Development of an Instrumentation System for Water Supply Network

*Jayeola F. Opadiji, Aye T. Ajiboye, Olalekan F. Adebayo, Hafeez O. Mahmud, Esther T. Olawole, and Ayodele J. Adesina
Department of Computer Engineering University of Ilorin, Ilorin, Nigeria
{jopadiji|ajiboye.at|adebayo.of|mahmud.ho|olawole.et|adesina.ja}@unilorin.edu.ng

Received: 09-AUG-2023; Reviewed: 23-SEP-2023; Accepted: 25-SEP-2023
http://doi.org/10.46792/fuoyejet.v8i3.1081

ORIGINAL RESEARCH

Abstract- Development of instrumentation system for water supply network is presented in this study. A lot of works has been reported in the area of developing instrumentation system for water flow rate measurement. The output of most of the water flow rate instrumentation systems encountered in the literature may not be accurate because neither their sensors nor the systems themselves were calibrated. Therefore, development of an instrumentation system with calibrated sensor is presented in this study to ameliorate the system output. To realise this system, the water flow was sensed using flow sensor, the output signal from the sensor was processed using microcontroller. The sensor was calibrated to guarantee accurate system output. The developed system was tested on a test rig comprise of source and destination water tanks linked via 4 parallel pipes. Also, the output data from the microcontroller was transferred to the computer for formatting and storage. The calibration results give minimum and maximum calibration error of 1ml and 26ml corresponding to 0.33% and 3.47% respectively. The network nodal rule of source flow rate equals the summation of the destination and leakage flow rate was validated.

Keywords- Flow rate, Flow sensor, Instrumentation, Microcontroller.

1 INTRODUCTION

A lot of works has been done by researchers in the area of developing instrumentation system for water flow rate measurement. The data collected during the measurement can be used for immediate display of flow rate value, stored for future use or for controlling the flow of water in the pipe network. Development of an instrumentation system for low-cost automatic water flow meter using G1/2 Hall Effect water flow sensor with its outputs pulse train serving as input to a microcontroller was presented in (Sood1 et al., 2013). The developed instrument is simple and cheap. (Mwangi, 2016) developed an automatic water flow rate meter using G1/2 flow sensor andPIC18F4550 microcontroller for sensing the water flow rate and processing the sensor output signal respectively.

In the smart water flow rate meter proposed by Amir et al., (2022) the digital output from the water flow sensor is sent to an Arduino microcontroller for processing and conversion to the form required for displaying. In Dalle et al., (2020), data needed for implementation of water debit measurement was generated using flow sensor and microcontroller for flow sensing and data processing respectively. A combination of water flow sensor and Arduino microcontroller was employed by Rahmat et al., (2017) for sensing and producing the required data for monitoring flow rate and leakage along water pipeline. The major drawback in their work is the limitation of the leakage detection capability to a maximum range of 2 meter.

*Corresponding Author

Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
Can be cited as:
Opadiji J.F., Ajiboye A.T., Adebayo O.F., Mahmud H.O., Olawole E.T., and Adesina A.J. (2023), Development of Instrumentation System for Water Supply Network, FUOYE Journal of Engineering and Technology (FUOYEJET), 8(3), 319-323. http://doi.org/10.46792/fuoyejet.v8i3.1081

In Kumar & Mahmoud (2017), monitoring and controlling of tap water flow at homes using android mobile application was carried out. The instrumentation aspect of the project was realized by mounting the flow sensor on water pipe for sensing the flow of water. The sensor output was interfaced with microcontroller which in turn process the sensor output signal into appropriate format for monitoring and control purpose. The instrumentation system for generating the data required for automatic monitoring of water usage was realized in the work carried out in Saseendran & Nithya, (2016) and Koshoeva et al., (2021) by interfacing water flow sensor with Arduino microcontroller. Flow rate monitoring system for water pipeline was developed by Ismail et al., (2014), in their work, water flow rate was obtained via MPU6050 vibration sensor which is connected to an Arduino board for processing of the sensor output. It should be noted that the system can only be used for low water pressure. To monitor, control usage and flow rate of clean water, YF-S201 flow sensor and ATmega328P microcontroller were used by Khaery et al. (2020) for sensing the water flow and process the sensor output signal respectively.

In Ali & Saidi, (2021) accurate water leakage and usage in a residential building was determined by measuring the water flow rate in a pipe supplying the building using YF-S201 water flow sensor and Raspberry Pi 4 as the signal and data processor. Hall effect-based water flow sensor was employed by (Patil et al., 2020) to detect and determined the level of water leak and the sensor output was processed by microcontroller for water leakage detection. A method of water flow rate and quantity measurement based on sound wave was presented by (Ibarz et al., 2008). Here, Bluetooth audio device (Headset) was modified to become sound transducer by replacing the loud speaker with microphone. Since the sound produced by the microphone is directly related to the water flow rate, the sound information was sent to a computing unit where audio data is transformed to water flow rate. The system required application of artificial neural network (ANN) to function.

It should be noted, the output of most of the water flow rate instrumentation systems encountered in the literature (Sood et al., 2013; Mwangi, 2016; Amir et al., 2022; Dalle et al., 2020; Saseendran & Nithya, 2016; Koshoeva et al., 2021; Ali & Saidi, 2021; Patil et al., 2020) may not be accurate because neither their sensors nor the systems themselves were calibrated. Therefore, in this study development of an instrumentation system with calibrated sensor is presented. The system leakage detection range is large, it works perfectly with pressure within the sensor rating and very simple because it does not require ANN to function. To realise the aim of this study, the system was outlined and each of the stages analysed. The model equation for flow rate was determined and used as the basis for programming the microcontroller. The system components were connected and the sensor was calibrated. Finally, the programme for parameters logging was installed and test was carried out on the developed system.

2 Methodology

2.1 Instrumentation System Outline

The block diagram of the developed instrumentation system is shown in Figure 1. The system is made up of power supply unit; water flow sensing unit; signal processing unit; and data storage units (laptop personal computer). The power supply provides the necessary power for the system components while the sensing unit senses the water flow. Also, the signal processing unit condition the signal to a form suitable for processing and storage by the data processing unit and computer respectively.

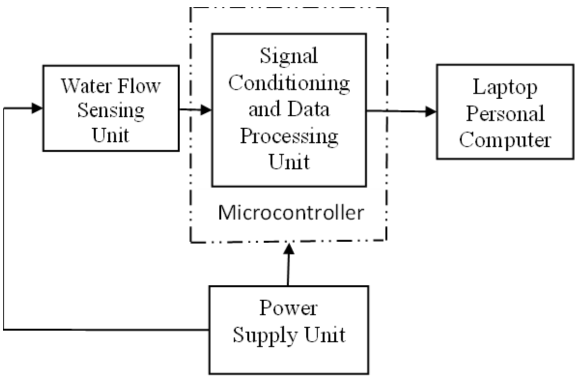

Fig. 1: Block diagram of the developed flow rate instrumentation system

2.2 Water Flow Sensing Unit

Based on the location of the source and the destination water tank, the determined maximum pressure and flow rate are 0.53 MPa and 25 litres/min. respectively. Therefore, the YF-S201 flow sensor was selected because its robustness and wide range of parameters (0- 2.0 MPa and 0-30 litres/min). YF-S201 has three terminals, one for supply voltage, one for ground and the last one is for output. The sensor is supplied from 5v while its output is connected to the input of the signal processing unit as shown in Figure 1.

2.3 Signal and Data Processing Unit

The output of the selected sensor is electrical pulses that has frequency which is directly proportional to the water velocity. Therefore, there is the need to convert the signal to flow rate which is the expected output of the developed system using signal conditioner. As miniaturized device was desired in order to reduce both the physical size and power consumption, ESP 32 microcontroller module was selected for use as signal conditioner and data processor.

2.4 Determination of Flow Rate

The output from the flow rate sensing unit is fed to the microcontroller as explained in Subsection 2.1. The relationship between the flow rate (Q) in litre per unit time and the output signal from the sensing unit is expressed in equation (1), based on this equation the flowchart of Figure 2 was developed. To convert the input signal to water flow rate, the microcontroller code was written based on equation (1) (Rahmat et al.; 2017, Art of Circuit, 2023; Mwangi, 2016) by following the steps in the flowchart of Figure 2.

$$Q = \frac{f_p}{7.5\times60} \quad (1)$$

where f_p = Pulse frequency in Hz

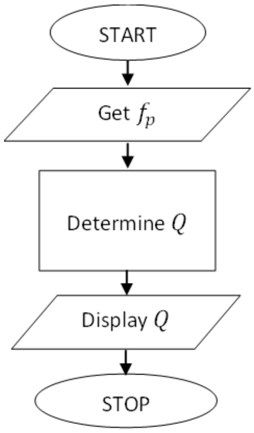

Fig. 2: Flow chart for flow rate determination.

2.5 Components Connection for the Developed Instrumentation System

The complete circuit representation of the developed system is as shown in Figure 3. ESP 32 was powered by a 5volt battery source and the output of flow sensor, YS-201 is connected to GPIO27 pin of ESP 32 microcontroller module. The YS-201 connected to ESP 32 module was installed on water pipeline to sense the flow of water and generates the corresponding electrical pulses which is sent to the microcontroller via pin GPIO27 for processing.

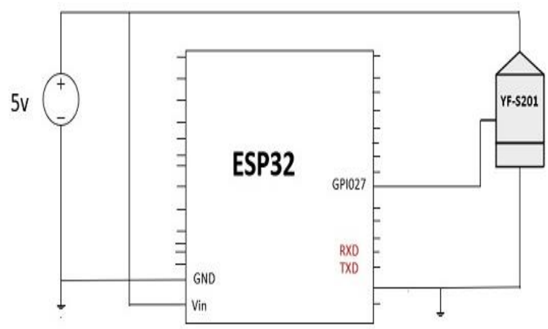

Fig. 3: Components connection for flow rate instrumentation system

2.6 System Calibration

The flow rate calibration factor (FRCF) of 7.5 was reported to have an error of ± 10% (Art of Circuit, 2023), therefore, in this study FRCFs of 7.0, 7.5, and 8.0 were experimented so that the one yielding optimum result can be selected. Calibration experiment was carried out using measuring cylinder graduated in millilitre (0 to 1000mL) to measure the volume of water dispensed via the developed flow rate instrumentation system. The dispensed water volume readings obtained from the measuring cylinder is the standard volume while the one obtained via the instrumentation system is the actual. The difference between the standard and actual volume (calibration error) was determined for each of the FRCF scenarios.

The experiment was carried out by first dispensing 50ml of water via the flow sensor. The dispensed 50ml is the standard and the reading indicated by the sensor is the actual volume. A total of 20 readings were taking by increase the volume of the dispensed water for a given scenario by 50ml from the immediate past value. This make the range of volume of water recorded for each of the FRCFs to be 50-1000ml. To determine best FRCF, the determined calibration data was graphically analysed.

2.7 Logging of Flow Parameters

After the calibration exercise, the source flow rate (Q_s), destination flow rate (Q_d), and leakage flow rate (Q_l) data were processed by the microcontroller in each of the instrumentation systems shown in Figure 4 using the flowchart of Figure 5. The data are then formatted and logged to the computer as shown in Figure 4 via wire communication using serial communication protocol (Ajiboye et. al., 2023). At this stage, the data can be logged as text, csv or excel file format. The logged data can easily be accessed using Notepad, MATLAB, or Microsoft Excel.

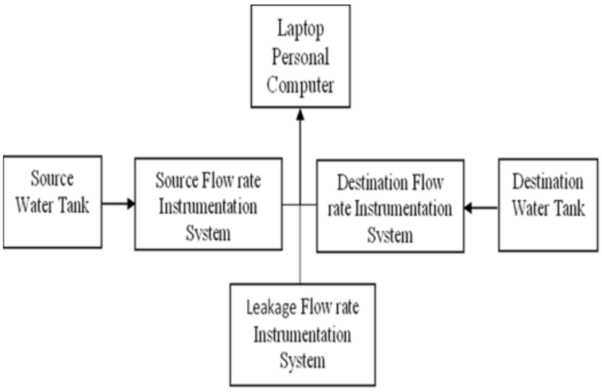

Fig. 4: Block Diagram of parameters flowing from sensing to logging

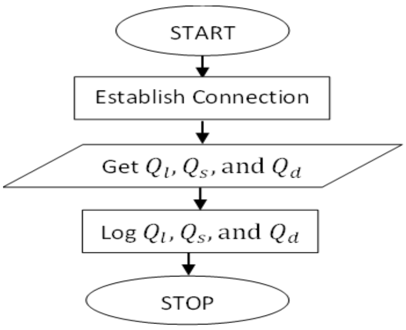

Fig. 5: Flowchart logging Q_s, Q_d, and Q_l to Laptop personal computer

3 Testing of the Developed System

The water needed for the experiment was pumped into the source tank with the aid of 1.5hp pumping machine. The source tank is connected to the destination tank through four (4) parallel pipes. Connected to each of these pipes are three (3) units of the developed flow rate instrumentation system, one at the source tank end, the second is at the destination tank end while the third on is at the leakage point end to monitor the flow rate. Also fitted to these pipes at the source, destination and leakage ends are control valve for varying the flow rate. The valves at the leakage end of these pipes are used to mimic leakage and emulate level of leakage since the degree of opening and closing of the valve can be controlled. The experimental rig showing the source and destination tank is shown in Figure 6.

Fig. 6: Experimental rig for water flow rate and leakage experiment

For the developed system to be functioning properly, equations (2) and (3), which represent the mathematical expressions for network nodal rule, must be satisfied.

$$Q_s = Q_l + Q_d \quad (2)$$

$$V_s = V_l + V_d \quad (3)$$

where V_s is the volume of water dispensed from the source tank in litre, V_d is the volume of water received by the destination tank in litre, and V_l is the volume of water leaked along the pipe in litre.

4 Results and Discussions

4.1 Calibration Results

The graph of volume of water measured, using measuring cylinder as standard, and the value indicated by the developed system for FRCF of 7.0, 7.5 and 8.0 against instances is shown in Figure 7 (a). As can be seen from Figure 7 (a), the closest plot to the standard is that of FRCF=8.0. To affirm the closeness of the resulting graph for FRCF= 8.0 to the standard, the graph of calibration error versus the instances was plotted as shown in Figure 7 (b). It is obvious from Figure 7 (b) that the error between the standard volume and the volume when FRCF=8.0 is the least with minimum value of 1 at instance 6 and maximum value of 26 at instance 15 corresponding to 0.33% and 3.47% respectively. Based on these results FRCF of 8.0 was selected for the system.

http://doi.org/10.46792/fuoyejet.v8i3.1081 engineering.fuoye.edu.ng/journal

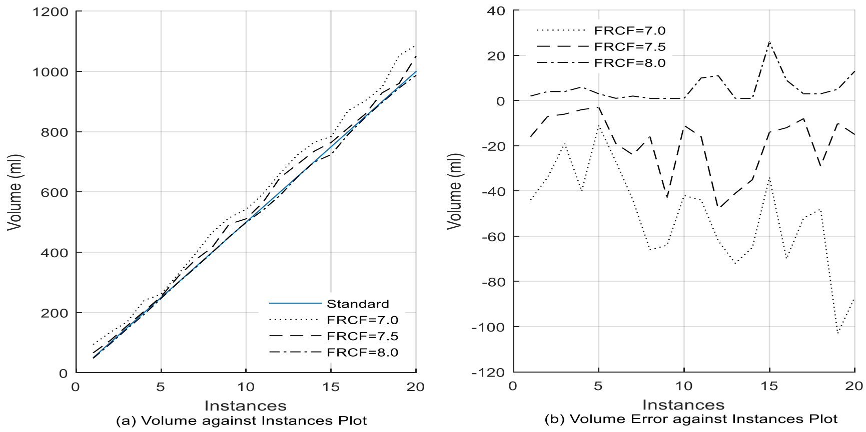

Fig. 7: Calibration graph

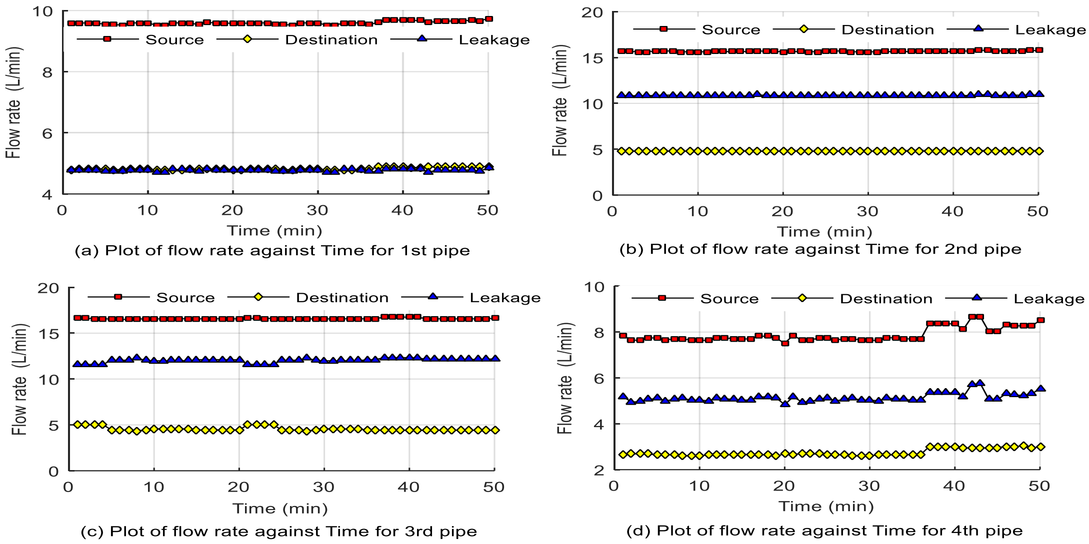

Fig. 8: Plot of flow rate at the source, destination and leakage point against time for each of the 4 pipes

4.1 Test Results

Figures 8 (a) to 8(d) are the graphs of flowrate at the source, destination and leakage points versus time for the 1st, 2nd, 3rd and 4th pipe respectively. Equations (2) and (3) is validated by these graphs as it can be seen at any time Q_s, is the sum of Q_d and Q_l. The nature of flow in the 1st and 3rd pipes is slightly turbulent, that of 4th pipe is more turbulent while the flow in the 1st pipe is laminar. These can be attributed to: (i) the location of the pipes on the source tank, and (ii) the nature and the degree of opening of the valves, assuming constant pressure at the source tank. The total volume of water dispensed via any of these pipes be it at the destination or leakage points can be determined at any pointing time by just finding the area under the curve over a given period of time.

Figures 9(a), 9(b) and 9(c) are the plots of flow rate at the source, destination and leakage point respectively against time for all the 4 pipes. As can be seen in Figure 9(a), the flow rate at the source of the 3rd pipe is the highest followed by the 2nd, 1st, and 4th pipe in that order. For the destination flow rate in Figure 9(b), the highest is associated with the 1st and 2nd pipes followed by the 3rd while the least is that of the 4th pipe. Figure 9(c) reveal that the leakage flow rate associated with the 3rd pipe is the highest followed by the 2nd, 4th and 1st pipe in that order. It should be noted that the value of the flow rate at any given time is a function of the pipe location on the source tank, nature and degree of opening of the valves if the pressure at the source tank is assume to be constant as earlier mentioned.

http://doi.org/10.46792/fuoyejet.v8i3.1081 engineering.fuoye.edu.ng/journal

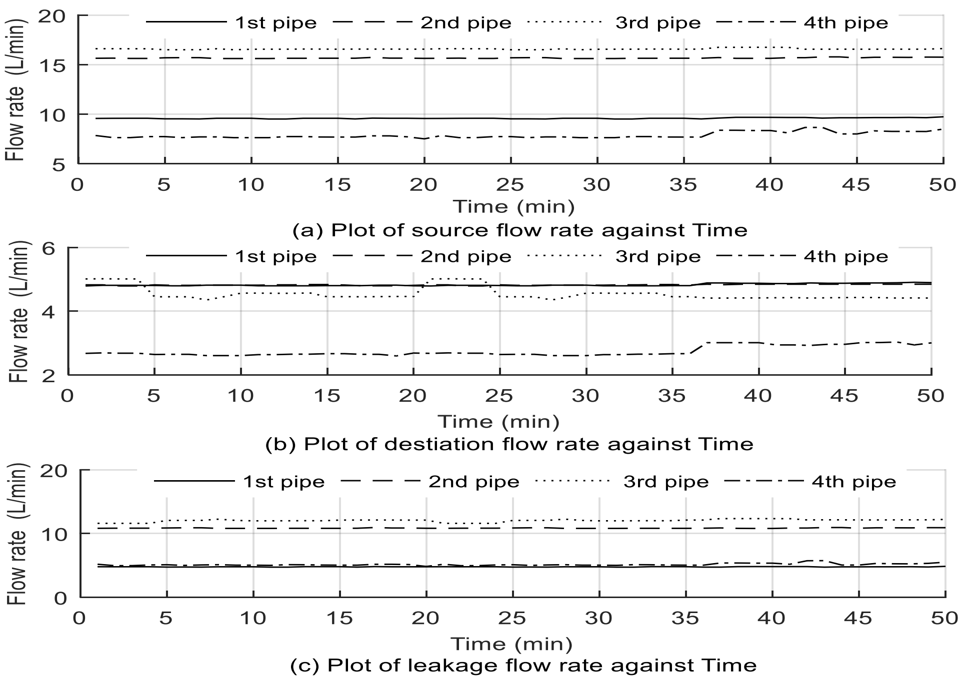

Fig. 9: Plot of flow rate at the source, destination and leakage point against time for the 4 pipes.

5 Conclusion

A low-cost water flow rate instrumentation system with accurate output was developed. The system was calibrated and tested. The developed system with the test rig can be used for real time water network and flow rate experiment in the universities, polytechnics, research institutes and public water works department. The results give minimum and maximum calibration error of 0.33% and 3.47% respectively for the FRCF of 8.0 used in this study. It also confirmed the network nodal rule of source flow rate equal the summation of the destination and leakage flow rate. The results reveal that the source, destination and leakage point flow rate for the 4 pipes may not be equal. The total volume of water dispensed via any of the pipe can be determined at any pointing time by finding the area under the curve obtained when flow rate is plotted against time.

Acknowledgment

This project was wholly sponsored by the Tertiary Education Trust Fund (TETFund) under the 2016/2017 Institution-Based Research (IBR) grant.

References

Ajiboye, A.T., Yusuf, A.O. Iyanda, M.O. & Popoola, O.J. (2023), Instrumentation System for a Model Laboratory Soil Bin. *FUOYE Journal of Engineering and Technology*. 8(1), 5-9.

Ali, F., & Saidi, M. F. H. (2021). Water leakage detection based on automatic meter reading. *2021 15th International Conference on Ubiquitous Information Management and Communication (IMCOM)*, 1-7.

Amir, A., Fauzi, R., & Arifin, Y. (2022). Smart water meter for automatic meter reading. *IOP Conference Series: Materials Science and Engineering*: vol 1212, 1-6.

Art of Circuit. (2023, July 14). https://artofcircuits.com/product/hall-effect-water-flow-sensor-1-30lmin-yf-s201

Dalle, J., Tamjidi, M., & Syafruddin, S. Y. (2020). Implementation of water debit measurement using microcontroller-connected flow meters. *TEM Journal*, 9(4), 1467.

Ibarz, A., Bauer, G., Casas, R., Marco, A., & Lukowicz, P. (2008). Design and evaluation of a sound based water flow measurement system, Smart Sensing and Context. *Third European Conference, EuroSSC 2008, Zurich, Switzerland Proceedings 3*: vol 5279, 41-54.

Ismail, M. I. M., Dziyauddin, & R. A. (2014). Water pipeline monitoring system using vibration sensor. *2014 IEEE Conference on Wireless Sensors (ICWiSE)*, 79-84.

Khaery, M., Gunawan, A. A. N., & Paramarta, I. B. A. (2020). Water flow control system by online based on ATmega328P microcontroller. *Contemporary Engineering Sciences*, 13(1), 303-314.

Koshoeva, B., Mikheeva, N., Mikheev, D., & Bakalova, A. (2021). Arduino-based automated system for determining water flow consumption in open flow. *Journal of Physics: Conference Series*: Vol 2142 012009

Kumar, K., & Mahmoud, M. A. (2017). Monitoring and Controlling Tap Water Flow at Homes Using Android Mobile Application. *American Journal of Software Engineering and Applications*, 6 (6), 128-136.

Mwangi, P., Mwangi, E. & Karimi, P. M. (2016). A low cost water meter system based on the global system for mobile communications. *International Journal of Computer Applications*, 142 (12), 0975 – 8887.

Patil, P. S., Kapgate, P. D., Rathour, S. B., Mawale, N. P., & Khope, R. (2020). Water level monitoring and leakage detection system using long range module (LoRa). SAMRIDDHI. *A Journal of Physical Sciences, Engineering and Technology*, vol 12, 41-45.

Rahmat, R., Satria, I., Siregar, B., & Budiarto, R. (2017). Water pipeline monitoring and leak detection using flow liquid meter sensor. *IOP conference series: materials science and engineering*: Vol 190 012036

Saseendran, S., & Nithya, V. (2016). Automated water usage monitoring system. *2016 International Conference on Communication and Signal Processing (ICCSP),* vol 334, 99-103.

Sood1, R., Kaur, M., & Lenka, H. (2013). Design and Development of Automatic Water Flow Meter. *International Journal of Computer Science, Engineering and Applications (IJCSEA),* 3(3), 49-59.

