Current Journal of Applied Science and Technology

32(2): 1-13, 2019; Article no.CJAST.45506
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Design and Implementation of a Wireless Sensor Network for Monitoring Oil Pipeline

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2019/45506
Editor(s):
(1) Dr. Samir Kumar Bandyopadhyay, Professor, Department of Computer Science and Engineering, University of Calcutta, India.
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Complete Peer review History: http://www.sciencedomain.org/review-history/28097

Original Research Article

Received 26 December 2018
Accepted 17 December 2018
Published 03 January 2019

ABSTRACT

This work presents a wireless sensor network (WSN) using pressure variations in monitoring oil pipeline against leaks. It incorporates pressure sensors, ardiuno board containing ATmega328P – 8 bit AVR family microcontroller, GSM module, and LCD for data acquisition, processing, communication, and analysis, to be used for the localization of leaks (either natural or man caused). An experimental investigation of the relationship between leaks or bursts and pressure variations was carried out at a designated location along the prototype oil pipeline. Results showed that a drop in pressure is associated with leak and the wider the size of the leak, the more drop in pressure that is observed. The wireless sensor network uses the concepts of signal (energy) conversion and processing following a modular approach where pressure parameter is monitored in the prototype pipeline (field or transmitting section). Whenever the monitored pressure falls below a minimum set pressure point, the pressure information (signal) is converted into electrical signal, processed, and

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transmitted as radio waves and received at the monitor or control centre (master or receiving section). The received radio signals are converted back into electrical signal and used to drive the LCD and buzzer. Analyzing the audiovisual signal received will determine any further necessary action.

Keywords: Wireless sensor network; pressure sensor; sensor nodes; microcontroller.

1. INTRODUCTION

Pipeline systems are required for transporting a variety of important resources such as water, crude oil and its products like petro, diesel, gas, e.t.c. from one point to another usually over millions of miles. In the event of resource leakage from pipes as a result of either natural burst due to aging or man-made burst due to vandalism, resources will be wasted with attendant economic losses and negatively impacted environment. This assertion is supported by Nwilo [1] when they posited that if a petroleum or chemical pipeline leaks, the result is environmental and ecological disaster. It is therefore imperative to detect leakages on time so as to mitigate their negative effects on the environment. And this is why Radosveta [2] noted that efficient and accurate use of resources in pipeline systems has become very significant in recent times because of global warming issues. A sure way of detecting leaks in pipeline system is real-time monitoring of the system against leakages so as to locate defective portions, and appropriate actions can be taken by humans to prevent further damage, [3]. Various methods of monitoring oil pipeline for leaks exist and these range from the traditional human physical patrolling, fibre optic technology, pipeline SCADA (Supervisory Control and Data Acquisition) system to acoustic measurements and lately wired sensor networks and wireless sensor networks using pressure measurements. These various methods were basically divided into two by Bilman and Isermann [4] as external and internal leak detection systems. All these methods except wireless sensor networks have high cost and significant manpower implications.

Pressure-based leakage detection techniques are basically classified into time domain techniques and frequency domain techniques in which signal analysis in time domain involves system transient response at more than one locations but signal analysis in frequency domain entails system transient response at only one location in order to study behavioral changes and detection of anomalies, [5-8]. Cataldo, Cannazza, De Benedetto, and Giaquinto opined that frequency domain signal analysis is direct and less computationally intensive. Most of the techniques under the classification above are simulation based and use the supervisory control and data acquisition (SCADA) field monitoring data to calibrate system parameters. These parameters represent burst or leakage.

Wireless Sensor Network (WSN) is a communication network composed of many sensor nodes deployed over a geographical region to sense and gather information about the region, process the information, and then communicate the information through wireless links, either with other sensor nodes in the network or directly with a master node, a node where the information is received and analyzed for actions to be taken or stored for future use. This information may be connected to the internet and this is where the concept of internet of things (IoT) may be explored. Ferrante and Brunone [9] defined a Wireless Sensor Network as a network of sensor nodes (devices), which can sense the environment, gather information about the environment, and communicate the information gathered through wireless links to a sink (usually referred to as controller or monitor) and the information consumed locally or connected to the internet through a gateway. Biradar, [10], presented a wireless sensor network as a network of many tiny disposable low power devices , called nodes, which are spatially distributed in order to perform an application-oriented global task, and form a network by communicating with each other either directly or through other nodes. Alwadi, [11] viewed a wireless sensor network as consisting of spatially distributed autonomous sensors to monitor the physical environment, and to co-operatively pass their data through the network to a main node or central location (base station). Akyildiz, [12] stated that the sensor nodes are independent and frequency and bandwidth limited. Wireless sensor network for monitoring oil pipeline is one of the latest ways of using pressure variations in detecting leaks in pipelines in real time. Kachavimath [13] posited that sensor nodes are small devices and are made up of four basic subsystems namely the sensing subsystem, processing subsystem, wireless communication subsystem, and energy supply subsystem.

2. RELATED WORK

Yunana, [14] showed how a wireless sensor network can be used to provide monitoring of critical pipeline infrastructure. They carried out a simulation experiment using MATLAB Simulink environment. Pressure and flow rate measurements data taken from sensors showed that a leak in the pipeline is evident in the changing pressure and flow rate curves of the simulation output results. Their work thus showed the capability of the wireless sensor network to detect leakage along a pipeline as evident in the flow rate and pressure measurement trend of the graphical output results.

Saini, Ritika, and Vijay [15] used simulation to study and analyze Bellman-Ford routing algorithm at different wireless sensor network protocol stack layers and found out that these layers (application layer, transport layer, network layer, MAC layer, and physical layer) exchange data adjacently between each other.

Tala't, M., Yu, C., Ku, M., and Feng, K. [16] worked on efficient hybrid energy utilization for wireless sensor networks where they used simulation to confirm that a Markov decision process (MDP) can effectively achieve an optimal solution for balancing the minimization of the constant energy source consumption and packet dropping probability (PDP). They therefore showed from simulation results that the performance of optimal solution using MDP achieves a significant improvement compared to solution without its use.

Yuanwei and Ali [17] developed a leak detection based on the use of acoustic sensing devices like Lead Zirconate Titanate (PZT) acoustic sensors. Here, signals generated by the acoustic sensors travel along the pipeline and are used to detect anomalies like leaks, corrosion, e.t.c. along the pipeline. When waveforms of signals at some points do not correlate with waveforms of reference signals stored for the monitored area, anomalies are detected. With an anomaly detected, an alarm message is sent via communication links to a human operator for analysis. A drawback of this technique is that the acoustic sensors are customized to the structure of the pipeline, and therefore makes it not applicable for other types of pipeline technologies. Significant work on this subject has been done by Nayyar, and Puri [18,19], Puri, [20].

Rest of the paper is organized as follows: Section 2 describes the methodology used in the design and implementation of the wireless sensor network while section 3 presents experimentation carried out. Section 4 provides results obtained and discussion. Conclusion and future work are presented in section 5.

3. METHODOLOGY

A modular step by step method was used in designing and implementing this wireless sensor network prototype for monitoring oil pipeline. The methodology employed in the design and implementation of the wireless sensor network for monitoring oil pipeline made use of the concepts of signal (energy) conversion and signal processing following the modular approach where pressure parameter is monitored in a prototype pipeline (field or transmitting section). In this work, pressure sensors which are parts of the field sensor nodes were installed at three points along the prototype pipeline to measure and monitor pressure values at those points. When pressure values fall below a set point, the pressure value is converted to voltage by the pressure sensor and then sent to microcontroller where processing is done. Thereafter, the signal is sent to the GSM module of the field sensor node where signal transmission is carried out and the transmitted signal is received by the GSM module of the master sensor node. The received radio signal is converted back into electrical signal and used to drive the LCD and buzzer.

On the prototype pipeline, leak was simulated using installed valves such that close valve represents absence of leak situation while open valve means presence of leak situation.

3.1 Components Used

All the components used in this work were carefully selected considering material properties, processing, and environmental factors. This is done to ensure that cost is minimized while meeting system's performance goals. This section presents each component chosen, especially the ardiuno board containing ATmega328 microcontroller, the GSM module, and the pressure sensor, and discusses the various features and interface components. A sensor node architecture basically consists of four units as shown in Fig. 1 (a: Field sensor node and b: Master sensor node for one way communication) and namely a sensor unit for sensing the environment and data acquisition from the physical environment, a processing unit for performing simple computations, a communication unit made up of radio transceivers for communication, and a power source unit. The analog signal output from the sensor is converted into digital signal before being worked upon by the microcontroller in the processing unit. The microcontroller processes and decides the magnitude of signal to be transmitted by the communication unit. The power source is the most important component of the sensor node, without which it will not function. To prolong the life of the power source, it may be supported by a power scavenging unit like solar cells or the use of solar biscuits composed of solar cell as power source and a super capacitor as an energy storage device.

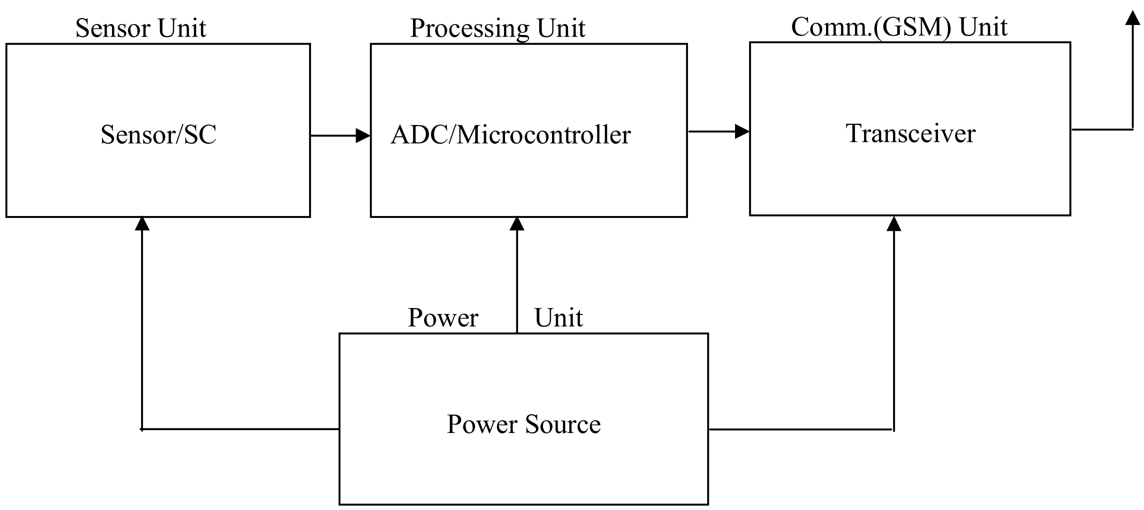

Fig. 1a. A field sensor node architecture

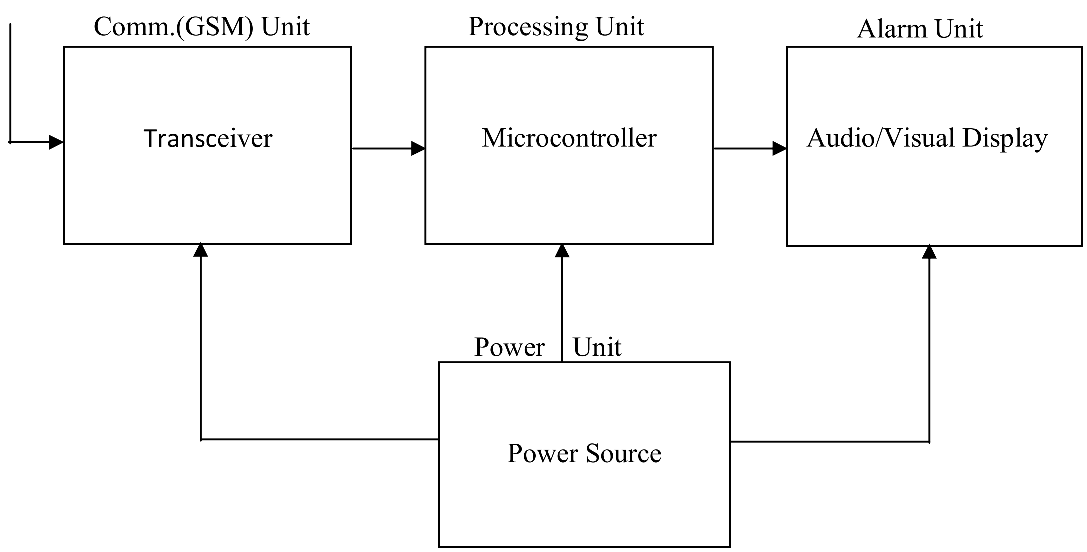

Fig. 1b. A master sensor node architecture

The principal hardware used in this design and implementation includes:

- HK1100C Oil Pressure Sensor
- Arduino Uno board containing ATmega328P microcontroller
- SIM800L GSM module
- JHD162A LCD module
- Audio alarm Buzzer
- 9V battery terminal for mobile operation

3.2 Components Description

HK1100C Oil Pressure Sensor: The HK1100C oil pressure sensor is a low cost pressure transmitter manufactured by HaiHuiLai Company. It comes with a stainless steel package, socket type connection, half inch pressure connector, quick connect pressure interface. It is convenient in installation and replacement and prominent in the engineering applications for oil pipeline pressure sensing. The input voltage and pressure range can be customized. The supply voltage is 5V dc, the output has range of 0.5 - 4.5V dc, and the pressure range is 1200kPa.

Fig. 2.

Arduino Uno Board: The Arduino Uno board is a microcontroller based board on 8-bit ATmega328P microcontroller. It contains other components such as crystal oscillator, serial communication, voltage regulator, e.t.c. to support the microcontroller. It has 14 digital input/output pins, 6 analog input pins, a USB connection, a power barrel kack, an ICSP header and a reset button. It operates with 5V dc and a frequency (clock speed) of 16MHz. The C++ programs (codes) for the three field sensors are given in Appendix 1, 2, and 3 while the C++ program (code) for the master sensor is given in Appendix 4. In programming the microcontroller in C++ programming language, the flowchart in Fig. 3 was used for the field sensors while the flowchart in Fig. 4 was used for the master sensor.

SIM800L GSM module: The SIM800L GSM module is a miniature cellular module which allows for GPRS communication; sending and receiving SMS and also for making and receiving voice calls. It has low cost, small footprint, and quad band frequency support and a recommended supply voltage of 4V. It can be put in the sleep or idle mode. In this work, the field sensor GSM module is used only for transmission while the master sensor GSM module is used only for reception.

JHD162A LCD module: The JHD162A LCD module is a 16 X 2 LCD module based on the HD44780 driver from Hitachi and it has 16 pins and operated in 4-bit mode (using only 4 data lines). It has supply voltage of 5V dc. A 16 X 2 LCD means it can display 16 characters per line and there are 2 such lines. The LCD has two registers namely the Command and Data registers. While the command register stores the command instructions, the data register stores the data to be displayed on the LCD.

3.3 Experimental Test Bed

To demonstrate the concept of leak detection using pressure variation in fluid flow, a mini kerosene pipeline test bed was set up between the Registry and the Vice Chancellor buildings in Campus 2 of the Delta State University, Abraka Campus. The pipeline test bed is composed of ½ in.pvc pipes, 50 litres plastic drum, 1hp electric pumping machine; drain valves, and three pressure sensors. The 50 litres plastic drum was used as kerosene supply reservoir while the 1 hp electric pumping machine was used to provide kerosene flow round the pipeline. The drain valves were used to simulate leaks for experimentation and testing while the three pressure sensors were used to measure and monitor pressure variations at three designated locations. Fig. 3 gives the experimental test bed.

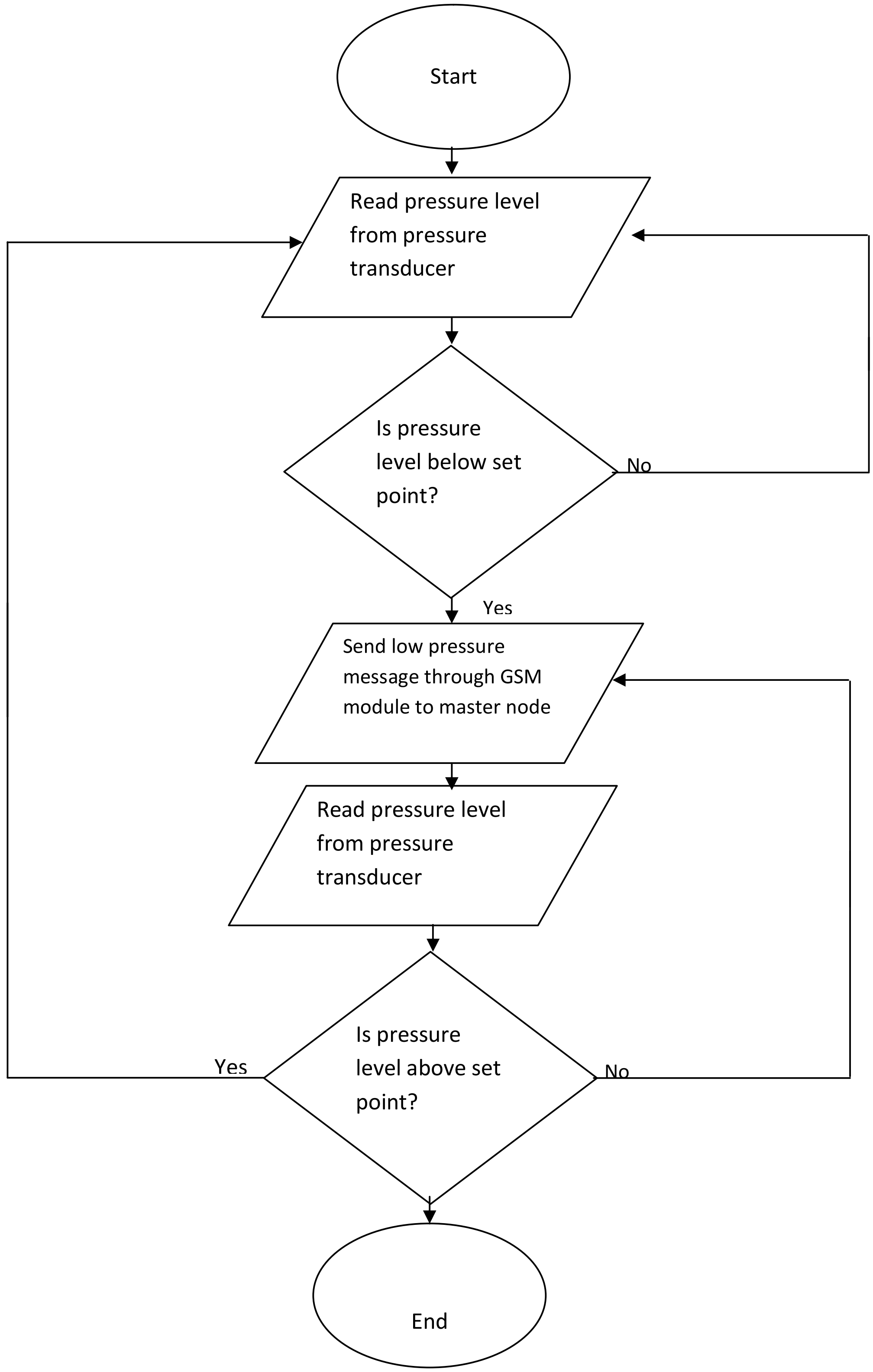

Fig. 3. Field Sensor Microcontroller programming flowchart

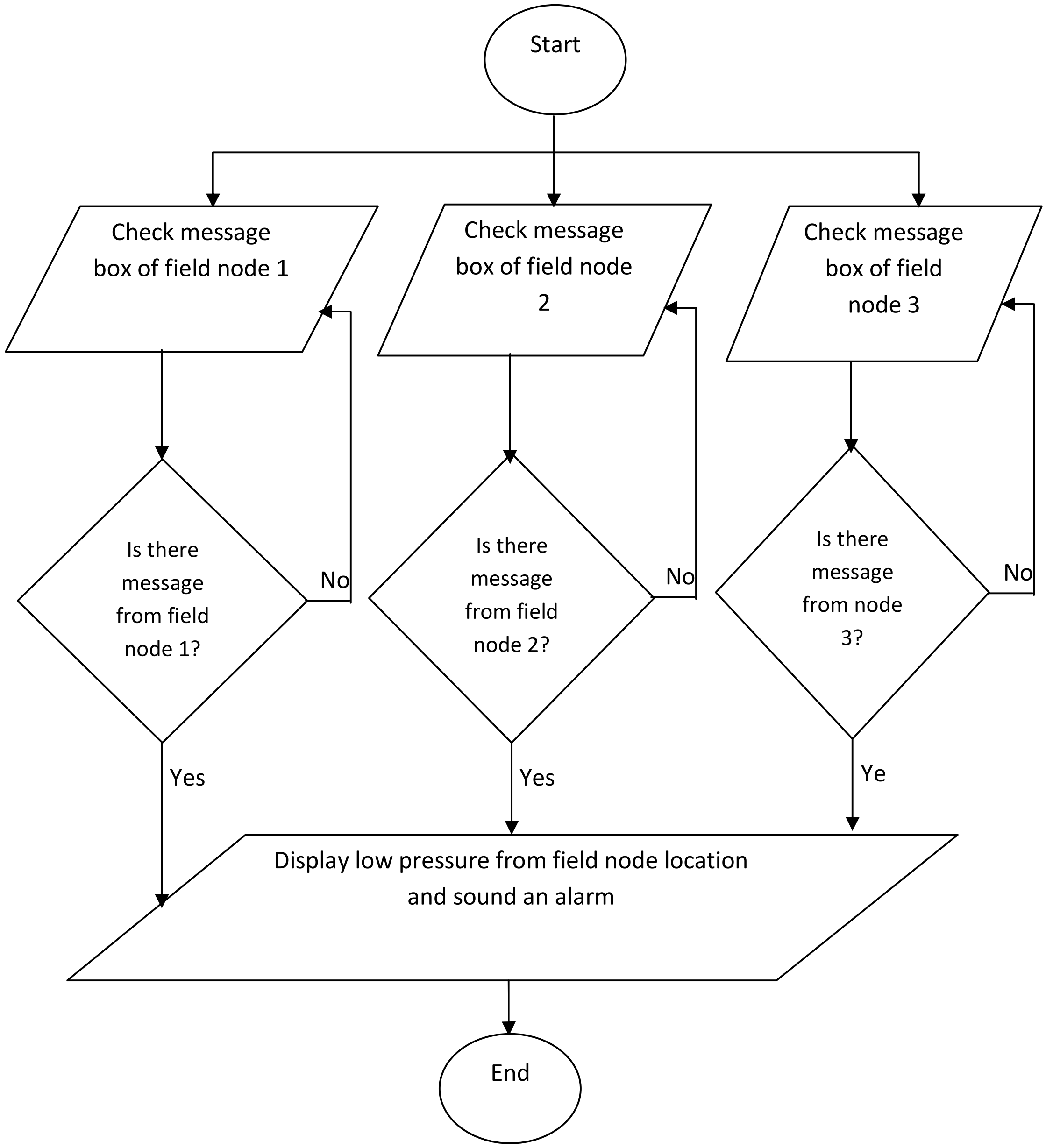

Fig. 4. Master Sensor Microcontroller programming flowchart

Using the experimental test bed above, pressure and corresponding voltage data were measured and recorded using data log software and memory card module for the first pressure sensor. The data were saved in a memory card inserted into the memory card module. The experiment was carried out in two stages corresponding to absence of leak state and presence of leak state. The drain valves were adjusted manually to these two states: valve closed presenting high pressure and valve opened indicating low pressure. Opened valve is to simulate pipe leakage. Measure and recorded pressure and corresponding voltage were taken from 0 second to 5508 second. The drain valve was closed from 0 second to 3624 second and opened between 3624 second and 5508 second. If a sensor fails, it will be replaced. The complete circuit diagram of the field sensor node is presented in Fig. 9 and complete circuit diagram of the master sensor node is given in Fig. 10.

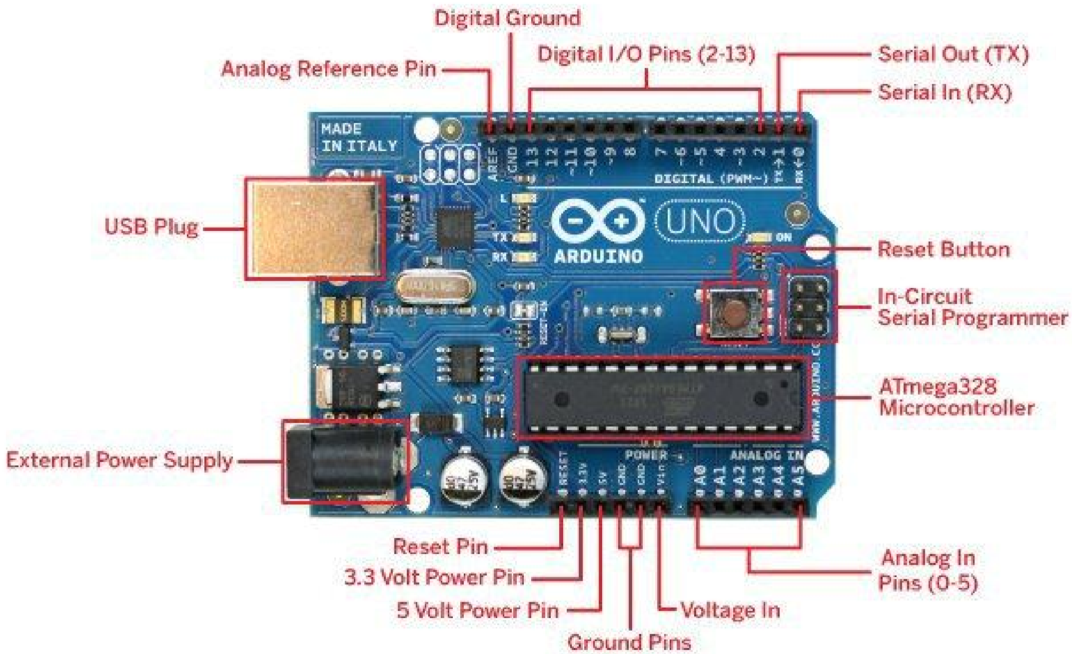

Fig. 5.

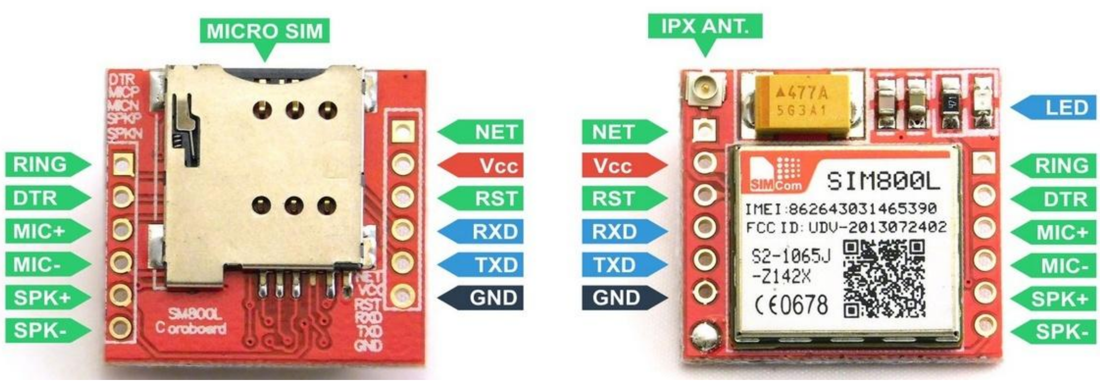

Fig. 6.

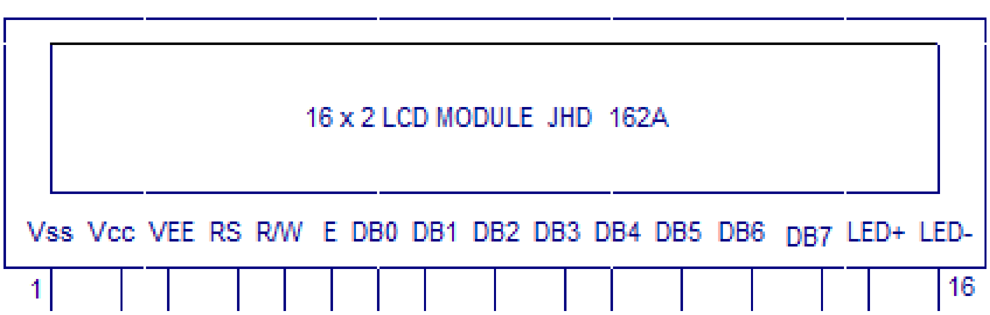

Fig. 7.

Fig. 8. Experimental Test Bed

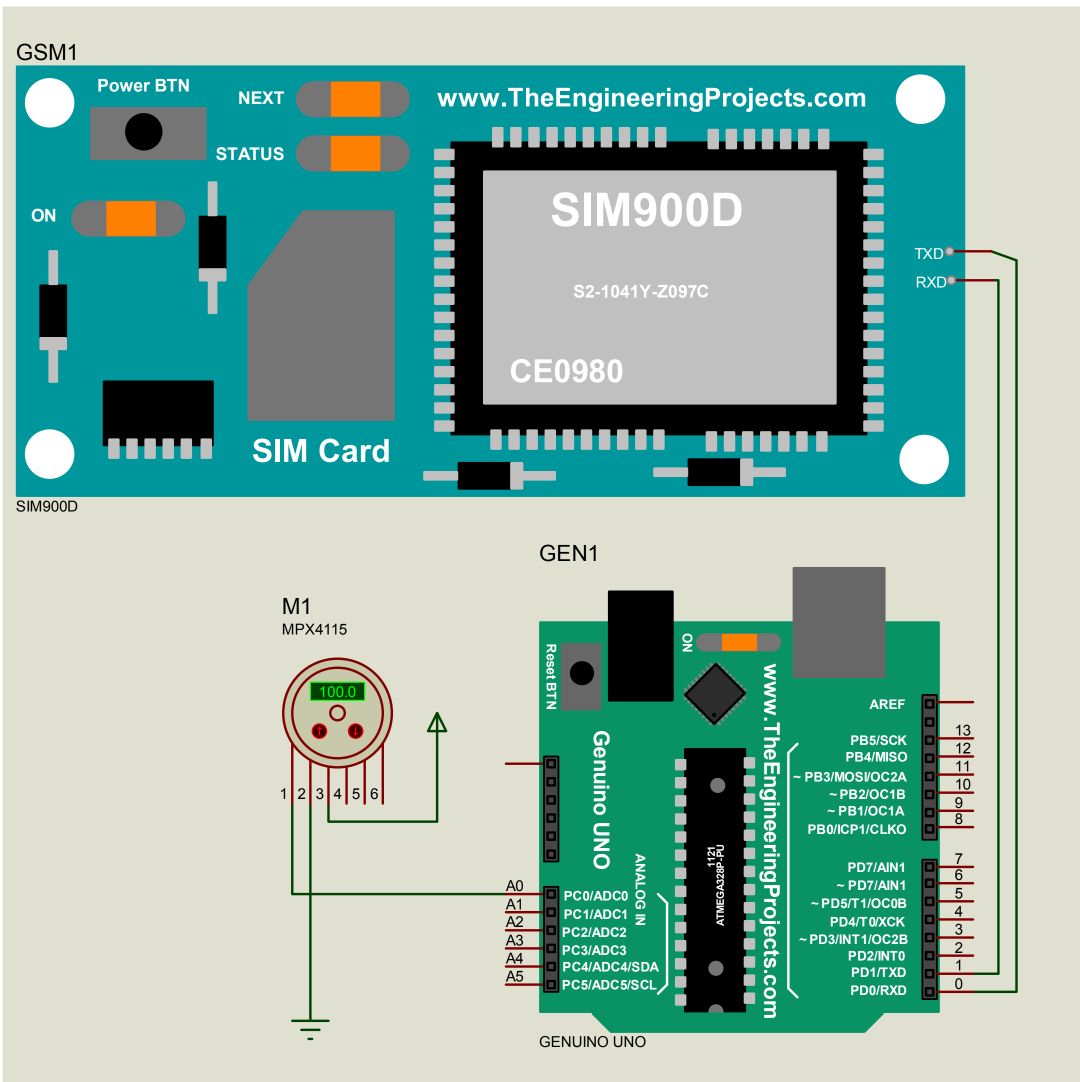

Fig. 9. Complete simulated field sensor node circuit diagram

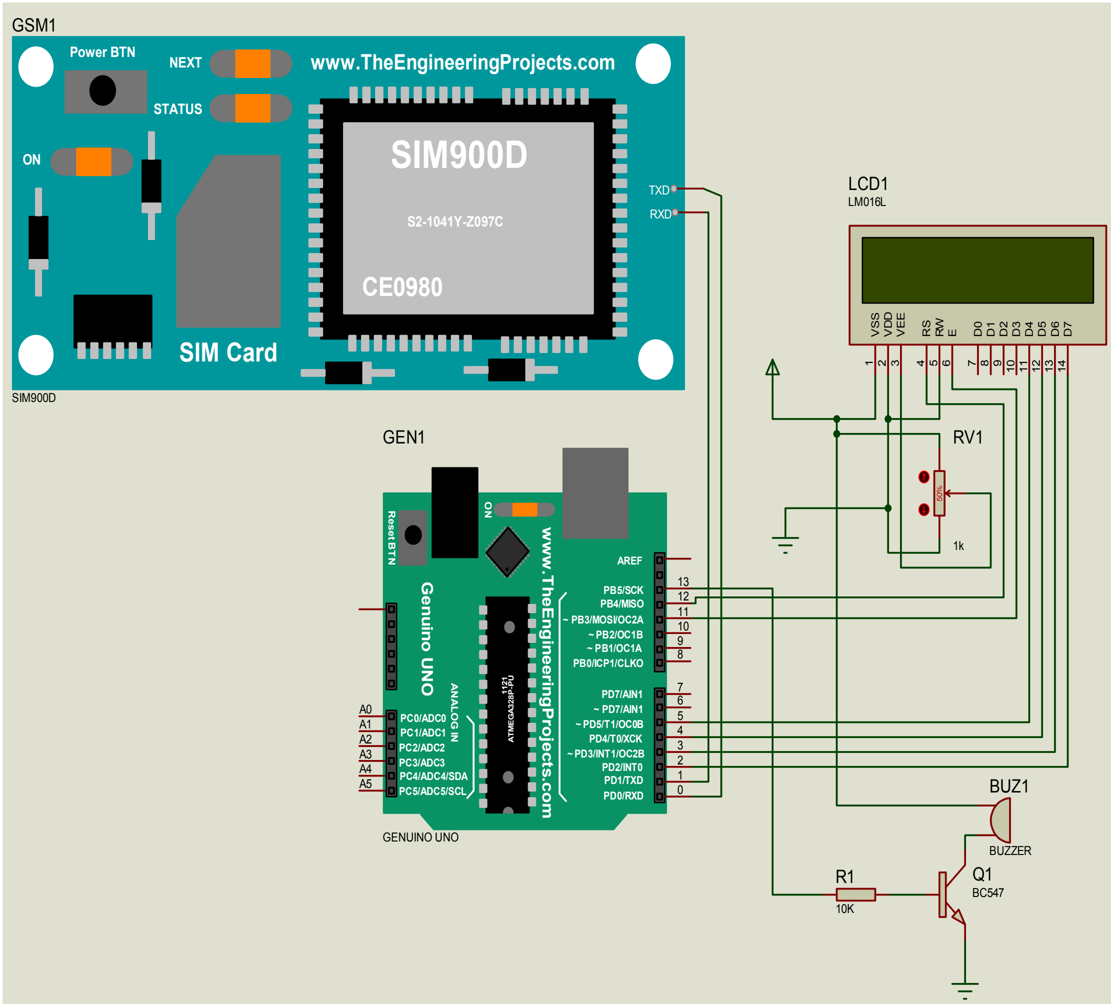

Fig. 10. Complete Simulated Master sensor node circuit diagram

4. RESULTS AND DISCUSSION

The measured and recorded pressure and corresponding voltage data for every second were analyzed using Matlab software. Pressure and voltage profiles as a function of time from one pressure sensor are presented in Figs. 4 and 5 respectively. A plot of pressure against voltage is given in Fig. 8.

We evaluated the pressure profile for closed valve representing absence of leak and opened valve representing presence of leak. It can be observed from Fig. 4 that the pressure profile for absence of leak is fluctuating between 12psi and 13psi. The fluctuation is due to ac voltage fluctuations to the electric pumping machine, which consequently led to fluctuations in the speed of the electric pumping machine. The pressure profile for presence of leak is also not stable but fluctuates around about 9psi. It can be seen from the pressure profile that when the valve was opened to simulate leak, there was an instant and sharp fall in the pressure profile indicating the presence of leak.

The voltage profile is exactly the same as that of the pressure profile indicating linear or direct proportionality. This is also evident in the plot of pressure against voltage which gave a straight line graph. The intercept of the straight line on the y-axis (pressure axis) indicates that measurements or readings were taken from pressure values of above 8psi.

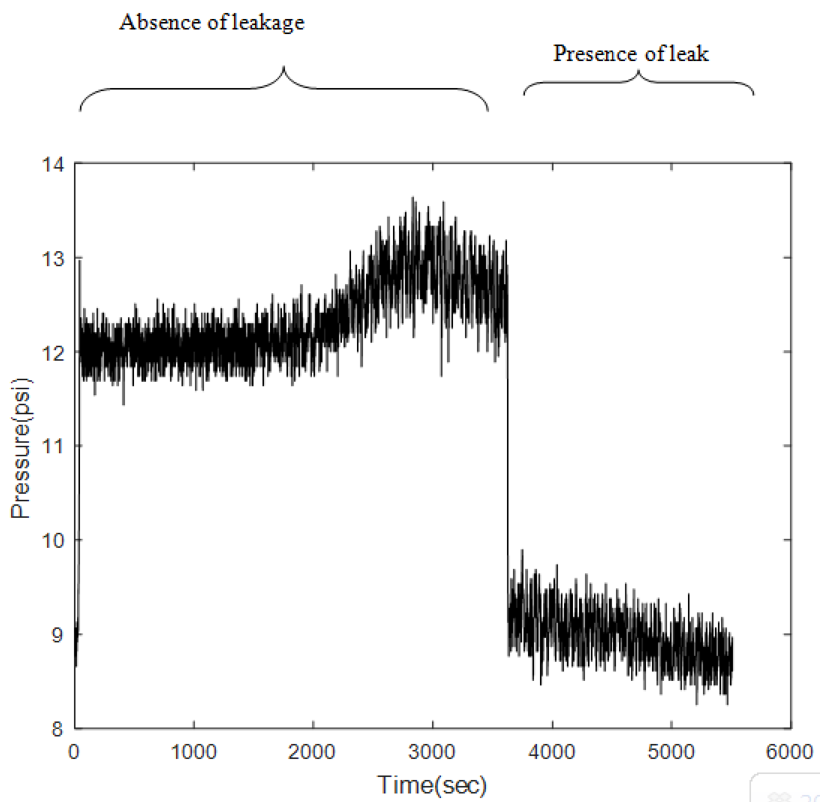

Fig. 11. Pressure Profile

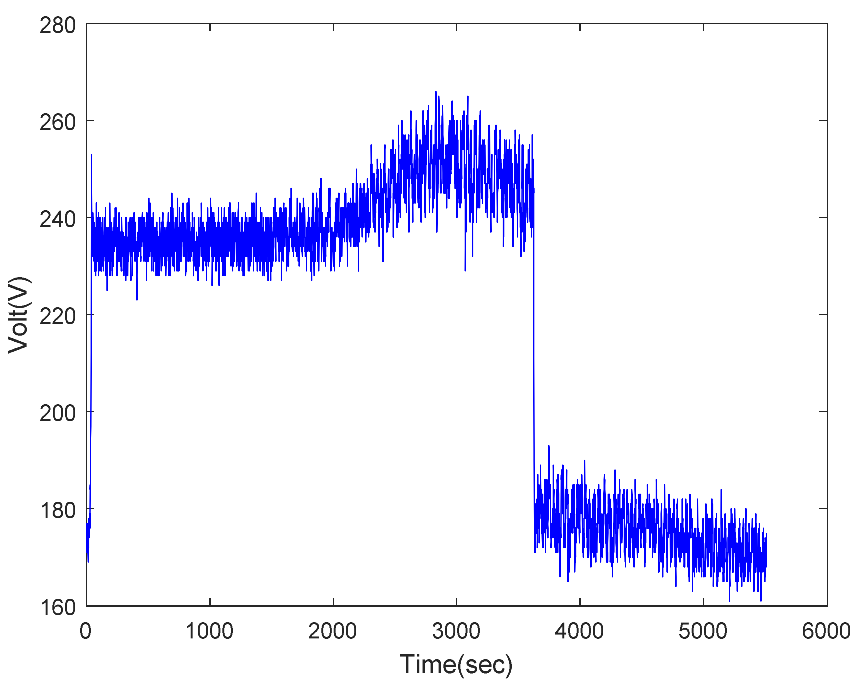

Fig. 12. Voltage Profile

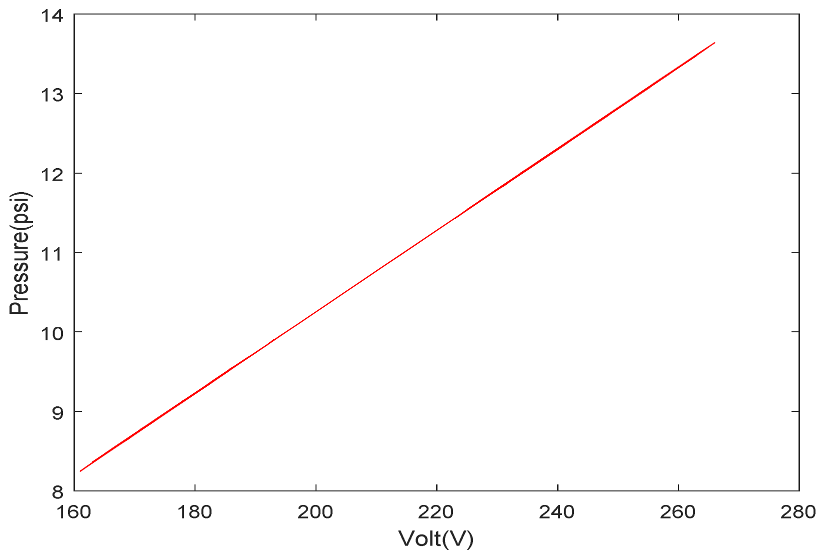

Fig. 13. Plot of pressure against voltage

5. CONCLUSION

In this research work, a wireless sensor network was developed to monitor a prototype oil pipeline against leakage using pressure variation (from pressure sensors). The monitoring network consists of two parts: field sensor nodes for data acquisition and monitoring and master sensor node for data gathering and analysis. These two parts are connected with wireless link. Experimental results showed that a leak is accompanied by a drop in pressure in which the size of the leak determines the extent of the pressure drop. Pressure drops or variations are therefore used to localize leaks. Accuracy of leak locations will be increased by using more field sensors. In the future, we intend to increase the number of field sensors to about six and also monitor temperature simultaneously.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/28097