Wireless Sensors and Actuators Distributor for Anti-Pipeline Vandalization Programme Using Iot Philosophy: A Case of Niger Delta Area

Isaac, Efemena Roseline., Ituma, Chinagolum., Anyim, Chukwuemeka, and *Nwogbaga, Nweso Emmanuel

Computer Science Department, Ebonyi State University, Abakaliki

***Corresponding Author**

DOI: https://doi.org/10.51584/IJRIAS.2024.909001

Received: 02 August 2024; Revised: 17 August 2024; Accepted: 21 August 2024; Published: 26 September 2024

ABSTRACT

The environment in which humans operate is influenced by various factors such as temperature, moisture, light, vibration, humidity, smoke, fire, and even sudden car engine failures. Identifying and understanding these factors, especially in critical areas like crude oil and gas pipelines, is crucial for developing effective intervention strategies. Wireless sensor networks (WSNs) offer a promising solution for detecting and addressing environmental issues. For instance, these systems can identify a fire in a remote area, enabling timely intervention by fire services. As wireless communication technology advances, the ability to design flexible and efficient WSNs for continuous environmental monitoring becomes increasingly feasible. Such networks can monitor, analyze, and control factors like pipeline vandalism in regions like the Niger Delta Area. Unlike traditional wired networks, wireless designs provide greater flexibility in managing these environmental challenges. In this project, a WSN was implemented using the open-source hardware platforms Arduino and Raspberry Pi. The system was designed to be low-cost and highly scalable, making it ideal for environmental monitoring applications. The sensor nodes were designed to be as compact as possible, using 1-wire sensors like the DS18B20 temperature sensor. Unlike analog sensors that rely on analog pins, these digital sensors can be driven by a single digital pin, allowing a single sensor node to support multiple sensors. To ensure continuous operation, the voltage of the battery powering the sensor nodes is also monitored. The system automatically connects new sensor nodes that come within range of the base receiving node, ensuring seamless data tracking from the sensors. Data transmission and reception are facilitated by nRF24L01(+) radio modules, while a user interface provides remote access. An HTTP web server was established at the base station, allowing the received data to be retrieved via a web browser on a PC. The overall system architecture, including detailed hardware and software design, is presented. Example measurement results are provided to demonstrate the system's effectiveness in environmental monitoring.

Keywords: Arduino, nRf24L01+, 1-Wire, Dynamic, wireless sensor network, Auto-detect, Base station, environment, monitoring, range, Web page. Raspberry Pi.

INTRODUCTION

A wireless sensor network is a system made up of spatially distributed devices that use sensors to monitor physical or environmental conditions without the need for wires (Silviu et al., 2015). Research on this topic shows that the use of wireless sensor networks has rapidly advanced over the years, with numerous applications emerging across different fields. For instance, these networks have been utilized to monitor heart rates (Vinay et al., 2015), track weather conditions (Bharani et al., 2014), and enhance agricultural practices (Burak et al., 2014), among other applications.

The benefits of wireless sensor networks are clear: they reduce the cost and effort associated with traditional wiring, allow data communication over longer distances, and enable easier movement of terminals while consuming less power. However, many earlier systems relied on outdated analog sensors that were limited by the number of available microcontroller analog pins (Jelicic et al., 2013), restricting the number of sensors that could be used. In contrast, this project employs modern digital 1-Wire sensors.

Recent advancements in wireless sensor networks point towards a shift in development, particularly with the use of open-source hardware and software. This paper introduces a dynamic wireless sensor network system developed using the Arduino open-source hardware platform, Raspberry Pi, and the nRF24L01+ radio module. The system is designed to be low-cost and easier to maintain compared to earlier wired systems or other radio-standard networks. Environmental challenges, such as storms damaging infrastructure, highlight the difficulties in maintaining wired networks, especially over long distances.

In the past, sensor networks faced significant challenges in becoming viable for engineering, commercial, and scientific applications due to issues like lack of flexibility, scalability, reliability, and ease of maintenance. The system implemented in this project addresses some of these challenges, offering room for future expansion through the automatic addition or detection of new sensor nodes that are compatible with the system.

An overall system architecture of the sensor network system comprises of the base station, sensor nodes, PC/Laptop, router, internet and the links, as shown in Figure 1 below. How this system operates will be explained in subsequent sections.

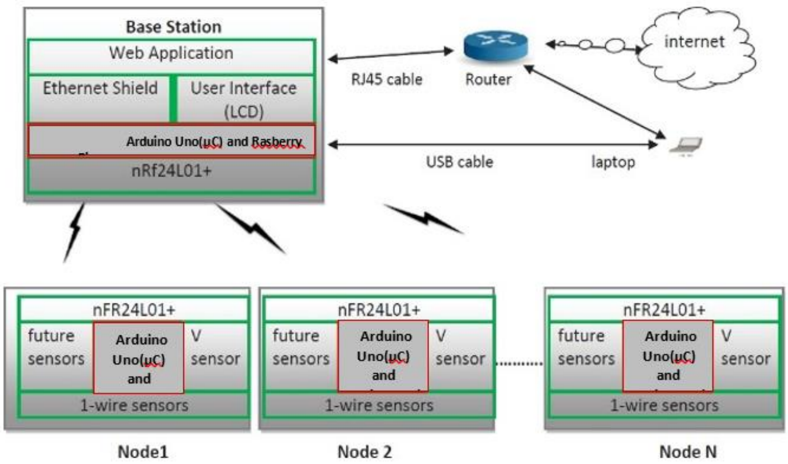

Figure 1: System Architecture

A sensor node in this project includes a microcontroller board based on the Arduino NANO, a Raspberry Pi board, multiple sensors, and an nRF24L01+ radio transceiver module. The network is centrally managed by a base station, which consists of an Arduino UNO microcontroller, a Raspberry Pi, and the same type of radio module used in the sensor nodes. This setup facilitates remote access and management of the sensor nodes. To enable interaction with the sensor network and external data access, an Ethernet Shield is attached to both the Arduino UNO and Raspberry Pi boards. This configuration supports the creation of a web application at the base station, using an HTTP web server, allowing users to access sensor data through an internet connection. For additional remote monitoring, an LCD display and software serial monitor on the Arduino/Raspberry Pi boards are also available.

The designed network system in this project is suited for small-scale environmental monitoring. The system is organized in a star network topology, where each sensor node connects directly to a central hub, the base station, as depicted in Figure 1. One of the key benefits of this star topology is the ease of adding more nodes to the network. However, a significant drawback is that the entire system can fail if the base station encounters an issue, as it serves as the single point of failure.

Scope of the Thesis

This thesis will focus on the development of a dynamic wireless sensor network system utilizing the Arduino and Raspberry Pi platforms. The system is designed to include a base station that wirelessly communicates with

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

multiple sensor nodes, specifically for monitoring the environmental conditions of oil and gas pipelines in the Niger Delta region. The sensor nodes, which will be equipped with 1-Wire sensors and powered by batteries, will play a crucial role in this monitoring process.

The base station will serve as the central hub for the system, providing a user interface where sensor management and monitoring are conducted. The system will automatically detect any new sensor devices that come within range, establish a connection, identify the sensor type, and determine the kind of data the sensors will transmit, along with the specific environmental parameters they measure. Once recognized, these sensors will be integrated into the user interface for continuous monitoring.

Additionally, the system will be designed to adjust the data transmission frequency as needed, detect and report any errors to the user interface, and provide notifications if a sensor moves out of range or if a battery starts to fail. The project will also address solutions for keeping the sensor nodes compact and energy-efficient, ensuring that they can operate effectively over extended periods.

Hardware Architecture

Overview: This project involves the design and modeling of an online ambient monitoring system that uses low-power wireless sensors, integrated with ARDUINO (ATMEGA328) and Raspberry Pi microcontroller boards. The system is designed to monitor key environmental parameters such as temperature, relative humidity, absolute pressure, and the level of black carbon deposits (soot) in oil and gas pipelines. These deposits, often caused by illegal refining activities, are a significant issue in the Niger Delta region of Nigeria, stemming from pipeline vandalism.

The system's sensors gather real-time data on these conditions, which are then processed by the microcontrollers. The data collected is further analyzed using machine learning decision tree algorithms running on the Raspberry Pi. These algorithms enable the system to make crucial predictions based on the extensive data collected from the sensors installed on the pipelines. This predictive capability is vital for taking proactive measures to prevent pipeline vandalism in the Niger Delta.

The architecture of the system serves a dual purpose: it monitors and gathers data, and it also contributes to the prevention of pipeline damage. Once the data is processed, it is uploaded to the internet, allowing for global access and monitoring through the Internet of Things (IoT). The IoT framework enables users to remotely view and analyze numerical and graphical data trends over time and set up alerts for specific triggers.

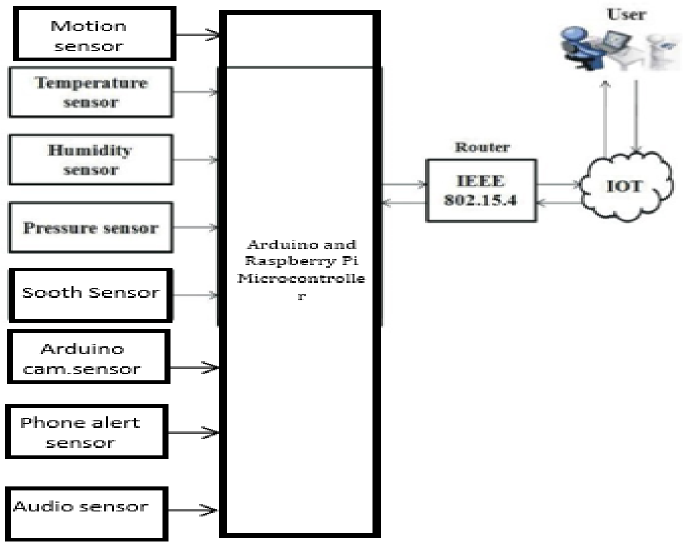

Figure 2: Block diagram of ambient system (use case)

Arduino Uno Microcontroller: The Arduino Uno is a versatile microcontroller board built around the ATmega328 chip. It comes equipped with 14 digital input/output pins, 6 analog inputs, an ICSP header, a 16

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

MHz ceramic resonator, a power jack, a USB port, and a reset button. This board is designed to be user-friendly, with all necessary components integrated into a single unit. It can easily connect to a computer via a USB cable and can be powered either by a battery or an AC-to-DC adapter, making it straightforward to start working with.

A notable feature of the Uno is its 16U2 microcontroller, which is programmed to function as a USB-to-serial converter. This differentiates it from other boards that typically use FTDI chips for USB-to-serial conversion. The system's program memory can be reprogrammed through the on-chip In-System Programming (ISP) Flash, using the Serial Peripheral Interface (SPI). This can be done either via an on-chip bootloader running on the AVR core or through a traditional nonvolatile memory programmer.

The Arduino Uno employs high-density nonvolatile memory technology, ensuring robust performance for embedded system applications. The bootloader software can utilize any interface to load the application program into the flash memory, allowing the bootloader to continue operating even while the application flash memory is being updated. The Atmel ATmega32 microcontroller provides a powerful, flexible, and cost-effective solution for a wide range of embedded system projects.

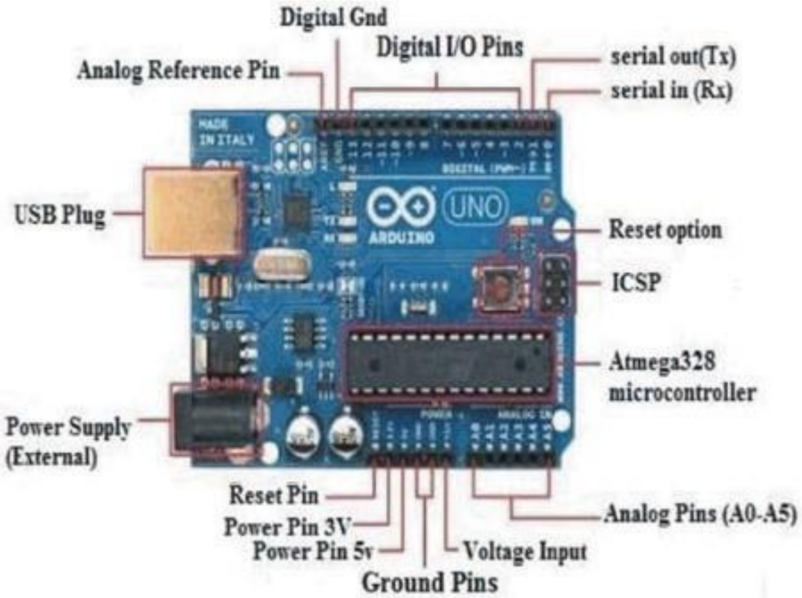

Figure 3: Arduino Uno microcontroller

Input and Output Functions of the Arduino Uno: The Arduino Uno is equipped with 14 digital pins that can function as either inputs or outputs. These pins are controlled using the digital Read (), digital Write (), and pin Mode () functions, and they operate at 5 volts. Each pin is capable of handling a maximum current of 40 mA and includes an internal pull-up resistor ranging between 20-50 kOhms. The board also has 6 analog input pins labeled A0 to A5, each providing a 10-bit resolution. The resolution, which is measured from ground up to 5 volts, can be adjusted using the analog Reference () function and the AREF pin.

Communication Capabilities: The Arduino Uno offers several communication options for connecting with a computer, other microcontrollers, or additional Arduino boards. The ATmega328 microcontroller on the Uno supports UART TTL serial communication, which is accessible on digital pins 1 (TX) and 0 (RX). The board also includes an ATmega16U2 microcontroller that handles the USB-to-serial conversion, allowing the Arduino to communicate with a computer via a virtual COM port without needing external drivers, as the standard USB drivers are embedded within the 16U2 firmware. On Windows systems, however, an .inf file is required to run the program.

The Arduino software includes a serial monitor, which facilitates the sending and receiving of text-based data from the Arduino Uno board. The board's TX and RX LEDs light up when data is transmitted through the USB connection to the computer. The Uno also supports serial communication through its digital pins using the Serial library software. In addition to UART, the ATmega328 microcontroller supports I2C, SPI, and PPI protocols, with the Arduino software offering a Wire library for I2C communication.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

IEEE 802.15.4 Protocol: IEEE 802.15.4 is a protocol for wireless personal area networks that uses packet data communication. Channel access is managed through the CSMA/CA method. The protocol supports data rates of 250 kbps, 40 kbps, and 20 kbps, with a primary focus on low power consumption. It also offers multiple levels of security. The transmission range varies from 10 to 100 meters, depending on power output, with mesh networking used for long-distance communication. This protocol is commonly used in embedded sensing, home automation, medical data collection, and building control systems.

Figure 4: LM 35 temperature sensor

Humidity Sensor: The DHT22 sensor is utilized to measure the relative humidity within the pipeline environment. Humidity sensors are essential tools for detecting moisture levels in various settings. Monitoring and regulating humidity is crucial in both industrial and domestic applications, as the presence of water vapor in the air can impact human comfort and influence numerous manufacturing processes. Additionally, humidity plays a significant role in various physical, chemical, and biological processes.

In industrial contexts, accurate humidity measurement is vital because it can directly affect the health and safety of workers, as well as the quality and efficiency of production processes.

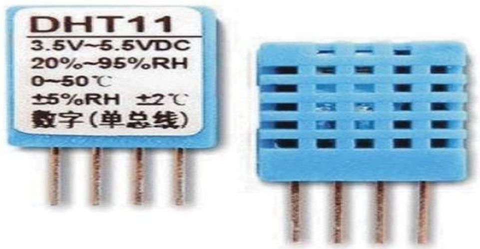

Figure 5: DHT 11 Humidity Sensor

Soot Sensor: The MQ135 soot sensor operates with a small heater and an electrochemical sensor housed within it. This sensor is designed to measure CO concentrations in the air with high sensitivity and a quick response time. It can detect various gases at room temperature and is particularly effective for indoor environments. To ensure accurate readings, the sensor requires calibration with a known concentration of soot.

The sensor functions on a 5V power supply and can detect CO concentrations ranging from 200 ppm to 10,000 ppm. A drive circuit is necessary to power the heater coil by applying 5V through a load resistance. The sensor outputs an analog signal, which can be read by the Arduino microcontroller's analog input. The analog resistance value is then connected to an ADC for further processing.

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Figure 6: MQ135 Sooth sensor

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

Pressure Sensor: The MPL115A2 absolute pressure sensor was selected for its broad pressure measurement range. It offers an initial accuracy of ±1 kPa and measures absolute pressures from 50 kPa to 115 kPa. This sensor is energy-efficient, consuming only 5 µA during active operation and just 1 µA in shutdown mode. It utilizes piezo-resistive transducers and advanced micromachining techniques to achieve its measurements. The analog output signal of the sensor is directly proportional to the applied pressure.

Figure 7: MP3V5050 Pressure sensor

MAX 232 Line Driver: The MAX 232 is an integrated circuit featuring two receivers and two drivers. It converts RS-232 signals to TTL voltage levels and vice versa. This allows bidirectional conversion of RS-232 signals. One pair of driver and receiver handles TX and RX signals, while the other pair manages CTS and RTS signals. Operating with a 5V power supply, the MAX 232 is known for its low power consumption and efficient power-saving features in shutdown mode. The IC includes 16 pins and requires four external capacitors for proper configuration.

Software Architecture: The software architecture encompasses wireless sensors, an application web server, and client devices. Data from the sensors is transmitted to the web server using the User Datagram Protocol (UDP), which is a connectionless service. Integrating wireless connectivity with ambient sensors offers energy-efficient solutions. This setup minimizes overall energy consumption and allows for real-time data display on a web application.

A web page is designed to monitor and control sensor data. By entering the IP address into a web browser, users can access this page to view ambient temperature, pressure, humidity, and other parameters from the pipeline environment. The collected data is stored in the cloud at various intervals, enabling users to analyze and manage the information from anywhere in the world. The web page is developed using Java or .NET, as these platforms are compatible with web server applications.

Figure 8: Sensors in a wireless sensor network (use case)

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

Arduino IDE: The Arduino IDE is a versatile open-source software platform designed for developing microcontroller-based projects. It supports creating digital devices and interactive objects that interface with the physical world using microcontrollers, commonly from the Atmel AVR or ARM series. The IDE provides a user-friendly environment for programming these microcontrollers and includes various digital and analog input/output pins for connecting expansion boards and other circuits. It supports programming in languages such as C, C++, and Java, and uses serial communication interfaces, including USB, for uploading programs from a personal computer.

Proteus ISIS7 Simulator: Proteus 7.0 utilizes Virtual System Modeling (VSM) to integrate microprocessor models, circuit simulation, and animated components, allowing for comprehensive co-simulation of microcontroller-based designs. This simulation tool is ideal for testing and refining designs before building physical prototypes. Users can interact with their designs through virtual components such as LEDs, LCDs, switches, and buttons.

Proteus 7.0 includes a Circuit Simulation component, which combines a SPICE3f5 analog simulator with an event-driven digital simulator. It supports SPICE models from various manufacturers and offers advanced debugging features like single-stepping, breakpoints, and variable displays. This helps ensure that designs are functional and optimized before hardware implementation.

Program Compilation: The Arduino Uno is programmed using the Arduino software, which includes a pre-installed bootloader on the Atmega 328 microcontroller. This bootloader allows new code to be uploaded without the need for an external hardware programmer, using the STK500 protocol. Additionally, the Arduino ISP (In-System Programming) can bypass the bootloader to directly program the microcontroller via the ICSP header. The software compiles the embedded C code into a hex file, which is temporarily stored before being uploaded to the microcontroller.

To compile the program by using ARDUINO IDE until without errors, after compilation the program is dumped on the microcontroller.

Figure 9: Program compilation

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue IX September 2024

SIMULATION RESULTS

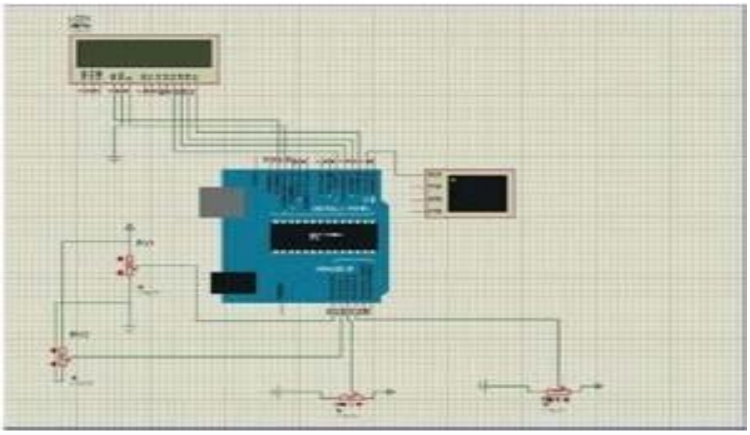

Figure 10: Simulink diagram

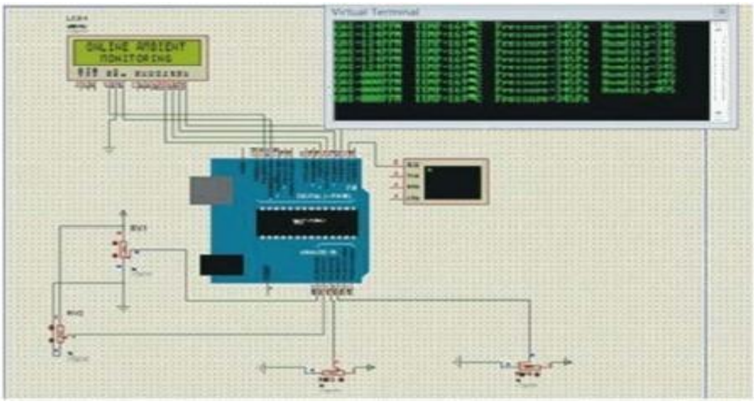

Figure 11: Continuous monitoring parameters

Figure 12: Final data value

CONCLUSION

An online ambient monitoring system based on Arduino and Raspberry Pi microcontrollers was successfully designed and implemented. The system effectively monitors various environmental parameters such as temperature, relative humidity, motion, audio, video, soot levels, phone alerts, and absolute pressure within the oil and gas pipeline environment of the Niger Delta Area. The data collected by the sensors is transmitted to the internet via a serial peripheral interface, enabling remote access and analysis. The performance and characteristics of the system were thoroughly evaluated using Proteus 7 simulation software.

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