An Enhanced Water Pipeline Monitoring System in Remote Areas Using Flow Rate and Vibration Sensors

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Abstract. Currently in India and most of the other countries, if there is any leakage of water pipes in remote areas then it's difficult to trace and repair the leakage within a short span of time, it takes some amount of time usually two to three days to locate the leakage and to repair it. During this time a lot of water is wasted. In this paper we discuss the techniques to detect the leakage and locate the leak point on the pipeline. In the proposed approach we discuss efficient techniques for monitoring, detecting leakage in pipes and checking the durability of the pipes using flow rate and vibration sensors. The objective is to build a prototype model for detecting leakage in water pipeline using flow rate sensors and also to predict the durability of the pipe using vibration and pressure sensors. Data from remote sensors are collected through wireless medium and are monitored in a server. If there is any leakage in the pipelines then the server sends the sms message to the water board authorities and notifies the leak point in the pipeline system. Further the durability of pipe can be predicted using pressure sensor so that the authorities can be intimated in prior about chances of breakage in pipelines. Thus the proposed system can save huge amount of water by intimating the authorities in time. Thus the experimental result validates the effectives and reliability of the proposed system.

Keywords: Water leakage · Detection · Monitoring · Leak detection

1 Introduction

The scarcity of drinking water is one of the critical issues that everyone is facing in their day today life. According to the sources there is only 2.5% of fresh water available among which only 1.5% is used for drinking purpose. In future if proper water pipelines monitoring system is not adopted means, this water scarcity of drinking water will lead into a biggest challenge for mankind survivability. The water leakage is mainly due to poor monitoring, maintaining and aging of pipes, to prevent future water losses many techniques have been proposed for detecting leakage in pipeline which has some limitations as discussed in Table 1.

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Table 1. Pipeline leakage detection techniques

Detection parameters considered	Methods followed
Acoustics	Sound produced by leak is sensed using hydrophone device
Optical	Fiber optical temperature profile sensing
Cable sensing	Electrical cables are used that when come into contact with hydrocarbons of soil
GPR (Ground penetrating radar)	Electrical radiation is used in microwave band
Vapour sampling	Vapour monitoring uses monitoring wells as testing locations for leaking product
Video inspection	Real-time event is detected using digital video inspections

In conventional water pipeline maintenance system a robust and efficient techniques lack, due to which a huge volume of water is getting wasted. So we need to overcome these techniques by adopting new latest technologies which are very robust and reliable in detection and maintenance of pipeline leakage in remote areas. If any leakage is detected in pipes which are located in remote locations then it will be difficult to trace the location of pipeline leakage, sometimes the concerned authorities may take several days to race the location and repair the pipe where the leakage is happening. So this delay causes large quantity of water loss. So this conventional approach need to be automated by adopting sensors based technology for identifying the leakage and tracking the location were exactly leakage is happing so that within short period of time leakage can be repaired or prevented so that there is no much loss of water.

The main objective of proposed system is to survey the existing methods and solutions and propose an enhanced method for detection and monitoring of pipelines in remote locations using different sensors.

There are mainly four objectives which describes the complete working of the system.

1. To detect water leakage using flow rate sensors.
2. Monitoring pipeline system using Vibration sensors.
3. Sending notification message to concerned water management system authority when leak is detected.
4. To develop an efficient pipeline system to prevent leakage of water.

2 Related Work

In today's world drinking water is essential for every leaving organism, so we need proper water distribution mechanisms so that the drinking water reaches to all the people with required quantity. The need of sustainable water supply system is ever increasing. In the conventional approach the leakage of water is detected manually. As discussed in Table 1 various different methods are used to detect pipeline leakage [1].

Monitoring leakage of underground pipelines now has become one of the important and challenging tasks. Acoustic emission effects and wireless connection for communication makes the system easy to deploy. Acoustic emission based deployed systems are inexpensive and gives accurate results [2]. The main objective is to detect the underground pipeline leakage which will be monitored in the server. The system is designed and developed using different types of sensors such as temperature, acoustic, flow rate and pressure sensors, the readings are continuously recorded from these sensors and are processed in the server to detect and locate the exact leakage point in the pipelines [8].

2.1 Classification of Leak Detection Techniques

According to the survey the leak detection techniques can be classified into two main categories i.e. hardware and software based methods. The Fig. 1 shows the classification of leak detection techniques.

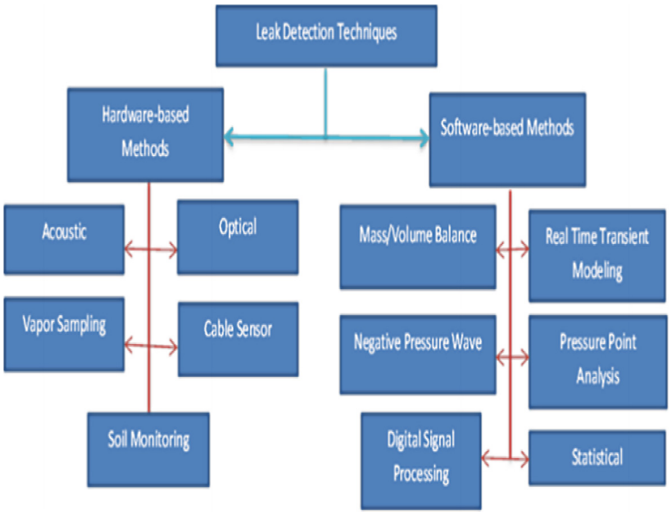

Fig. 1. Classification of leak detection techniques

In case of hardware based leak detection the leak is detected externally outside the pipeline by visualization or through some devices [3]. These methods have potentially good sensitivity to detect leak and are very accurate in tracing the leak location.

In software based leak detection different software techniques are used, programs are written to monitor and different algorithms are used to continuously monitor the water pipeline considering the following metrics such as flow rate of the water within the inlet and outlet of pipes, temperature, vibration and pressure of the water flowing through the pipe. The above discussed methods need power and continuous monitoring service to maintain the pipeline system in good condition [5]. Along with these

techniques there are few more techniques which are efficient to maintain and monitor the pipelines in the rural and remote areas where the water board authority workers find it difficult to continuously walk around and monitor so to overcome these issues and challenges the water board management authority can use latest and efficient techniques such as ground penetrating radar (GPR), pressure measurements and acoustic measurements, these techniques helps to identify the leakage and can be used to maintain the good condition of the pipeline system.

The leak detection systems discussed in Table 1 can be broadly classified into non-invasive and invasive. Non-invasive leak detection techniques are used to detect external leak of pipes using sensors or visual inspection [8]. In case of Invasive leak detection we continuously monitor the pressure, temperature and flow rate of the water. Invasive leak detection techniques require drilling of holes or pipe cutting to mount the device inside the pipe, so it's not that flexible and often disrupt the pipeline mechanism.

2.2 Cable Sensing Method

This method involves installation of cable through the entire pipeline. Here the sensor consists of two electrical circuits, one circuit is used to monitor the cable life, and the second circuit is used to sense the leakage in pipes. Whenever there is a leakage in the pipe the spilled water will get in touch with the embedded circuit board and this intern may lead into short circuits and breakage of complete system. So the cable sensing method basically uses wired networks which have major drawbacks such as cost, maintenance, installation. And if there is damage in the cable then it will directly affect the network performance.

Maintenance of these wires is difficult and we need to pay for labour and repair cost is high [7]. A wireless sensor network seems to be a better solution compared to traditional wired networks. In fact most of the researchers have given more focus on wireless sensor network considering feasibility, high performance, low cost and easy deployment for monitoring the pipeline detection system.

2.3 Leak Edge Detection Method

In leak edge technique we usually measure the pressure using the acoustic based methods. The acoustic based pressure measurement techniques are very costly and consume lot of time for the deployment, repair and maintenance of the pipeline system [9]. In leak edge detection technique the major focus is on steady state, but we need to migrate this from steady state analysis to transient state analysis.

According to the survey there are so many limitations of existing system such as

- It needs more human resource.
- There can be human error.
- It is costly.
- It is time consuming. During that time there can be more water leakage.
- Inspection and replacement of pipelines as quickly as possible.

3 System Design

The overall block diagram of the enhanced pipeline monitoring system is as shown in Fig. 2, the system mainly consists of sensors, server, GSM, GPS and microcontroller.

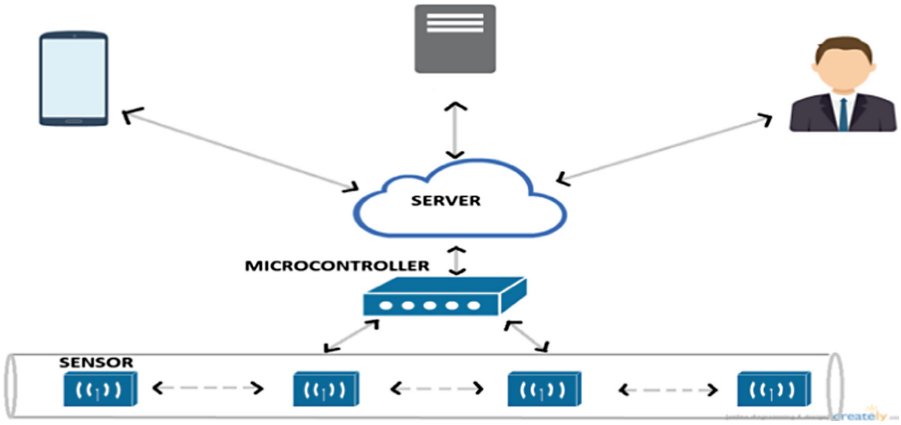

Fig. 2. System architecture

The proposed system model mainly consists of two modules, the transmitter module and the receiver module. In the transmitter model the flow rate sensors and vibration sensors are deployed to capture the flow rate of water within the pipe, the sensor generates the pulses. A microcontroller used to process the pulses and provides the desire results. A wireless module is mounted at the transmitter end to transmit the sensed pulse vales to the server; these pulse values will be continuously monitored.

3.1 Transmitter Module

The Fig. 3 shows the representation of transmitter module. Flow rate sensors are used to get the flow rate of water within the pipe. These sensors are installed at the inlet and outlet of the pipes the values of flow rate sensors are captured and compared with the threshold value. A threshold value is fixed considering the flow of the water within the pipe. If the difference of the flow rate of water is greater than the threshold value, then a notification message about the leak detection will be sent to the concerned authority of water board management.

The main goal here is to reduce leakage and save water, so just informing concerned authority about leakage can work to certain extent, but informing them about the break in the pipe well in hand, can help them to take corrective measures before any pipeline breakage. To measure the durability of the pipe vibration sensors are used, if the pipe is too old and about to break then also a notification message will be sent to the concerned authority so that pipe leakage can be avoided.

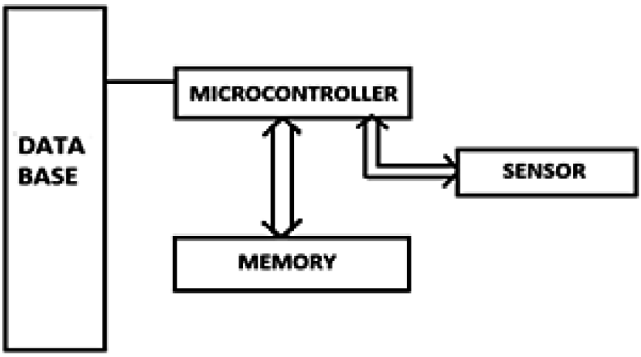

Fig. 3. Transmitter module

3.2 Receiver Module

The Fig. 4 shows the receiver module setup, the receiver model consists of web server which receives the data from the transmitter module and monitors that data continuously. If there is leakage detection or the pipe is too old with cracks, then the receiver module will send the notification message to the concerned authority.

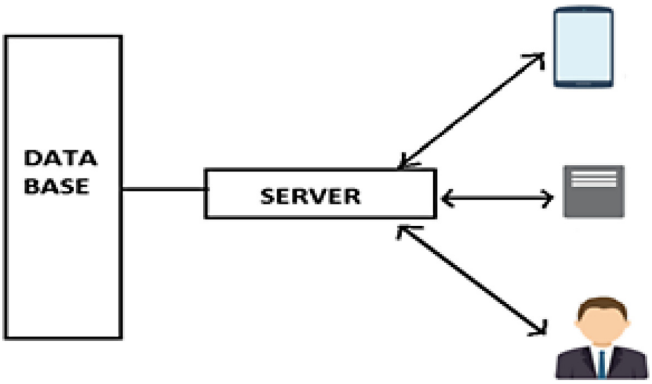

Fig. 4. Receiver model

3.3 Flow Rate Sensor

The flow rate sensors are used to measure the flow rate of water within the pipe at both inlet and outlet of the pipeline, the Fig. 6 illustrates the setup of Water pipeline monitoring system using flow rate sensor, the prototype of the proposed system mainly consists of a pipeline of 3 feet length with the two valves and the sensors which are mounted on the two ends of the pipe i.e. one at the input end from where the water enters the pipe and another one is the output end from where the water comes out of the pipe, if there is a leakage in-between the pipe then the flow rate sensor values will be

processed in the microcontroller, if the flow rate sensor reading are different at both inlet and outlet ends, and if this difference is more than the threshold value then it indicates that there is leakage in the pipeline. Two sensors are mounted on pipe one at the inlet and other at outlet end, both the sensors value are compared to infer the status of the pipe. The flow rate sensors are usually made up of plastic valve body Hall Effect sensor with a water rotor. When the water passes through the rotor, the speed of the rotor changes along with the flow rates of the water. The hall-effect sensor provides the corresponding output pulse signals (Fig. 5).

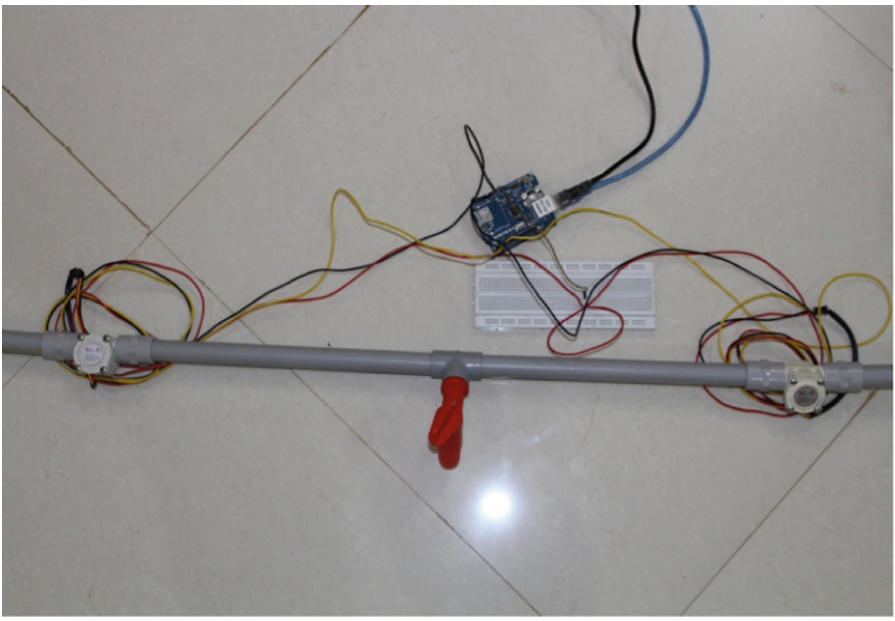

Fig. 5. Pipeline setup for leak detection using flow rate sensor

The parameters considered for flow rate sensors are

- Working range: 1–30 L/Min
- Water pressure: ≤ 1.75 MPa.

3.4 Vibration Sensor

A 6DOF sensor – MPU6050 using accelerometer sensor is used to identify the leak of pipe, The sensor values are continuously transferred to the server system at an interval of 1 s over an Wi-Fi network, the sensor values is analysed at the server system to identify the leak-aged pipe or normal pipe.

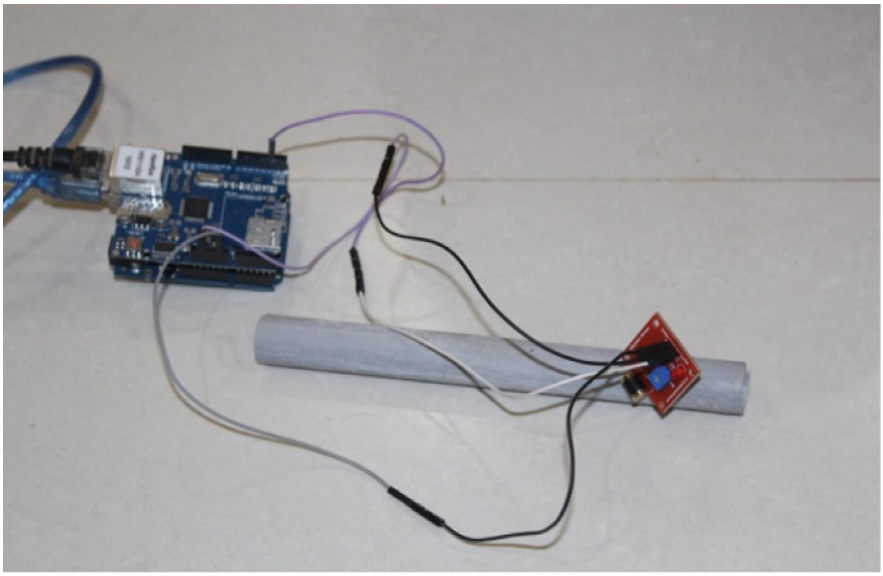

Fig. 6. Pipeline setup for leak detection using MPU6050 sensor

The Table 2 shows the MPU6050 sensor configuration and sensitivity.

Table 2. MPU6050 sensor configuration and sensitivity

Accelerometer full range scale	Accelerometer sensitivity (LSB/g)
±2 g	2048
±4 g	4096
±8 g	8192
±16 g	16384

The Fig. 6 shows the setup of water pipeline monitoring system for leak detection. The experiment was carried out considering two sensors, flow rate and vibration sensors, these sensors are connected to arduino board and are continuously monitored. The arduino board is programmed and set a sensitivity of MPU6050 sensor. The sensitivity of MPU6050 sensor is set to ±15 g and ±20000/s.

3.5 Arduino Controller Board

Arduino UNO micro-controller is used for sensing data and to control physical devices. The arduino board is based on ATmega328 (datasheet). It basically consists of 14 digital input/output pins among which 6 pins are used for PWM output, 16 MHz crystal oscillator, a USB connection, 6 analogue inputs, a power jack and an ICSP header (Fig. 7).

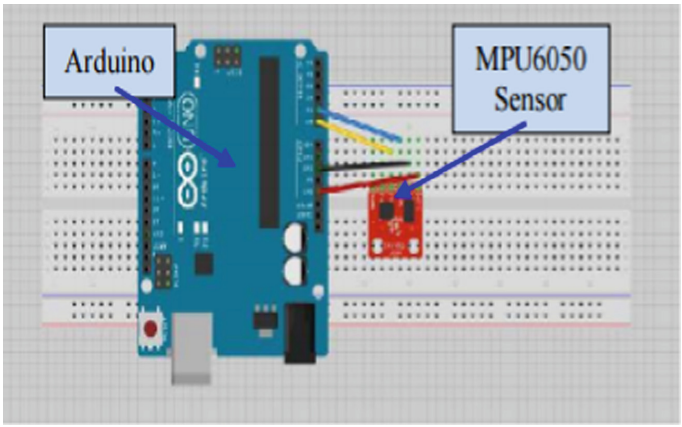

Fig. 7. Arduino Board with MPU6050 sensor

4 Implementation

4.1 Leak Detection Algorithm

Algorithm 1 Leak Detection

```
Read flow rate sensor values.
Store data into database.
Calculate the difference in the flow rate sensors.
if the difference is greater than 1 l/min then
    Enter into For loop.
    for i less than 15 do
        read sensor value
    end for
    if Still the difference is greater than 1 l/min then
        Inform authority about the leakage
    end if
end if
```

4.2 Flow Chart for Leak Detection

The Fig. 8 describe the step by step operations carried out to detect the leakage, the first step is to read the flow rate sensor values and transfer these values to the server system database using a wireless network. In second step calculate the difference in the flow rate values of two sensors if the difference is less than the threshold values then send a notification message to the concerned authority. The threshold value is fixed considering 15–20 readings after the configuration.

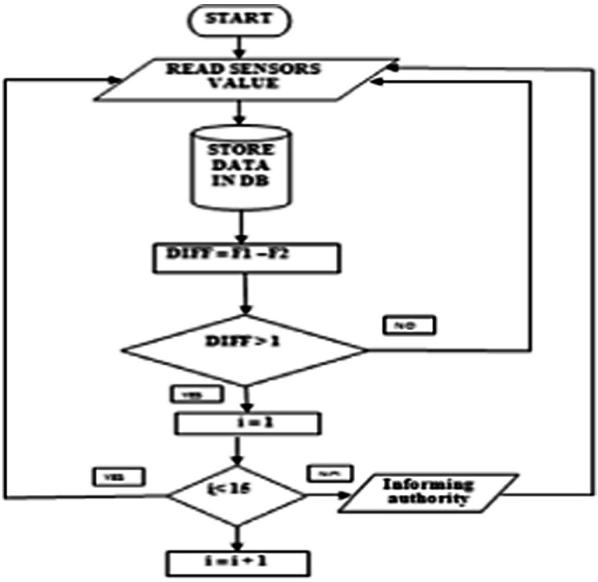

Fig. 8. Flow chart for leak detection

4.3 Flow Chart for Damage Alert

The Fig. 9 describes the step by step operations carried out to detect the leakage using vibration sensor and indicating the damage alert. The first step is to read the values

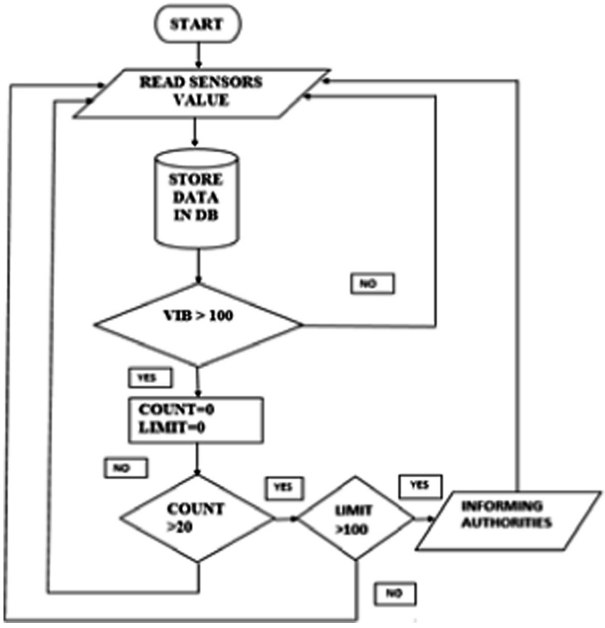

Fig. 9. Flow chart for damage alert

from MPU6050 sensor and transfer these values to the server system database using a wireless network to confirm the damage in pipe, following 20 readings are taken, and a counter is incremented whenever it crosses the threshold. If this counter is greater than 10, then there is a high probability that there is damage and a notification message will be sent to the authority.

4.4 Algorithm for Damage Alert

Algorithm 2 Damage Alert

```
Read vibration sensor values.
Store data into database.
if vibration is greater than 100 then
    Enter into For loop.
    for count less than 20 do
        read sensor value
    end for
    if count is equal to 20 and limit is greater than 10
then
        Warn authority about the break
    end if
end if
```

5 Results and Discussion

5.1 Capturing Flow Rate Sensor's Values and Processing

The Fig. 10 shows the result analysis of the two flow rate sensors which are mounted at inlet and outlet of the pipe continuously the readings are captured from both the sensors and difference is being calculated which is shown in the below graph.

5.2 Threshold Value

The pipe which was used for the experiment is 1 inch in diameter and 1 m in length. After taking 25–30 readings for observation the average value of the readings was calculated to fix the threshold value, i.e. 1 L/min was set as threshold for leakage

The Fig. 10 shows the difference value computed considering the readings from flow rate sensors. If water flows uniformly then there will be a linear graph which indicates that there is no leakage in the pipeline. And suppose if there is any variation in the flow rate of water because of leakage in the pipe then there won't be a linear growth in the graph.

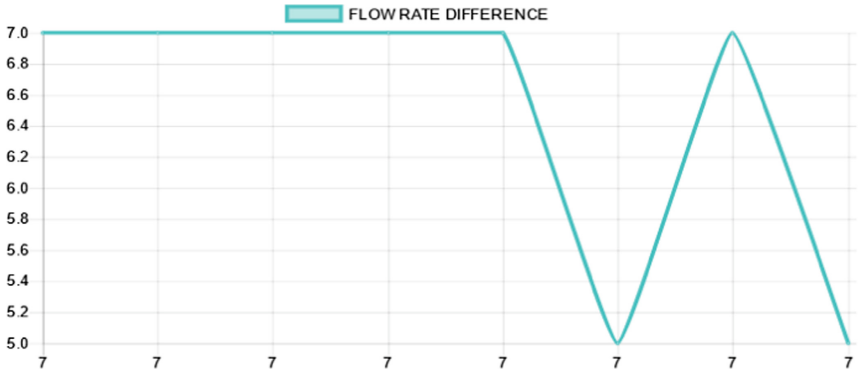

Fig. 10. Graph for monitoring flow rate sensor readings – (flow rate1 vs. flow rate2)

5.3 Vibration Sensor's Readings in the Database

The Table 3 shows the vibration sensor data value stored in the database. If there is any disturbance in the pipe, the vibration increases. If the disturbance remains for about 2 min, then there are chances of pipe being broken.

Table 3. Vibration sensor values in the database

Time stamp	Vibration sensor value
2016-12-26 14:49:16	0
2016-12-26 14:49:20	56
2016-12-26 14:49:22	38
2016-12-26 14:49:24	110
2016-12-26 14:49:26	40
2016-12-26 14:49:28	52
2016-12-26 14:49:30	0
2016-12-26 14:49:32	50
2016-12-26 14:49:34	25
2016-12-26 14:49:36	33
2016-12-26 14:49:38	32
2016-12-26 14:49:40	0
2016-12-26 14:49:42	103

5.4 Vibration Sensor's Values and Processing

To analyse the leakage in pipe, vibration sensors can also be used. The Fig. 11 shows the vibration sensor readings vs. the timestamp graph, again if the readings are more than the threshold value then a leak is detected.

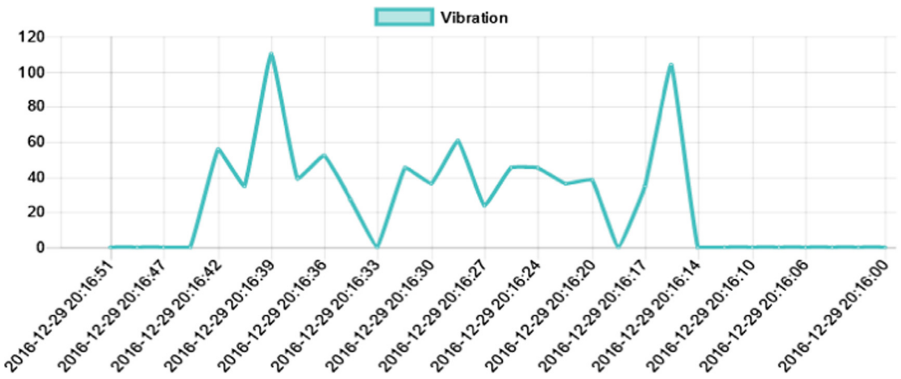

Fig. 11. Graph for monitoring vibration sensor readings

5.5 Sending Notification Message

The two sensors will be continuously sending there readings if the sensor reading is more than the threshold value then a notification message will be sent to the concerned water board authority so that quick action is initiated to repair the pipe. The Fig. 12 shows the message that is received whenever there is leakage or break in the pipes, to transmit these messages we are using wireless medium which will be sent to the water board authority through the server system.

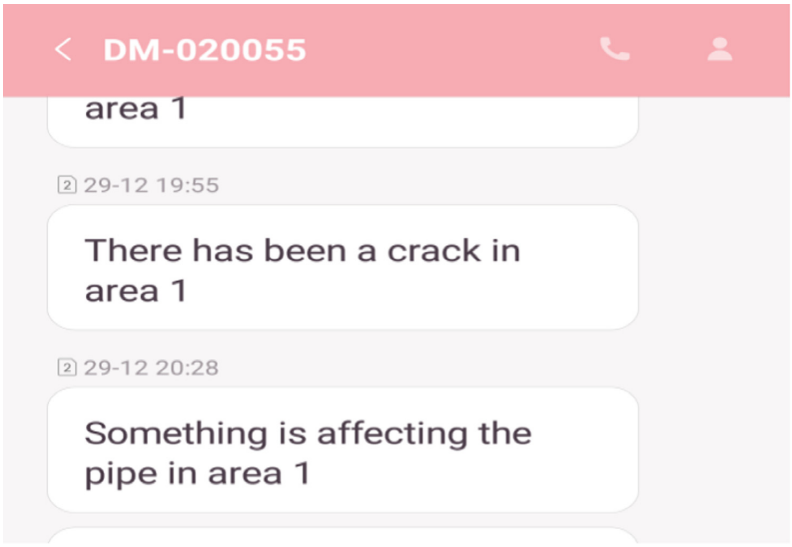

Fig. 12. Notification message

6 Conclusion

In today's life style water is essential and the crucial element for human beings. In majority of the places water is wasted in large volumes due to poor and low quality pipelines which result in breakage of pipes and no proper and quick methods are adopted to repair the pipes, which basically lead into water wastage. So to minimize public health risk and economic loss we need to manage and maintain the pipeline systems, water board authorities regularly audit their Pipeline distribution systems and perform pipeline detection survey. In the remote locations its very challenging and difficult to monitor and repair the pipes due to unavailability of the resources and we won't get to know the leakages so to address these challenges, we designed and developed the smart pipeline monitoring system in which flow rate and vibration sensors are embedded on the pipe to detect leakage in pipe if any. As soon as the leakage is detected a notification message is sent to the concerned authorities so that a quick action is taken to repair the pipe and stop the water leakage. Experimental observations show that flow rate and vibration sensors are best suited to detect the leakage in water pipeline monitoring system.

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