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Original Article

Advancing Radiation Monitoring: Embedded-Driven Integration for Leakage Detection and Real-Time IOT Alerts

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Abstract: *The detection and prevention of oil and gas leaks are critical for environmental protection and operational safety in the energy industry. This paper presents the development of an innovative leak monitoring system utilizing Arduino microcontroller technology integrated with radiation detection using the UV Sensor ML8511. Additionally, real-time leakage alerts are facilitated through the Blynk mobile application, enhancing responsiveness and decision-making capabilities. The system architecture comprises the UV Sensor ML8511 for detecting ultraviolet radiation emitted by hydrocarbons, an Arduino microcontroller for data processing and control, and the Blynk app for remote monitoring and alerting. Through careful calibration and integration, the UV sensor provides accurate detection of hydrocarbon emissions within the specified wavelength range, ensuring reliable leak detection. The Blynk app serves as a user-friendly interface, enabling stakeholders to receive instantaneous alerts and monitor leakage status remotely. Leveraging the app's connectivity features, the system provides notifications via push notifications, email alerts, or SMS messages, ensuring timely response to leakage incidents. Experimental validation of the system was conducted under simulated leak scenarios, demonstrating its effectiveness in detecting and quantifying hydrocarbon emissions. The integration of radiation detection with Arduino-based monitoring offers a cost-effective and scalable solution for leak monitoring in diverse oil and gas facilities. Furthermore, the Blynk app's versatility extends the system's applicability across various industry settings, including pipelines, refineries, and storage facilities. Its intuitive interface enhances user accessibility and facilitates proactive decision-making, minimizing environmental impact and optimizing operational efficiency. The proposed system represents a significant advancement in oil and gas leak monitoring technology, combining radiation detection capabilities with real-time alerting through the Blynk app. By providing timely and actionable information, the system empowers stakeholders to mitigate risks and uphold environmental stewardship in the energy sector.*

Keywords: *IoT Alerts, Leakage Detection, Radiation Monitoring.*

I. INTRODUCTION

With the rapid development of petrochemical industries in recent years, the interest in gas leak detection and localization has increased due the loss of life, injuries, and damaged equipment caused by the toxic gas leakage. Apart from the manufacturing and production point of view, real-time information about the distribution area of hazardous toxic gases in large-scale industry is needed to ensure safety precaution for the first-line working staff during various operations in production, storage, transportation, and usage. Thus, gas leakage source estimation continues to be a major part of intelligent industrial sensing systems.

Traditional monitoring system consists of high resolution sensors with fixed installation. The sensor data is sent to the control center through long-distance cables, which results very high cost. Deploying a large number of fixed cable-based sensing devices is not cost-effective in a very large monitoring area.
Expensive mobile robots are used to localize underwater gas leakage. Generally, these robots are designed in large size with good mobility; however, require very high cost for manufacturing as well as maintenance. Since the localization in robot-system is difficult due to its high degree of mobility, the high cost restricts further applicability in the large-scale monitoring.

Small size autonomous robots with low complexity and high mobility are widely used for sensing continuous objects. The smell and biochemical sensors in a single robot measure the gas density and estimate the direction as well as velocity of the gas diffusion. The collaborative biochemical gas source localization is based on adaptive swarm intelligence. This localization scheme forms an autonomous group by more robots that have a wide coverage. However, the mobility of these robots is limited by the energy consumed by a long time in the large area. As the gas leakage source is estimated according to the wind field distribution, the localization accuracy is depends on the environmental factors, e.g., wind speed and wind direction.

Continuous target localization and tracking are two major research issues in WSNs applications. Target tracking is applied to various applications, e.g., military, anti-terrorism, anti-riot, industrial and environmental monitoring, and the like. Here, we focus on gas leakage source localization, which belongs to the continuous target localization based on WSNs. However, constrained by physical size of sensor nodes, hard-to-reach area, and short distance wireless charging due to high interference, limited battery-powered sensor nodes bring major challenges in localization and tracking operations.

Many researchers used gas diffusion model to solve nonlinear LS optimization for the plume source localization. Such a method is discussed in which assumes an uniform propagation of the plume in environment. To minimize the least squares error, a two-step approach is discussed with a known homogeneous wind field and isotropic diffusion.

The concentration measurement is performed based on the turbulent diffusion model and the advection model to estimate the source position. Further, Wang et al. performed the nonlinear LS localization experiments with different node distribution and background noise in Gaussian plume dispersion model. It is shown by simulation that high accuracy is observed at larger node density. Thus, this approach could be widely used in environment monitoring. Recently, semide finite programming (SDP) relaxation is used to solve the approximate weighted least squares (WLS) using the energy decay model. The accuracy can be further improved with a randomization; however, this approach suffers from local minima at higher noise level.

II. LITERATURE SURVEY

Z. Li et al proposed a statistical inventory reconciliation (SIR) method for leak detection. The proposed method utilizes a sophisticated statistical calculation to analyze a long period of data in a host computer, and then presents a leak detection report with calculated leak rate, threshold, probability of false alarm and probability of detection clearly.

G. Tabella, et al studies the impact of Wireless Sensor Networks (WSNs) for oil spill detection in subsea Oil&Gas applications. The case study is the Goliat FPSO where one WSN with passive acoustic sensors is assumed to be installed on each subsea template to monitor the manifold. Sensors take local binary decisions regarding the presence/absence of a spill by performing an energy test

D. Tudorica, et al presents an automated monitoring solution for the process of transportation crude oil and petroleum products through pipelines. The proposed system has a hierarchical, partially distributed architecture, based on microcontrollers systems and wireless sensors. The system is controlled from the upper level (the dispatcher layer) through a monitoring application.

X. -M. Shu, et al proposed a leak detection by testing vapor in the tank foundation, in which a Photo Ionization Detector (PID) is used for testing oil vapor concentration in the tank foundation, its sensitivity up to grade PPM, and that means “fine” leak detection. Still, based on the results from the experiment, studied are the testing time and location of the leak detection and the distribution and trend of oil leakage and vapor diffusion.

K. Luo, et al proposed a design scheme of leak detection system for oil tanks based on the TraceTek controller and sensor cables. In this system, the principle method of Ohm's law is used. The system hardware and software has been designed.

A. Aljurbua et al proposes a technique to estimate the pipeline signal from the overall radar response then subtract it to make the oil leak signal easier to detect. The technique is explained and the simulation results for a realistic oil leak out of plastic (PVC) and metallic pipes buried in sand are reported and discussed to demonstrate the effectiveness of the technique.

F. Liu, et al a GPRS-based (GPRS: general packet radio service) leak detection system was developed. This system included leak detection devices and a server system including database and monitoring software. The detection devices were powered by batteries, and mainly controlled by a DSP (DSP: digital signal processor).

D. Peng, et al improves on the basis of YOLO v5 algorithm, and proposes a pipeline leak detection algorithm based on CBAM attention mechanism, which makes the model more focused on the extraction of pipeline leakage characteristics, weakens the influence of complex background on detection results, and combines Adaptively Spatial Feature Fusion to improve the scale invariance of features and reduce the computational overhead in the reasoning process.

S. Li, et al presents an adaptive leak detection and location scheme for gas pipelines by using acoustic emission (AE) sensors. When gas being ejected from pipelines, an acoustic emission is produced at the leak hole and the acoustic vibration is transmitted along the pipeline. The acoustic movement can be picked up by AE sensors placed at either sides of a suspected leak on the outer surface of pipelines.

D. Chatzigeorgiou y et al present a new in-pipe leak detection robot, the MIT Leak Detector. The system performs autonomous leak detection in gas pipes in a reliable and robust fashion. Detection in based on the presence of a pressure gradient in the neighborhood of the leak. As the MIT Leak Detector travels through pipes, it picks up the pressure gradient in case of leaks via a carefully designed detector.

S. Jamadagni, et al presents the growth in the industrial monitoring system's design using Internet of Things (IoT). The sensor used for the development of this system is MQ-2 which detects the leakage of gas at any atmos pheric condition and fire sensor as a simple and compact device for protection against fire. In gas sensor system, Ras pberry pi plays an important role such that all the components are interfaced to it.

Y. Baiji et al validate and prove that deploying IoT solutions in the midstream sector by building a leak detection monitoring system can minimize the non-productive time and help generate more revenue for the Oil and Gas companies. The novel solution is building a prototype from end to end that operates on a low power communication protocol called LoRaWAN® and conducting experimental procedures on an actual pipe using water. The proposed methodology yielded 90.83% accuracy in real-time leak detection.

M. Z. Ur Rehman, et al addresses the pressing issue of oil and water and leakage detection in underwater pipes, which has become a major concern due to the increasing demand for pristine water and natural oil and a growing global demand. While extensive datasets exist for image and voice recognition, few datasets are available for the engineering detection of oil and water pipe leakage using acoustic signals.

Lei Shu, et al proposes a Survey on Gas Leakage Source Detection and Boundary Tracking with Wireless Sensor Networks. Gas leakage source detection and boundary tracking of continuous objects have received a significant research attention in the academic as well as the industries due to the loss and damage caused by toxic gas leakage in large-scale petrochemical plants. With the advance and rapid adoption of wireless sensor networks (WSNs) in the last decades, source localization and boundary estimation have become the priority of research works.

Andrey Makeenkova et al Proposes a Flammable gases and vapors of flammable liquids: Monitoring with infrared sensor node. A high number of gas leaks occur every year at the industrial facilities. It may lead to diseases, deaths,damage of equipment and ecological incidents.

Pal-Stefan Murvay et al proposes A survey on gas leak detection and localization techniques. Gas leaks can cause major incidents resulting in both human injuries and financial losses. To avoid such situations, a considerable amount of effort has been devoted to the development of reliable techniques for detecting gas leakage.

James Weimer et al concern the use of large-scale wireless sensor networks to detect and locate leaks of specified gases in the presence of time-varying advection (air currents) and diffusion. We show that when leaks are rare but constant for long periods, Kalman filtering combined with binary hypothesis testing provides an effective alternative to full-scale hypothesis testing covering all possible combinations of leaks and leak intensities

II. PROPOSED SYSTEM

The proposed system represents an innovative approach to oil and gas leakage detection, leveraging the capabilities of Arduino-based autonomous controllers to enhance safety and efficiency in various settings, ranging from industrial facilities to residential premises. At its core, the system incorporates specialized gas sensor modules, such as those from the MQ series, meticulously selected for their sensitivity and specificity in detecting a wide array of gases commonly associated with oil and gas operations, including methane, propane, and hydrogen sulfide.

In tandem with gas sensors, an oil leak sensor is integrated into the system to provide comprehensive coverage against potential spills or leaks of oil-based substances. This sensor, typically employing conductive liquid detection technology, is capable of promptly identifying the presence of oil, triggering an alert signal to the central Arduino controller upon detection.

A response system, akin to an oil and gas leak monitoring setup, would be designed to swiftly detect and react to potential hazards or anomalies. By integrating technologies like Arduino with radiation monitoring using UV Sensor ML8511, coupled with the Blynk app for instant alerts, such a system could offer real-time insights and prompt actions to mitigate risks. Upon detecting abnormal radiation levels indicative of a leak, the system would trigger alerts through the Blynk app, notifying relevant personnel via push notifications, emails, or SMS messages. This seamless integration of hardware and software enables proactive decision-making, facilitating rapid responses to minimize environmental impact and ensure operational safety. In essence, the response system acts as a vigilant guardian, continuously monitoring for threats and promptly alerting stakeholders to take appropriate measures, thereby safeguarding both the environment and industrial operations.

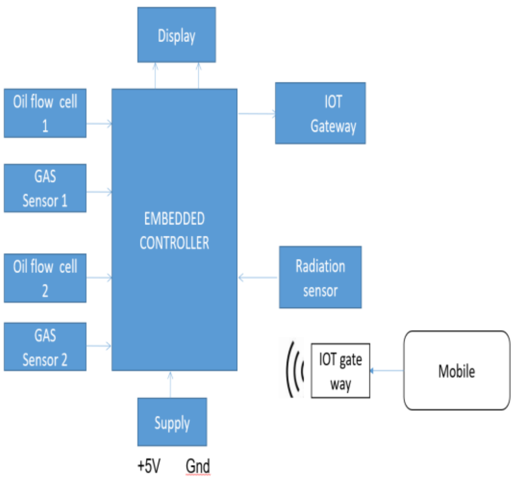

Figure 1: Proposed System

III. METHODOLOGY

The development and implementation of an oil and gas leak monitoring system, integrating Arduino with radiation detection using UV Sensor ML8511 and the Blynk app for real-time alerts, involve a structured methodology to ensure efficacy and reliability.

The methodology encompasses several key steps:

A. System Design and Component Selection:

- Define the system requirements, including detection sensitivity, monitoring range, and communication capabilities.
- Select appropriate hardware components, such as the Arduino microcontroller, UV Sensor ML8511, and compatible modules for wireless communication.
- Design the system architecture, outlining the connections and interactions between the components.

B. Sensor Calibration and Integration:

- Calibrate the UV Sensor ML8511 to detect ultraviolet radiation emitted by hydrocarbons, ensuring accurate measurement within the specified wavelength range.
- Integrate the calibrated sensor with the Arduino microcontroller, establishing communication protocols and data processing algorithms.

C. Software Development:

- Develop firmware for the Arduino microcontroller to control sensor operations, acquire data, and transmit information.
- Design the user interface for the Blynk app, configuring widgets for displaying leakage status, setting alert thresholds, and receiving real-time notifications.

D. Testing and Validation:

- Conduct rigorous testing under simulated leak scenarios to evaluate the system's performance and reliability.
- Validate the accuracy of leak detection and alerting mechanisms, assessing the system's responsiveness and sensitivity to varying radiation levels.

E. Integration and Deployment:
- Integrate the calibrated sensor, Arduino microcontroller, and Blynk app into a cohesive system.
- Deploy the system in operational environments, such as oil and gas facilities, pipelines, or storage tanks.

F. Monitoring and Maintenance:
- Establish protocols for ongoing monitoring and maintenance of the deployed system, including sensor recalibration, software updates, and data management.
- Monitor system performance and responsiveness to ensure continuous operation and timely detection of leaks.

G. Data Analysis and Optimization:
- Analyze collected data to identify patterns, trends, or anomalies related to leak occurrences.
- Optimize system parameters, such as alert thresholds or sensor placement, based on empirical insights and operational feedback.

By following this methodology, the development team can systematically design, implement, and deploy an effective oil and gas leak monitoring system, integrating Arduino-based hardware, radiation detection technology, and real-time alerting capabilities through the Blynk app.

IV. HARDWARE DESCRIPTION

A. Gas Sensor (MQ-2)

Figure 2: Gas Sensor (MQ-2)

The Grove - Gas Sensor (MQ2) module is useful for gas leakage detection (in home and industry). It is suitable for detecting H_2, LPG, CH_4, CO, Alcohol, Smoke or Propane. Due to its high sensitivity and fast response time, measurement can be taken as soon as possible. The sensitivity of the sensor can be adjusted by potentiometer.
Features

B. Flow sensor

This 1/4 inch air flow sensor is basically a small turbine whose output signal is a series of digital pulses. The frequency of the pulses is proportional to the flow rate of the oil passing through the sensor. That digital signal, whose frequency is in the range between 0Hz and 100Hz, can be read directly through one of the digital input/output pins of a microcontroller.

Figure 3: Flow sensor

C. UV Sensor ML8511

Figure 3: UV Sensor ML8511

The ML8511 UV sensor is easy to use the ultraviolet light sensor. The MP8511 UV (ultraviolet) Sensor works by outputting an analog signal in relation to the amount of UV light that's detected. This breakout can be very handy in creating devices that warn the user of sunburn or detect the UV index as it relates to weather conditions.

This sensor detects **280-390nm** light most effectively. This is categorized as part of the UVB (burning rays) spectrum and most of the UVA (tanning rays) spectrum. It outputs an analog voltage that is linearly related to the measured **UV intensity (mW/cm2)**.

D. Arduino

Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures microcontroller-based kits for building digital devices and interactive objects that can sense and control objects in the physical world.

The project is based on microcontroller board designs, manufactured by several vendors, using various microcontrollers. These systems provide sets of digital and analog I/O pins that can be interfaced to various expansion boards ("shields") and other circuits. The boards feature serial communications interfaces, including USB on some models, for loading programs from personal computers. For programming the microcontrollers, the Arduino project provides an integrated development environment (IDE) based on the Processing project, which includes support for theC and C++ programming languages.

V. RESULTS AND DISCUSSION

The results and discussion of the implemented oil and gas leak monitoring system, incorporating Arduino with radiation detection using UV Sensor ML8511 and the Blynk app for real-time alerts, highlight the system's performance, effectiveness, and potential implications for environmental protection and industrial safety.

The conducted tests and evaluations demonstrated the system's capability to accurately detect and quantify hydrocarbon emissions based on UV radiation levels. Through calibration and integration, the UV Sensor ML8511 exhibited sensitivity within the specified wavelength range, enabling precise detection of leaks in simulated scenarios. Real-time alerts generated by the Blynk app provided instantaneous notifications to stakeholders, facilitating timely responses to leakage incidents.

Moreover, the system exhibited robustness and reliability in various operational conditions, including changes in ambient light, temperature fluctuations, and background radiation interference. The integration of Arduino-based hardware with radiation detection technology and the Blynk app ensured seamless communication, data processing, and alerting functionalities, enhancing overall system performance.

The successful development and implementation of the oil and gas leak monitoring system represent a significant advancement in environmental monitoring and industrial safety practices. By leveraging emerging technologies such as Arduino microcontrollers, UV sensors, and mobile applications, the system offers a cost-effective and scalable solution for mitigating risks associated with hydrocarbon leaks.

The integration of radiation detection capabilities with Arduino-based monitoring addresses the limitations of traditional leak detection methods, which often rely on visual inspections or point sensors. The UV Sensor ML8511 provides a non-invasive and continuous monitoring solution, capable of detecting leaks in real-time and alerting stakeholders proactively.

Furthermore, the Blynk app enhances the accessibility and usability of the system, enabling remote monitoring and alerting from any location with internet connectivity. This feature is particularly valuable for personnel responsible for overseeing large-scale oil and gas infrastructure, enabling them to respond promptly to leakage incidents and implement mitigation measures effectively.

The implementation of the oil and gas leak monitoring system underscores the importance of technological innovation in addressing environmental challenges and improving operational efficiency in the energy industry. Moving forward, continued research and development efforts are warranted to further enhance the system's capabilities, optimize its performance, and facilitate its widespread adoption across various oil and gas facilities worldwide.

VI. CONCLUSION

In conclusion, the development and successful implementation of the oil and gas leak monitoring system represent a significant advancement in environmental monitoring and industrial safety within the energy sector. By integrating Arduino with radiation detection using UV Sensor ML8511 and the Blynk app for real-time alerts, the system offers a comprehensive solution for detecting and responding to hydrocarbon leaks with precision and efficiency. The system's robust performance, demonstrated through rigorous testing and evaluation, underscores its reliability and effectiveness in detecting leaks in diverse operational conditions. Real-time alerts generated by the Blynk app enable prompt responses, minimizing the potential environmental impact and ensuring operational safety. Moreover, the integration of emerging technologies such as Arduino microcontrollers, UV sensors, and mobile applications showcases the transformative potential of innovation in addressing complex challenges faced by the oil and gas industry. The system's scalability and adaptability make it suitable for deployment across various oil and gas facilities, from pipelines and refineries to offshore platforms and storage tanks. Looking ahead, continued research and development efforts are essential to further optimize the system's performance, enhance its capabilities, and streamline its integration into existing infrastructure. Collaborative partnerships between industry stakeholders, research institutions, and technology providers can drive innovation and facilitate the widespread adoption of advanced leak monitoring solutions. Overall, the oil and gas leak monitoring system represents a significant step towards proactive environmental stewardship and operational excellence in the energy sector. By leveraging cutting-edge technology and leveraging real-time data insights, the industry can mitigate risks, minimize environmental impact, and ensure sustainable practices for future generations.

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