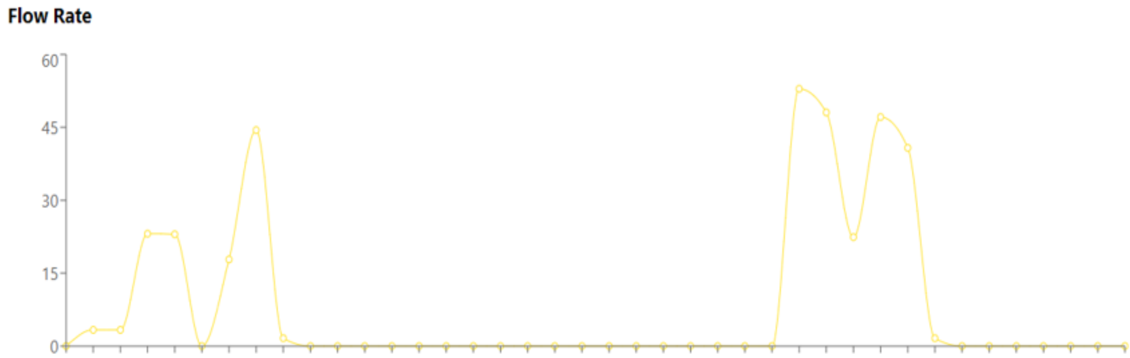


Fig. 7 Flowrate Data Timeline Characteristic Curve

Hardware Implementation Results

Fig. 8 shows the hardware integration of components, the Arduino Uno the sensors (vibration, flowrate and temperature sensor), the GSM module and the LCD display. The system is accessed through a web platform where the user can view the transactions carried out in the pipeline distribution system. The web app was made using Nodejs web framework which is a JavaScript-based with mongo dB at the backend of the framework. The Arduino gets the reading from the sensors and sends them to the webapp through the GSM module.

Fig. 8 Hardware system implementation diagram

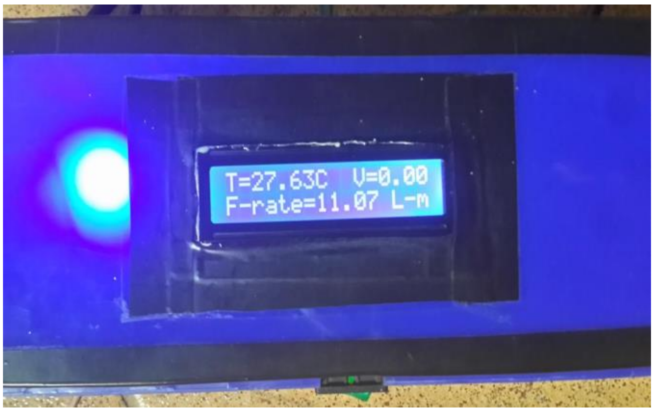


Fig. 9 IOT based pipeline product distribution using block chain technology

The entire design was tested by connecting the flow rate sensor to a PVC pipe and allowing a fluid a flow through it. As discussed the case study water was used as the fluid in this design. The temperature sensor and was immersed in the fluid while the vibration sensor was attached to the pipe. The flow rate of the water and the temperature were display on the lcd screen. The vibration data was also displaced on the screen.

Power Supply Test

The power supply test was done to ascertain or verify the actual voltage and current flowing into the circuit. A 12V, 500mA transformer was used in the design. The transformer produces an output voltage of 12V when an input voltage of 220V is applied to it. However, a digital multimeter which was calibrated to the AC voltage point, was used to to measure the output voltage of the transformer. The output voltage was found to be 11.3V AC. This is because the input voltage from the mains is not always constant.

Sometimes the mains voltage can lower or higher which do affect the output voltage. After undergoing the rectification stage to convert the 11.3V AC to 11.3V DC, the signal produced was disorder due to ripples. The signal was view using an oscilloscope which is shown in Fig. 10. In order to compensate for this, a filter capacitor was used which smoothen the signal thus removing the ripples. The capacitor also helps to raise the output voltage to a voltage which is determine by the capacitor rating. In this design a 4700 UF, 25V was used and the output voltage was measured after the filtering stage using the digital multimeter. It was found to be 12.42V DC.

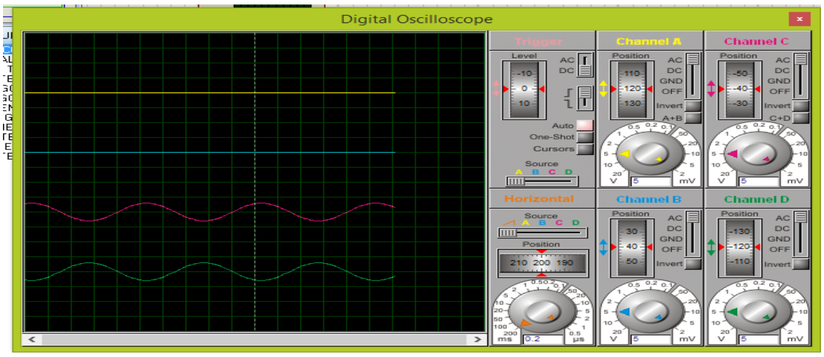


Fig. 10 Output signal of the power supply before and after rectification and filtering

Now the operating voltage of the entire circuit apart from the GSM module is 5V DC and in order to achieve this a 7805 voltage regulator was used. The voltage regulator has a voltage rating of 5V and a current rating of 1.5Amp. This rating is its specified value. The output voltage from the regulator was measure to verify the specified value by using the multimeter which was found to be 4.86V DC. A summary of the result obtained from the test is shown in Table 2.

Table-2 Summary of the result obtained from the test

	Transformer	7805
Vin	220V AC	12V DC
Vout	12V AC	5V DC
Current	500mA	1.5A
V specified	12V AC	5V DC
V measured	11.3V AC	4..86V DC

SIM 800 Test

The SIM 800 test was carried out by inserting a SIM-card into the SIM-card slot and thereafter powering it by connecting its power pin to the buck boost converter. At the initial stage the power led in the GSM module blinks rapidly but when the module has established connection with the network service provider, the blinking status changed to once every three seconds. At this stage a call can be placed to the mobile number to further verify its connectivity status. The SIM 800 is also equip with the GPRS features which makes browsing with the module possible. When there is data in the SIM-card, the GPRS feature is activated thus sending information to the internet. In the GPRS mode, the power led blinks once in every second at a very fast rate. One of the factor affecting the performance of the GSM module is the current in the power supply. A buck boost converter which output a current of 2A was used for powering the GSM module. The GSM module operate best at 4.0V, so the rheostat in the buck-boost converter was adjusted to 4.0V bench mark.

Sensor Test and Results from individual Sensors

The vibration sensor, flow rate sensor and temperature sensor was used in this design. The sensor was tested to know if they are working or not. The sensitivity of the vibration sensor was adjusted by tuning the rheostat in it. The vibration sensor is a digital sensor which produces an output logic state 1 (HIGH) when vibration is detected. In its default state it output is LOW. As a means of verifying if it is good or not the condenser on it was made to vibrate by hitting it. The output led went low (OFF), which verifies that it is in a good condition. To test if the temperature sensor was in good condition, it was interfaced with the microcontroller and the temperature was view on the serial monitor which has a room temperature of 25 degrees. Likewise, the flow rate sensor was also tested by interfacing it with the microcontroller. The flow rate sensor has two opening which are the water inlet and outlet. By allowing water to flow from the inlet to the outlet, the rate of flow was seen on the serial monitor. The result of from the block-chain based website sent through the GSM module are shown in Table-3, Table-4, and Table-5

Temperature Sensor

The result below shows the output reading of the temperature sensor at different degrees of changes.

Table-3 Temperature Sensing Under Different Condition

S/N	Temperature(Degree Celsius)	Conditions
1	29	Room Temperature
2	28	Temperature of a fire flame
3	36	Human body temperature
4	40	Mildly Hot Water
5	49	Very Hot Water

Flow Rate Sensor

The result below shows the flowrate within 60 seconds.

Table-4 Flow rate Sensing Under Different Condition

S/N	Flow rate (m^3/s)
1	41.62
2	40.99
3	41.12
4	41.20
5	40.96

Vibration Sensor

The result below shows the vibration sensor when subjected to vibration(disturbance) and when nothing was done to it.

Table-5 Vibration Sensing Under Different Condition

S/N	Vibration(Hz)	Condition
1	1	Disturbance
2	0	No Disturbance
3	1	Disturbance
4	0	No Disturbance
5	1	Disturbance

Performance Evaluation Response Time of Sensing Unit

Table-6, Table-7, and Table-8 show clearly the average response time to be 2 seconds (temperature sensor), 56 seconds (Flow Rate sensor) and 1.8 seconds (Vibration Sensor).

Table-6 Response time table for temperature

S/N	Time Taken (Seconds)	Temperature Reading (ºC)
1	1	29.06
2	2	31.50
3	1	28.40
4	3	33.21
5	3	33.91

Average Response Time = $\frac{1+2+1+3+3}{5} = 2\ seconds$

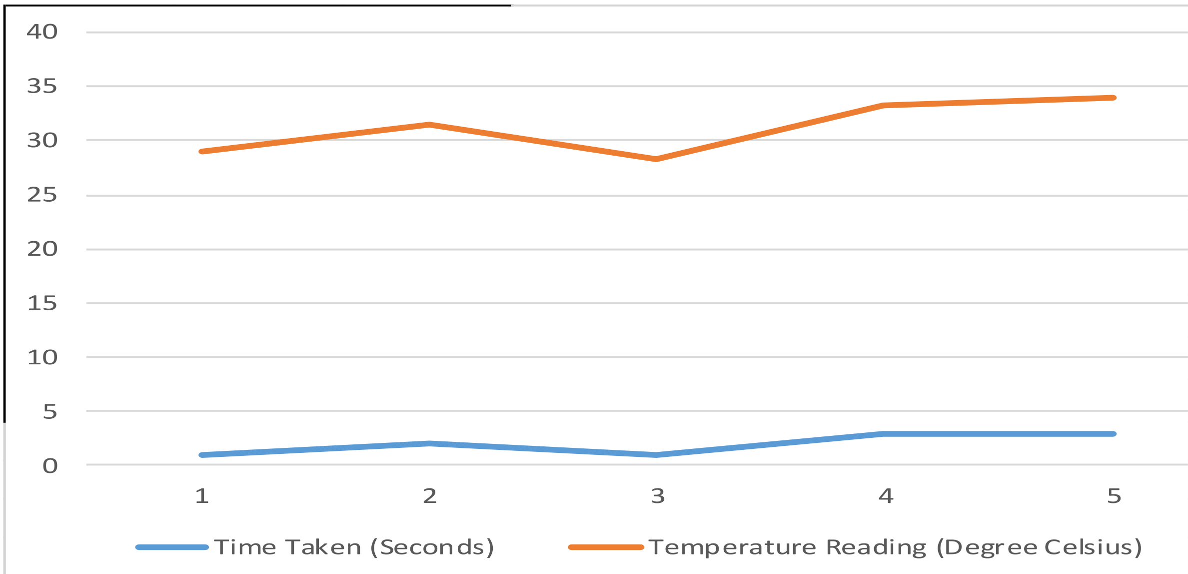


Fig. 11 Response time chart for temperature

Table-7 Response time table for Flow Rate

S/N	Time Taken (Seconds)	Flow Rate(m^3/s)
1	60	41.62
2	55	40.77
3	50	39.98
4	60	41.20
5	55	40.45

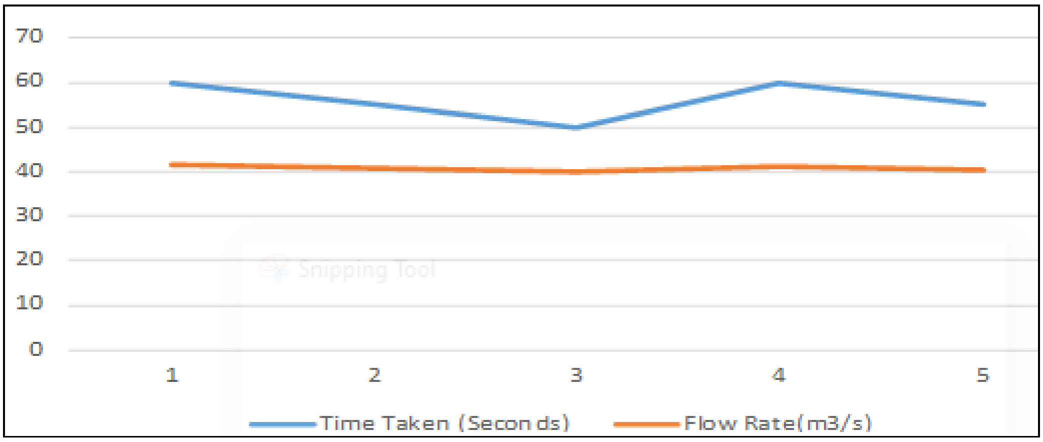


Fig. 12 Response time chart for flow rate

Average Response Time = $\frac{60+55+50+60+55}{5} = 56\ seconds$

Table-8 Response time table for Respiration

S/N	Time Taken (Seconds)	Vibration (Hz)
1	2	0
2	3	1
3	1	0
4	2	0
5	1	0

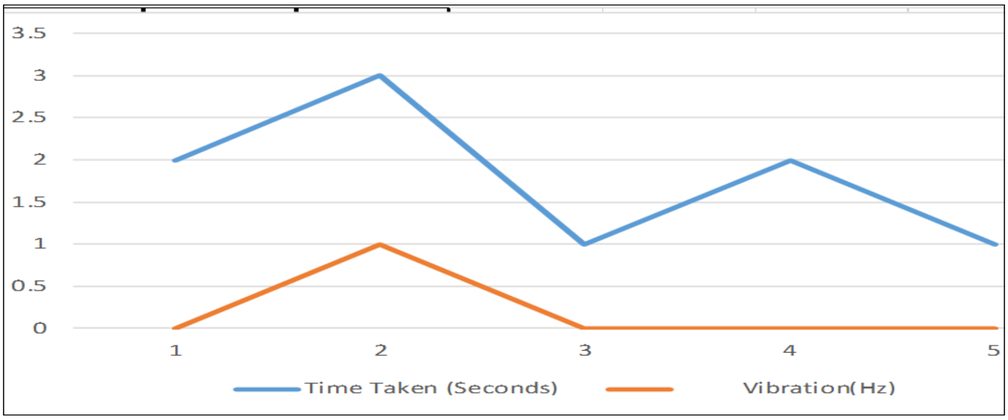


Fig. 13 Response time chart for respiratory rate

$$\text{Average Response Time} = \frac{2+3+1+2+1}{5} = 1.8\ seconds$$

the result from the test shows that the flow rate of any fluid increase with an increase in temperature. increasing the temperature will cause the particle within their molecule to gain freedom to move freely which is in accordance to kinetic theory. as can be seen from the result, the vibration sensor is a digital sensor which output either 0 or 1. Upon detection of vibration which is one of the feature associated with vandalism, the sensor output goes high and at the same time an alarm is been activated with the data also sent to the block chain website for view by the administrator another factor which affect the flow rate of a fluid is the pressure of the fluid. The more the pressure, the higher the flow rate. The temperature sensor enables the temperature of the product to be monitored from any destination. The sensor is a waterproof sensor which makes it suitable for this application. While the flow-rate sensor has an inlet and outlet connected to pipe containing fluid to estimate its flow rate, the temperature sensor is usually immersed into the fluid to measure the temperature. The sensor is place on the surface of the pipe to detect persistence vibration. The website designed to store the result was created using block-chain technology at the backend. The block chain technology ensures that the website is secure and protected from hackers. This is achieved through the use of an authorization token which is only known by the user. Without the authorization token, data cannot be sent to website by anyone. The user is the only one who is permitted to send data to the website using the token assign to him.

CONTRIBUTION TO KNOWLEDGE

Security is a crucial aspect of everybody, both globally and locally security should be given serious concern and attention. Various methods are already in place to tackle the issue of security, this project tried to improve on an already existing concept of IoT based pipeline distribution system, the system also plans to tackle the basic issue of security in the existing systems. The developed system is initiated to tackle a little aspect of a much broader scope problem by focusing on formal areas such as companies and industries, this project could be improved upon as to tackle greater and wider scope. As demonstrated in the discussion, the IoT based pipeline product distribution using block chain technology has been implemented in this design and it has proven to be efficient and reliable in securing data from hackers through the incorporation of block chain technology into the website design which is one of the major aim of this study. The design has also provided a pathway which allows user to access data from any part of the world. The inclusion of sensor such as vibration sensor into this design do not only send its data to the server but also alert passersby through the sound of an alarm in a situation where persistence vibration is detected which is one of the feature of vandalism with regard to pipeline.

RECOMMENDATION

The present study can be further improved through the addition of the following:

- Multiple sensors such as weight sensor, pressure sensor, density sensor and others can also be included into the system to enable more data to be collected.
- The system can also be improve through the use of GPS to indicate the location of the pipeline product.
- The inclusion of cameras to monitor activities will be a plus to the present study.
- The system can also be improved through the incorporation of wireless sensor network (WAN) into it.

REFERENCES

Adrian, F., Viorel, M., Bogdan, D., and Eugenia, M. (June 2011). Trajectory-Tracking and Discrete-Time Sliding-Mode Control of Wheeled Mobile Robots. *IEEE International Conference on Information and* Automation: 27-32 Shenzhen. Aalsalem, M. Y., Khan, W. Z., Gharibi, W., and Armi, N. (2017). *An Intelligent Oil and Gas Well Monitoring System based on Internet of Things*: 124–127

Abdelhafidh, M. (n.d.). Cognitive Internet of Things for Smart Water Pipeline Monitoring System. *IEEE/ACM 22nd International Symposium on Distributed Simulation and Real Time Applications (DS-RT)*, 1–8.

Abdelhafidh, M., Fourati, M., Fourati, L. C., & Chouaya, A. (2017). *I NTERNET OF T HINGS IN I NDUSTRY 4 . 0 C ASE S TUDY : F LUID D ISTRIBUTION*. 1–11.

Anilkumar, A., Vaibhav, M., Rakesh, S. N., & Balkrishna, D. R. (2020). Framework for the implementation of an Internet of Things (IoT)- based water distribution and management system. *Clean Technologies and Environmental Policy*, *0123456789*. https://doi.org/10.1007/s10098-020-01975-z

Dogo, E. M., Salami, A. F., Nwulu, N. I., and Aigbavboa, C. O. (2019). *Blockchain and Internet of Things-Based Technologies for Intelligent Water Management System*: 129–150.

Elleuchi, M., & Aseeri, M. (2019). Water Pipeline Monitoring and Leak Detection using soil moisture Sensors : IoT based solution. *16th International Multi-Conference on Systems, Signals & Devices (SSD)*: 772–775.

Hague, T. (2015). *The IoTs application in water : an enabled iots framewok for water distribution system*. *1*: 1–8.

Herath, I. S. (2019). *Smart Water Buddy : IoT based Intelligent Domestic Water Management System*.

Id, A. P., and Tapas, N. (2018). *Blockchain and IoT Integration : A Systematic Survey*. doi.org/10.3390/s18082575

Lakshmi, M. B. W., Pipe, U., & Monitoring, H. (2019). *Multi-Agent Based Water Distribution*. *Itng*: 395–400.

Maruthi H V et al, I. (n.d.). *An IOT based Water Supply Monitoring and Controlling System*.

Che, N.N., Series, C. (2021). *Water Pipeline Leakage Monitoring System based on Internet of Things*. doi.org/10.1088/1742-6596/1962/1/012025

Oh, S. W., Bae, J., Yoon, D., Yang, B., Kim, G. J., & Kim, H. S. (2018). A study on Improvement of Resource Efficiency for IoT-based Pipe Leak Detection. *2018 International Conference on Information and Communication Technology Convergence (ICTC)*: 1423–1425.

Lukman. A. Ajao , J. Agajo J. G. Kolo D. Maliki M. A. Adegboye,(2017). Wireless Sensor Networks Based-Internet of Thing for Agro-Climatic Parameters Monitoring and Real-Time Data Acquisition. *Journal of Asian Scientific Research*, 7(6): 240-252, DOI: 10.18488/journal.2.2017.76.240.252

Agajo, J., Jonathan G.K., Adegboye, M., Nuhu, B., Ajao, L., Aliyu, I. (2017). Experimental Performance Evaluation and Feasiblity Study of low pan Based Internet of Things. *Acta Electrotechnica et Informatica*,17(2): 16–22, Doi:10.15546/aeei-2017-0011.

Lulman. A. Ajao, J. Agajo, A. O. Ajao, J., Oke, T. (2017). Development of a Low-Cost Digital Logic Training Module for Students Laboratory Experiments. *Journal of Engineering and Technology,* 8(1)

Ajao A.L., Agajo, J., Kolo, J., Gana, I., Ogbole, C., and Edem E.A. (2017). Development of a Low Power Consumption Smart Embedded Wireless Sensor Network for the ubiquitous Environmental Monitoring Using Zigbee Module. *ATBU University Journal of Science, Technology & Education (JOSTE),* 5(1)

Ibrahim, A., Kolo, J.G., Aibinu, A.M., James, A., Abdullahi, M.O., Folorunso, T.A., Mutiu, A.A. (2017). A Proposed Fish Counting Algorithm using Digital Image Processing Technique. *ATBU Journal of Science Technology & Education (JOSTE)*, 5(1)

Agajo, J., Kolo, J.G., Ajao, L.A., Olusola, K.Y., Prince, A. (2016). Equipment, Security Personnel Tracking And Localisation Using Geo-Location Technique. *Journal of Engineering and Technology*, *7*

Okoli. Al Chukwuma; Orinya.Sunday. (2013). Oil Pipeline Vandalism and Nigeria's National Security. *Global Journal of Human Social Science Political Science, 13*(5): 66–75.

Priya, S. K., Shenbagalakshmi, G., & Revathi, T. (2018). IoT based Automation of Real Time In-Pipe Contamination Detection System in Drinking Water. *International Conference on Communication and Signal Processing (ICCSP)*: 1014–1018.

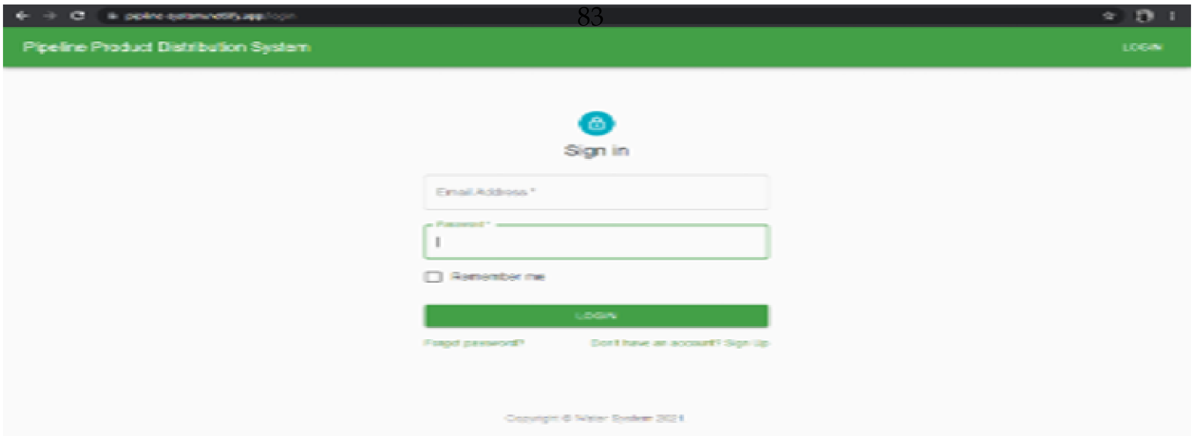
Rabêlo, R. A. L., & Rodrigues, J. J. P. C. (2019). *An IoT-based Water Monitoring System for Smart Buildings*. *6*

Shanmukh, S., Sai, M. P., Charan, S. S. S., and Chidambaram, N. (2019). *IoT-Based Pipe Burst Detection in Water Distribution Systems*. Springer Singapore. https://doi.org/10.1007/978-981-13-7082-3

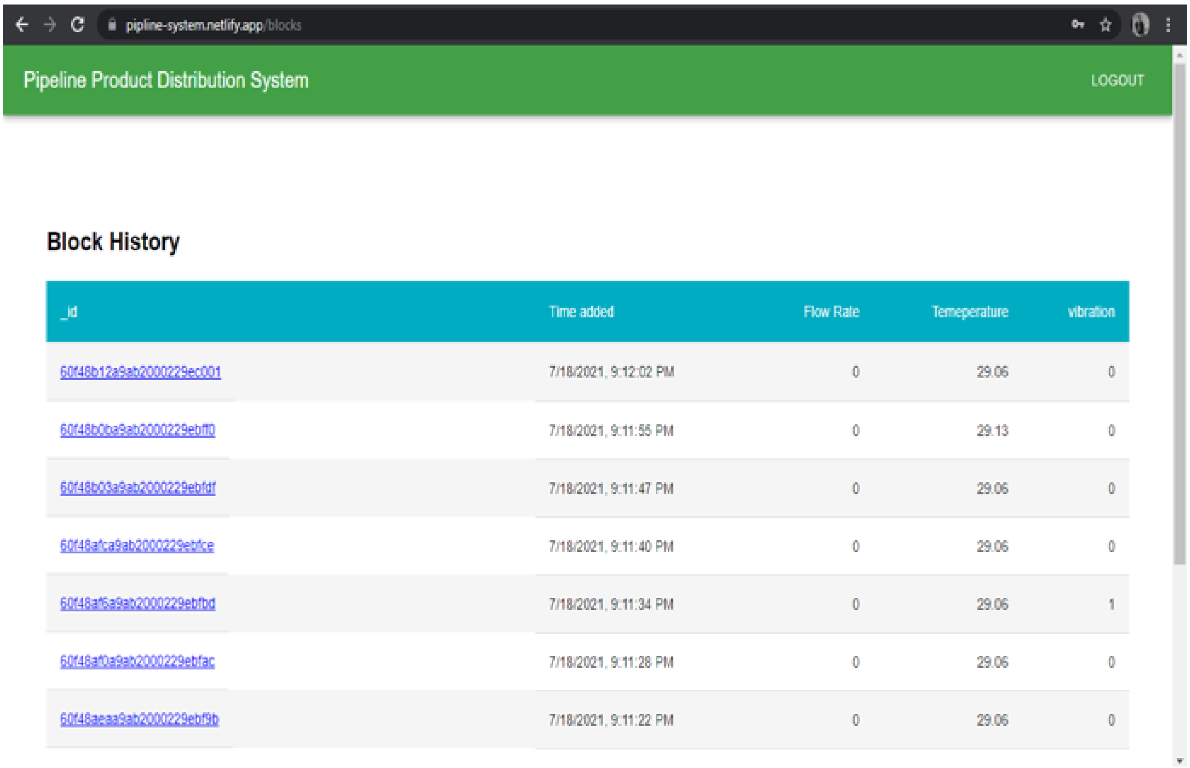
Suresh, M., Muthukumar, U., & Chandapillai, J. (2017). *A Novel Smart Water-Meter based on IoT and Smartphone App for City Distribution Management*. 1–5.

Dawn News,(2021) Gas transmission and distribution network to be separated, retrieve on 18th. Sept 2021, https://www.dawn.com/news/1519635

What is a Smart City?, retrieved online 18th. Sept 2021,https://www.cnu.org/publicsquare/2017/01/06/what-smart-city



Appendix 1 Login page of the pipeline product system's web app



Appendix 2 Homepage of the pipeline product system's web app (containing all transaction that has occurred in the system)

Appendix 3 Image of a Transaction Block in the Blockchain