Current Journal of Applied Science and Technology

32(1): 1-9, 2019; Article no.CJAST.45505
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Oil Pipeline Leak Detection and Localisation Using Wireless Sensor Networks

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Authors' contributions

This work was carried out in collaboration between all authors. Author AOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FIA and DE managed the analyses and the literature searches of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2019/45505
Editor(s):
(1) Dr. Cheng Siong Chin, Professor, School of Marine Science and Technology, Newcastle University, UK.
Reviewers:
(1) Aliyu Bhar Kisabo, Centre for Space Transport and Propulsion (CSTP), Nigeria.
(2) Gianfranco Manes, University of Florence, Italy.
(3) Grzegorz Sierpiński, Silesian University of Technology, Poland.
Complete Peer review History: http://www.sciencedomain.org/review-history/28007

Original Research Article

Received 22 September 2018
Accepted 07 December 2018
Published 29 December 2018

ABSTRACT

This paper describes the development of a wireless sensor network that uses pressure variation to detect and locate leaks in a prototype oil pipeline. The HK1100C oil pressure sensor is used as a sensing unit to sense/monitor pressure variation inside the prototype oil pipeline and outputs the corresponding voltage variation to a microcontroller. The whole network comprises mainly of HK1100C oil pressure sensor, Arduino Uno board containing ATmega328P microcontroller, SIM800L GSM module, JHD162ALCD module, audio alarm buzzer, 9V supply. The ATmega328P microcontroller was programmed in C++ programming language. If deployed in Nigeria, the wireless sensor network will be able to monitor oil pipelines against leaks and therefore reduce environmental degradation and economic losses resulting from oil leakages.

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Keywords: Wireless sensor networks; oil pipelines; leak detection; pressure data; pressure variation; ATmega328P microcontroller; C++ programming language.

1. INTRODUCTION

Pipelines carrying liquids such as water, crude oil, petrol, diesel, e.t.c. are subjects of attacks by vandals, and that is why Okoli and Orinya [1] quoted NNPC authorities in Nigeria to have reported approximately five thousand incidents of pipeline vandalism between the years 1976 and 1996 and even more damages between the years 2009 and 2011 wherein about 10.9 Billion dollars were lost. Unfortunately, these damages go unnoticed for a long period. The consequences are environmental degradation and economic losses which are evident in the polluted environment, health-related problems, loss of valuable products, service disruption, repair expenses, clean up cost [2].

Among the various methods of detecting and locating leaks in pipes are vision-based systems, acoustic measurements, fibre optic monitoring and multimodal, ground penetrating radar (GPR) based systems, pressure measurements, e.t.c. [3]. Yunana, Adewale et al. [4] presented other methods to include manual inspection using trained dogs and lately advanced satellite-based hyperspectral imaging methods. Osunleke et al. [2] posited that the above methods are useful but not good enough for continuous monitoring activity.

The shortcomings of the above methods led to the development and deployment of wireless sensor networks using pressure variations to detect and locate leaks in pipes on a continuous basis. Azubogu et al. (2013) presented a wireless sensor network as a collection of sensor nodes interconnected by wireless communication channels with each sensor node being able to collect data from its surrounding area, carry out simple processing, and communicate with other nodes in the network or directly with the base station. Nweke and Ogbu [5] stated that wireless sensor networks are the collection of self-powered sensor nodes that coordinates to perform some specific tasks while Akyildiz, Su, Sankarasubramaniam, and Cayiru [6] noted that the sensor nodes have sensing capabilities, communication components, and data processing facilities with all the nodes in the network collaborating. Puccinelli and Haenggi [7] stated that a field sensor node is composed of three main elements namely target sensing, processing of gathered data from the field of applications, and communication of processed results to the user who is remotely located. Saini et al. [8] gave some of the applications of wireless sensor networks to include military use for environment monitoring, earthquake warning, and home security. Other applications of wireless sensor networks are drug identification, automatic and recognition security, health applications, smart buildings, agriculture applications, structural monitoring, e.t.c. [9,10]. Buratti et al. [11] classified all the applications into two categories namely event detection (ED) and spatial process estimation (SPE).

This paper writes on a project carried out to monitor oil pipeline against leaks deploying a wireless sensor network using pressure variations. The wireless sensor network basically consists of two sections namely the field or transmitting section and the master or receiving section. The field section is mounted on a prototype oil pipeline to monitor the pressure inside the pipeline while the master section uses an LCD and a buzzer to signal pressure decrease and therefore leak. The project is based on the programming of a microcontroller contained in the Arduino board in C++ program to perform specific tasks.

2. NEED FOR SUCH A NETWORK

Since leakages must occur in pipelines resulting from either natural means or man-caused, it is therefore imperative to monitor pipelines on a continuous basis against leakages. This is to ensure that when and where leakages occur, they are promptly reported. Oil pipeline leakage results in oil spillage that leads to environmental pollution and economic losses. This is where the need for this wireless sensor network arises, which purpose is to monitor the pipeline on a continuous basis against leakages so that when a leak occurs, it is promptly reported and actions are taken to mitigate the environmental and economic consequences of oil spillage.

3. COMPONENTS DESCRIPTION

3.1 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 for installation and replacement and prominent in the engineering applications for oil pipeline pressure sensing. The input voltage and pressure range can be customised. The supply voltage is 5V dc, and the output has the range of 0.5 - 4.5V dc, and the pressure range is 1200kPa. The pressure sensor works for all types of flow.

3.2 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 analogue input pins, a USB connection, a power barrel jack, an ICSP header and a reset button. It operates with 5V dc and a frequency (clock speed) of 16MHz.

3.3 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 a 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. A service provider network was used, and so coverage area for the network is intended.

3.4 JHD162A LCD Module

The JHD162A LCD module is a 16 X 2 LCD module based on the HD44780 driver from Hitachi, and it had 16 pins and operated in 4-bit mode (using only 4 data lines). It has a 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.

4. BLOCK DIAGRAMS AND NETWORK OPERATION

4.1 Transmitting or Field Sensor Section

Fig. 1 gives the block diagram of the field or transmitting section which is otherwise called the field sensor.

In Fig. 1, the sensor unit consists basically the pressure sensor which measures and converts the pressure values to voltage values. The processing unit is composed of the Arduino board that contains the microcontroller. The microcontroller has at its input an analogue to

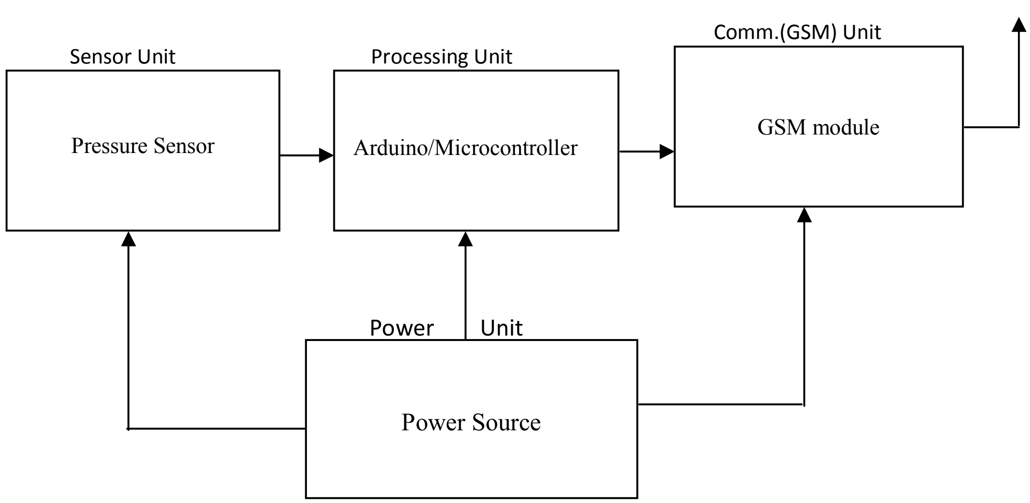

Fig. 1. The field sensor node block diagram

digital converter that converts the analogue voltage signal from the pressure sensor to digital signal before it is fed to the microcontroller. The microcontroller processes the digital voltage signal and produces an output that is sent to the communication unit that contains the GSM module. The signal from the microcontroller is modulated and radiated into the atmosphere in the communication unit. The GSM module is a transceiver, but it used here as a transmitter. The power source, which is a dc battery power the entire field sensor node.

4.2 Receiving or Master Sensor Section

Fig. 2 presents the block diagram of the master or receiving section which is also known as the master sensor.

When the transmitted signal is received in the communication unit, the signal is demodulated in the GSM module (used only as a receiver), and the output is sent to the processing unit. The microcontroller in the processing unit processes the demodulated signal and uses its output to drive both the LCD and the buzzer.

To understand the operation of this network, let us consider the flowcharts given in Figs. 3 and 4.

4.3 Field Sensor Flowchart

Fig. 3 presents the flowchart diagram for programming the microcontroller at the field sensor node.

4.4 Master Sensor Flowchart

Fig. 4 gives the flowchart diagram used in programming the microcontroller in master sensor node.

When the network (i.e. both the field and master sensors) is powered, the pressure sensor of the field sensor starts to read pressure values and convert them to voltage data. The analogue voltage signal is converted to a digital voltage signal and then fed to the microcontroller in the Arduino board. The microcontroller processes the information received by comparing the voltage level received with a voltage value stored (corresponding voltage setpoint) in its memory. See the flowchart of Fig. 3. When the voltage received by the microcontroller is equal or more than the voltage set point of the microcontroller, no signal is sent to the GSM module. But once the received voltage is below the voltage set point, a signal is sent to the GSM module, where it modulates the carrier signal in the GSM module. The modulated carrier signal is radiated and transmitted as radio waves to the GSM module of the receiving section. In the receiving section, the received radio waves are converted back into an electrical signal and processed by the microcontroller in the Arduino board of the master sensor. The output signal of the microcontroller is used to drive the LCD and the buzzer. An audiovisual alarm is therefore received by a human monitor who analyses the information received to locate the position of the leak at the field.

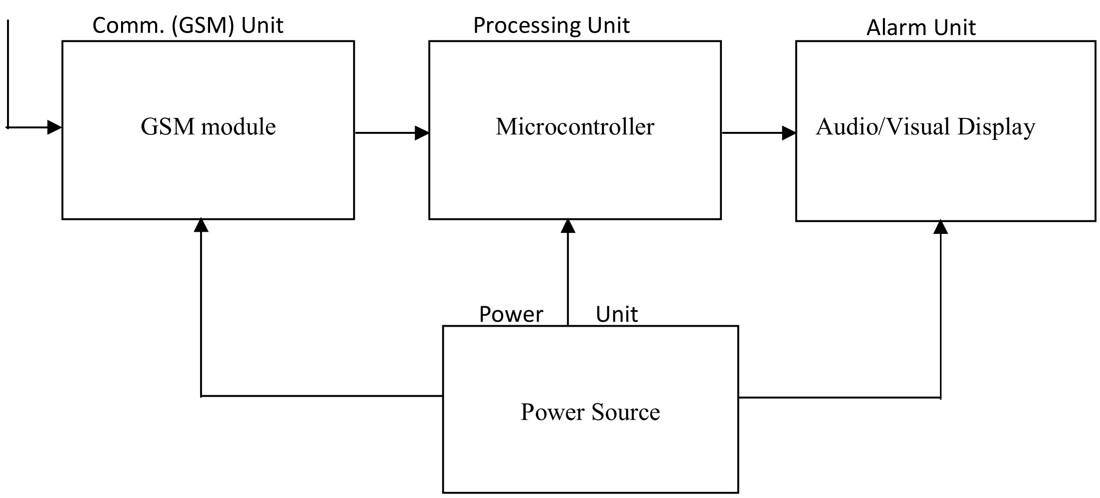

Fig. 2. Master sensor node architecture

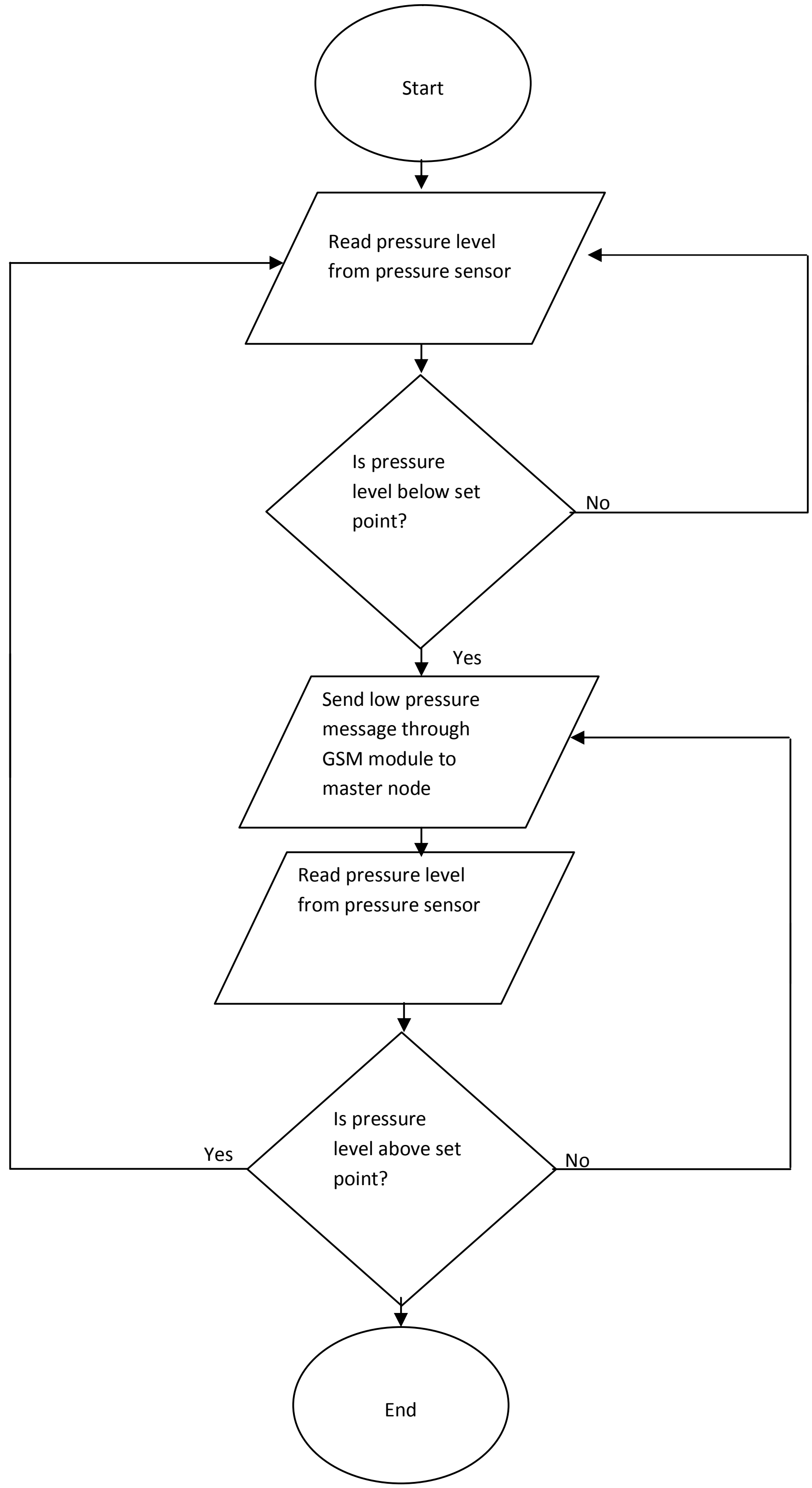

Fig. 3. Field sensor flowchart

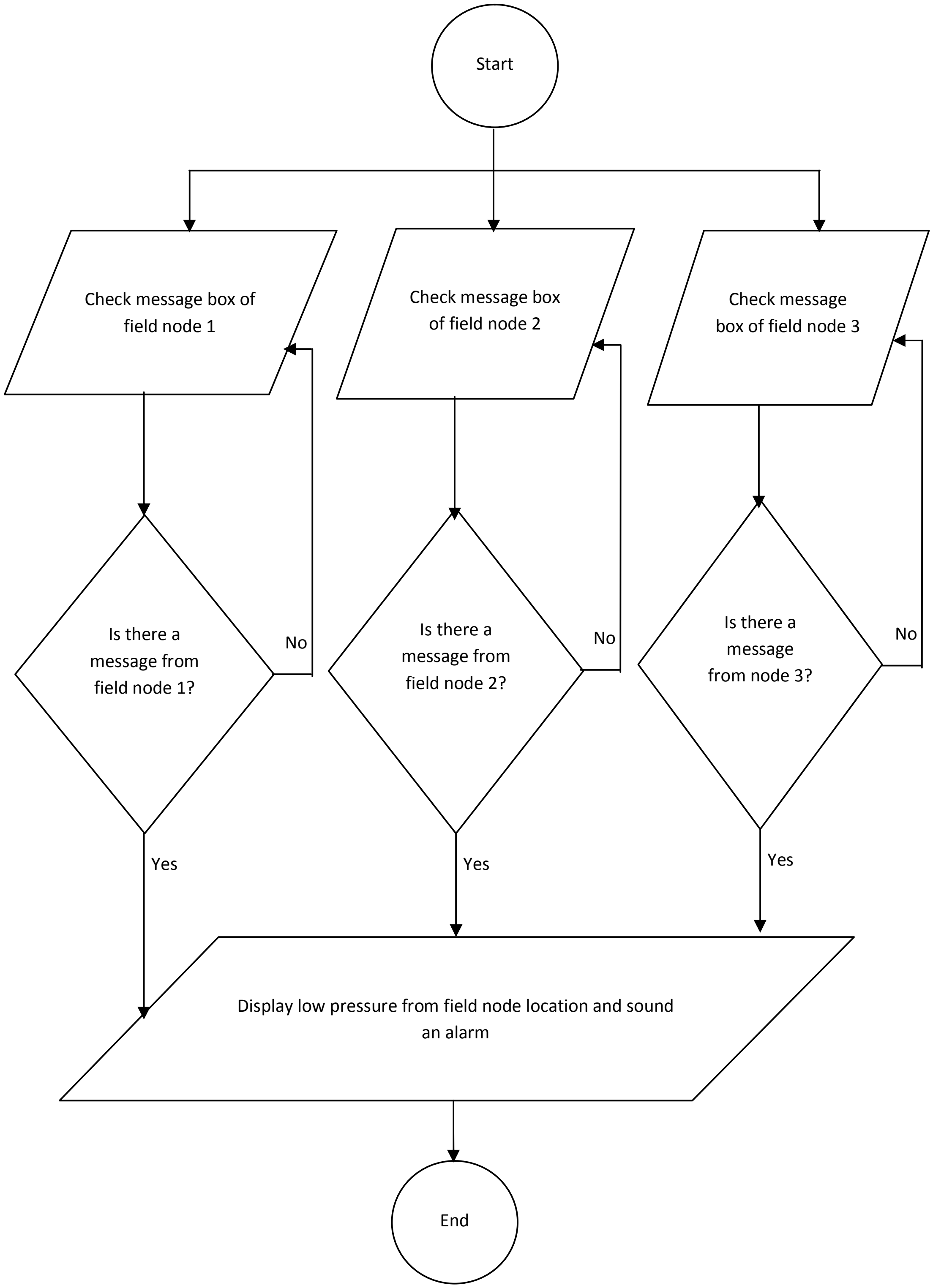

Fig. 4. Master sensor flowchart

4.5 Simulated Circuit Diagram

4.5.1 Transmitting section (Field Sensor Node)

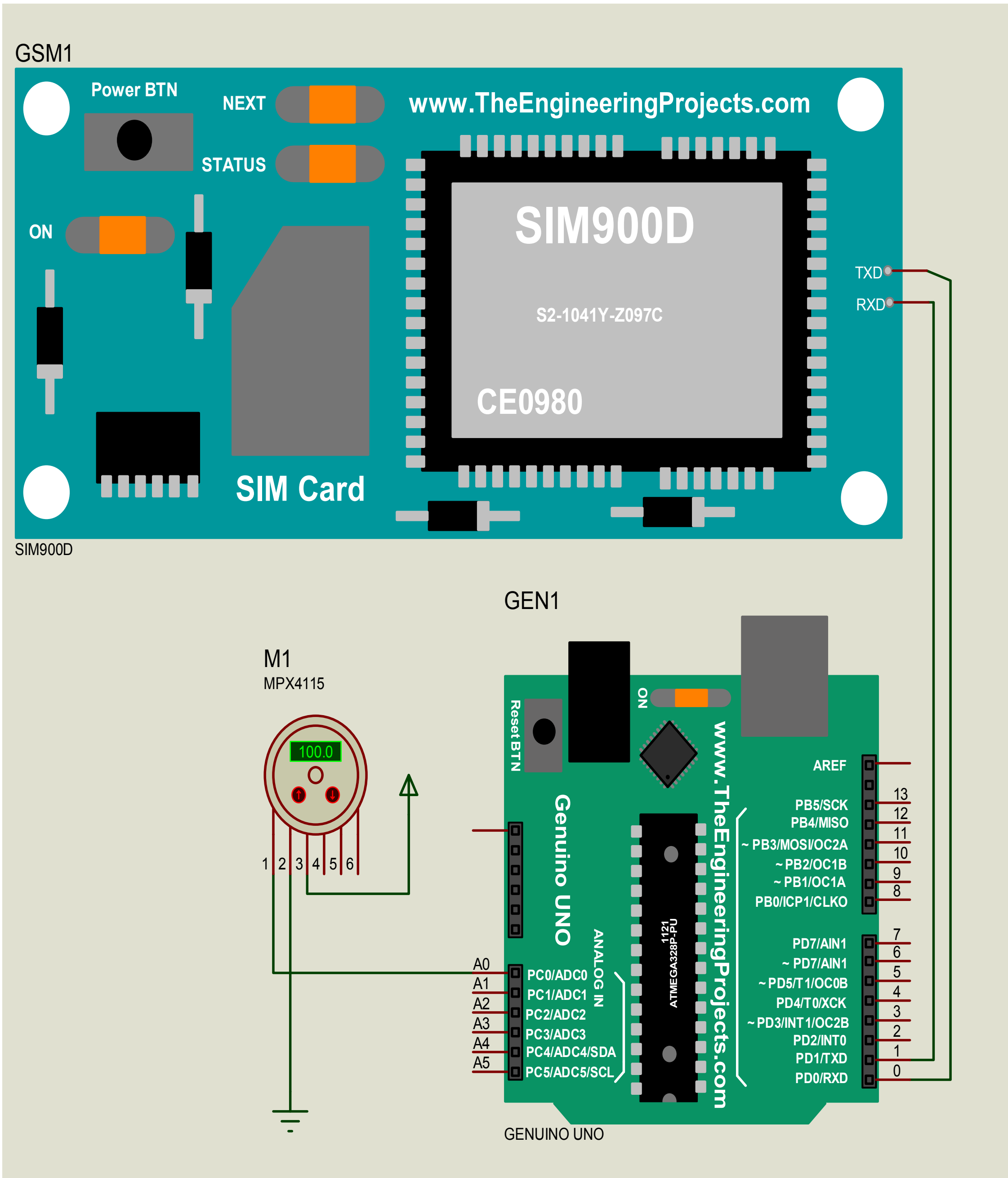

Fig. 5. Simulated circuit diagram of transmitting or field sensor section

Note: In this design, the pressure sensor is interfaced to the Arduino microcontroller through the analogue pin A0 as shown in Figure 5. Only three wires are used here (1, 2, and 3). The red wire (3) is connected to V_{CC}, the black wire (2) is connected to ground (GND), while the yellow wire (1) is connected to analogue pin A0 of the Arduino board

4.5.2 Receiving section (Master Sensor Node)

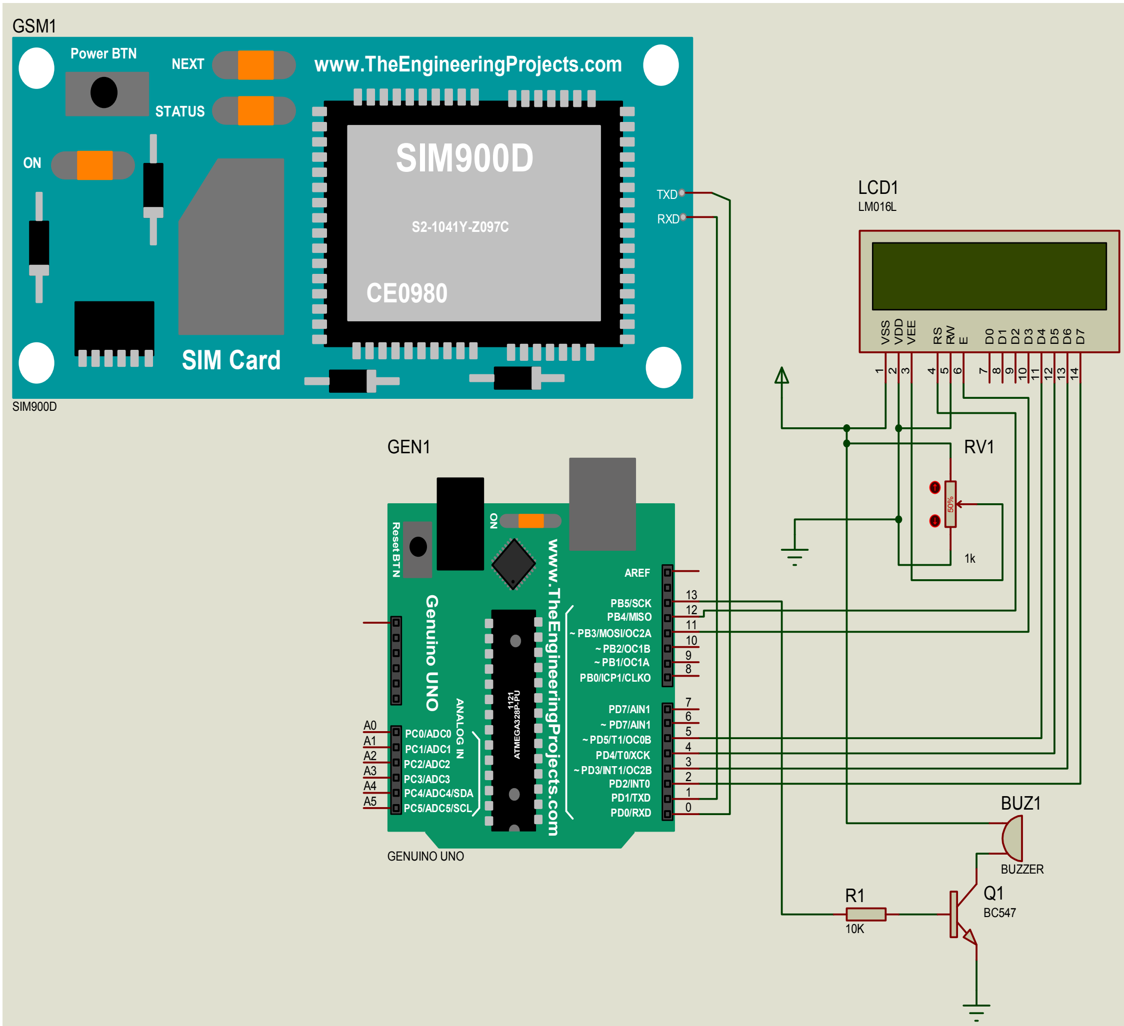

Fig. 6. Simulated Circuit Diagram of Receiving or Master Sensor Section
Note: Circuit diagrams were simulated in Arduino Uno environment

5. RESULTS AND DISCUSSION

A 'low pressure at node 1' information will be displayed on the LCD when a signal is received from field node 1 indicating a leak before field node 1. At the same time, an audio alarm will be sounded by the buzzer. Similarly a 'low pressure at nodes 2 and 3' will be received when signals are received from field nodes 2 and 3 and alarm sounded.

6. CONCLUSION

The purpose of this work was to implement a wireless sensor network that will monitor the pressure variation inside a prototype oil pipeline to detect any leakage. To this end, a wireless sensor network that uses pressure variations to detect leak was designed and implemented. Three field sensor nodes and one master sensor node were developed to monitor pressure variations at three designated points and report any reduced pressure below a set pressure point to the master sensor node. The information received at the master sensor node is analysed for action to be taken. If deployed in Nigeria, the wireless sensor network will be able to monitor oil pipelines against leaks and therefore reduce environmental degradation and economic losses resulting from oil leakages.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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DOI: 10.3390/s90906869

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/28007