IoT Natural Gas Pipeline Monitoring System

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Keywords: Long Range Radio (LoRa), Internet of Things (IoT), Daisy-Chain Topology, Natural Gas Storage, Natural Gas Safety, Methane, Ethane, Greenhouse Gas.

Abstract: In this paper, we discuss our construction of a natural gas monitoring system that utilizes a network of nodes that communicate with each other using LoRa modulation techniques. After the devastating gas leak in 2015 at the Aliso Canyon Natural Gas Storage Facility in Los Angeles county, in which a total of 104,400 tonnes of methane and ethane gas was released into the atmosphere, it became apparent that gas storage facilities and pipelines are in need of more efficient gas leak observation and monitoring methods. Our solution involves constructing nodes from a LoRa32 microcontroller, MQ-4 gas sensor, solar panel, and a 3.7V lithium battery. The nodes will be configured in a daisy-chain topology that can be positioned along any pipeline or gas storage facility. The daisy-chain topology will allow data to be sent along the chain to a data collection node and subsequently stored in the cloud hosted Firebase database. It is also anticipated that this monitoring system will be surveyed using an intuitive mobile application for iOS and Android devices.

1 INTRODUCTION

The monetary, environmental, and health implications of a gas leak are as immense as they are detrimental. Gas leaks can go undetected for weeks, and it can take months to identify the source of the leak. Thus, it is imperative that gas storage facilities and pipelines are closely monitored in order to minimize the damage done by gas leakage. According to Debra Wunch et al. in their article “Quantifying the loss of processed natural gas within California's South Coast Air Basin using long-term measurements of ethane and methane,” the South Coast Air Basin, with a population of about 18 million people, emits approximately 413,000 tonnes of methane and 23,000 tonnes of ethane annually (Wunch et al., 2016). These numbers are severely exacerbated by gas leaks, which is the issue that this project seeks to address.

One should consider the case of the Aliso Canyon Natural Gas Storage Facility. First discovered in October 2015, the Aliso Canyon gas leak was a prominent and dangerous natural gas leak in the Santa Susana Mountains of Southern California. The Aliso Canyon gas leak is credited as the worst gas leak in U.S. history (Conley et al., 2016). It released 97,100 tonnes of methane and 7,300 tonnes of ethane into the atmosphere (Conley et al., 2016). The severity of this gas leak was enabled by the fact that the gas leak was undetected for weeks, and it took several attempts by SoCalGas to finally stop the gas leak on February 12, 2016 (SoCalGas, 2016).

The Aliso Canyon gas leak negatively affected both the people living in the area and the Southern California Gas Company, the primary utility company providing natural gas to Southern California. The occupants of Aliso Canyon experienced several health complications, and nearly 3,000 households, 11,000 people, and two schools were displaced, causing more than 6,500 families to file for help (Gazzar, 2015). Methane and ethane are unsafe for humans to inhale in large amounts, and the residents of Aliso Canyon reported symptoms including mood changes, slurred speech, vision problems, memory loss, nausea, vomiting, facial flushing, and headaches because of gas inhalation from the leak (Abram, 2015).

Steve Conley, an atmospheric scientist at the University of California Davis, measured the massive gas leak’s emissions and cited that “[w]e do not have anything in place to measure giant leaks like this, or to watch them to solve issues” (Ortiz, 2016). There were eight infrared methane monitors installed at Aliso Canyon that were intended to measure the ppm of the methane in the air by sending an infrared beam between a sender and a receiver. However, it is possible that some weather conditions interrupted the

Cook, W., Felberg, H., Palos, N. and Yeh, J.
IoT Natural Gas Pipeline Monitoring System.
DOI: 10.5220/0010713600003062
In *Proceedings of the 2nd International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2021)*, pages 168-173
ISBN: 978-989-758-535-7

infrared beams, which may have resulted in inaccurate methane readings ("Aliso Canyon Infrared Fence-Line Methane-Monitoring System: SoCalGas", n.d). Since there was no reliable system in place to pinpoint the location of the leak, the leak was undetected for multiple weeks, and SoCalGas was found to be at fault for the massive gas leak. They were sued for \$119.5 million for the damages and other effects of the gas leak (Domonoske, 2018). This is just one case of a gas leak in the industrial sector going firstly unnoticed and secondly unfixed due to a lack of the technology in place to do so. Other major gas leaks that have occurred around the world include the following ("List of Pipeline Accidents," 2021):

- November 30, 2000: pipeline caught fire near the fishing village of Ebute near Lagos, Nigeria, killing at least 60 people
- July 30, 2004: Ghislenghien, Belgium killing 24 people and leaving 122 wounded, some critically
- 2011 Nairobi Kenya pipeline fire kills approximately 100 people and hospitalized 120
- November 22, 2013: Sinopec Corp oil pipeline exploded in Huangdao, Qingdao, Shandong Province, China, 55 people were killed
- June 27, 2014: a pipeline blast in Southern Indian state of Andhra Pradesh killed 22 people and injured 37

Thus, it is crucial that a more effective gas monitoring system is put in place in order to prevent the consequences of another massive gas leak.

To allow real-time monitoring of natural gas leaks, our team developed a low-cost Internet of Things (IoT) Natural Gas Pipeline Monitoring System. Our flammable and toxic gas monitoring system is low-cost, can be deployed over a wide area, has robust communication, and can be provisioned quickly and easily. Essentially, the installer could simply place and secure a self-contained portable monitoring unit in any appropriate location, push a button on their smartphone/tablet, and the new node would configure itself to be part of the monitoring system.

2 SYSTEM DESCRIPTION

Our IoT gas monitoring system consists of a network of sensor nodes placed around natural gas containers, transport facilities, pipelines, or openings that might leak. The first phase of the system involves sensor node modules, a communications network for the nodes, and a central interface. The nodes are built with the relevant gas sensor(s) (MQ-4 for methane and ethane, etc.), solar panels and batteries for power, and inexpensive communication modules. The system provides connectivity for each node's data using a variety of communication standards such as Bluetooth, WiFi, or LoRa, depending on the distance between the nodes. Each node's data is relayed toward the central node and aggregated to the cloud database. The user interface is built to work on a multitude of platforms (Android, iOS, Windows, macOS), providing widespread access to the cloud database and thus the current gas level readings of each node.

2.1 LoRa Sender Modules

The primary element of our natural gas monitoring system is a network of LoRa-based gas sensor modules. Figure 1 shows the block diagram of a LoRa sender module. Each of these modules consists of a LoRa32 microcontroller board, a low-cost (MQ-4) gas sensor, a solar panel, and a 3.7 Volt lithium battery. The LoRa32 is an ESP32-based microcontroller which acts as the bridge between the MQ-4 gas sensor module and the cloud database. LoRa stands for "long range", and provides low bit rate communications over distances up to 10 km. The LoRa32 module adds LoRa capabilities to the low-cost ESP32 IoT platform. The MQ-4 gas sensor is an extremely low-cost, widely available sensor that detects the presence of methane gas in the air. Methane (CH_4) is the principal constituent of natural gas, so leaks from natural gas processing facilities can be detected by measuring higher concentrations of methane gas in the atmosphere. Therefore, methane is an ideal gas for us to target, as it can be measured easily and affordably.

The solar panel and lithium battery provide local electrical power to the sender modules. They allow the modules to be placed anywhere outdoors without the need to connect to power supplies, which means that they can be deployed easily along gas pipelines and gas wells.

2.2 LoRa Receiver Module

The data collection node will not need a battery nor a solar panel as it will be installed at a gas distribution company's station where it will have access to power and network infrastructure such as WiFi. It will receive packets from the sender modules over LoRa and will store the data in the local and/or cloud-based database such as Google Firebase. Therefore, the data collection node will use both LoRa and WiFi communication.

2.3 Network

Our network of nodes is configured in a daisy-chain topology. Data packets will be passed to each other towards the data collection node. Each field node acts as both a sender and a receiver in the sense that it both receives packets from other nodes and sends those received data packets and its own data packets to the next node in the network.

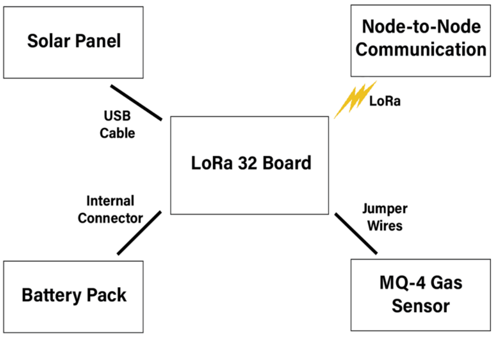


Figure 1: Block diagram of our LoRa sender module.

The measured range of the LoRa32 modules is up to 10 km; thus, nodes can be placed along a gas pipeline or gas storage system at up to 5 km from each other. This is so that a given node is in range of at least two other nodes in the network. This provides redundancy in the event of a node failure. If a node were to become disconnected from the network, the other nodes in the network would still be online.

2.4 Cloud Database

The cloud database will be where all of the data from the various sender modules will be stored. Our receiver module will connect to the cloud database and upload the measured methane levels from each sender node to the database. Once the data is in the cloud database, our website and mobile application will connect to the cloud database and display the data contained within it.

2.5 Mobile Application and Website

Our mobile application will run on iOS and Android devices and allow our users to monitor the pipelines our sensors are deployed on remotely. The website will provide the same feature set to our users, but will be accessible from any desktop device on any platform (Windows, macOS, and Linux).

3 CURRENT STATUS

Development of a prototype for this natural gas monitoring system has been completed. The prototype consists of two LoRa32 microcontrollers (one sender and one receiver) with the corresponding gas sensor, solar panel, and battery mentioned previously.

3.1 System Prototype

We have built working prototypes of our LoRa sender node and our LoRa receiver node. Both nodes use the same hardware, with the exception of the receiver node, which has no gas sensor due to its role being the accumulation and handling of data, and potentially no battery nor solar panel due to its easy accessibility to power.

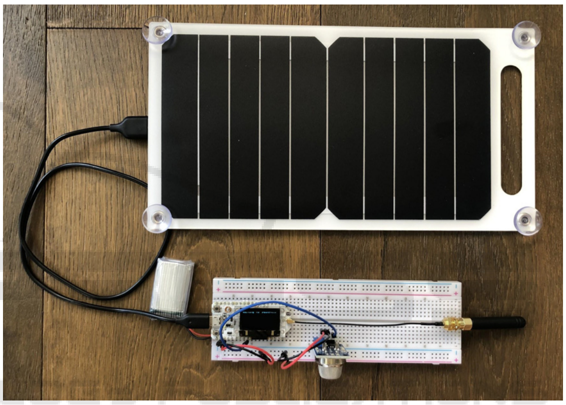


Figure 2: The prototype of the LoRa sender module.

Importantly, the total material cost of the prototype in very small quantities, including a solar panel, lithium battery, LoRa32, 9 different types of MQ-series gas sensors, but excluding a case, is under USD86 (~EUR73). Buying in larger quantities will significantly reduce the cost. With this sensor configuration, we expect that the total material cost including a weather-resistant case will be under USD100 (~EUR85).

The MQ-4 is a low-cost (~USD5, ~EUR4) chemical sensor with an SnO2 sensing layer, which has a detection sensitivity of 200ppm, and is applicable for the detection of gas leaks in the proximity of gas pipelines and wells. If higher sensitivity is required, such as for the detection of natural gas concentrations in the surrounding areas, sensors with sensitivities of 30ppm such as the SGX IR13BD IR Hydrocarbon Sensor are commercially available for USD200 (~EUR170). The use of higher sensitivity sensors is still extremely cost efficient for larger scale deployment.

Figure 3: Concept installation drawing of the LoRa sender module.

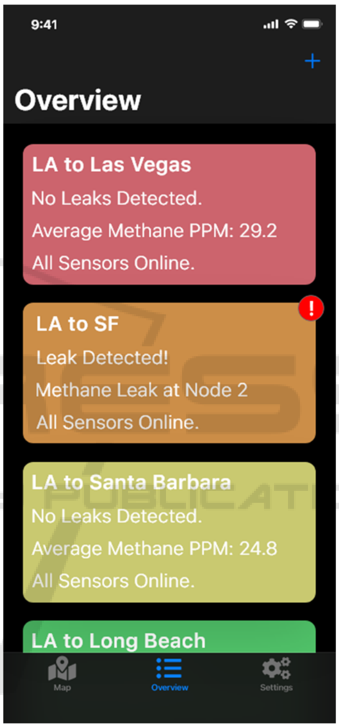
3.2 Mobile Application

The mobile application is being developed for iOS/Android devices and will allow the user to easily monitor each node to access the amount of methane present. This will allow the user to effortlessly pinpoint the location of a gas leak along a pipeline and prevent any hazardous effects that may ensue from an otherwise unnoticeable gas leak.

Figure 4: Screenshot of the map tab of the proposed mobile application.

Figures 4, 5, and 6 show screenshots of various tabs of the proposed mobile application: map, overview, and detail.

The map tab will display an entire map of the user's designated location that consists of each pipeline under surveillance. Each pipeline will be distinguishable by a unique color that can be identified by the given legend. The nodes of each pipeline will be represented by white circles that will change to red if a leak has been detected. Both the overview tab and the map tab will allow the user to observe every pipeline, but the map tab allows the user to visually identify the location of the leak on a map.



9:41

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Overview

LA to Las Vegas
No Leaks Detected.
Average Methane PPM: 29.2
All Sensors Online.

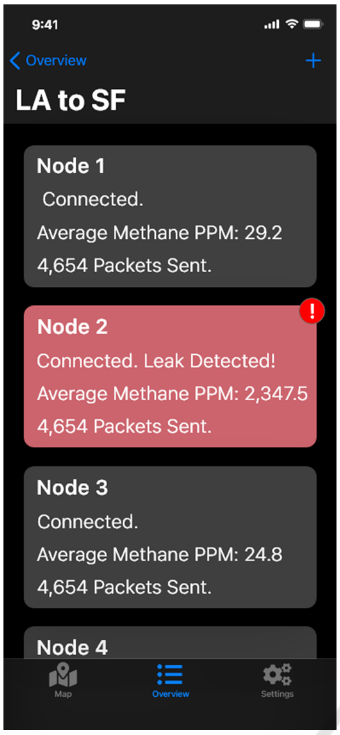
LA to SF
Leak Detected!
Methane Leak at Node 2
All Sensors Online.

LA to Santa Barbara
No Leaks Detected.
Average Methane PPM: 24.8
All Sensors Online.

LA to Long Beach

Figure 5: Screenshot of the overview tab of the proposed mobile application.

The overview tab will display a brief rundown of each pipeline that will indicate whether any of the nodes have detected a leak, if any of the sensors have disconnected from the network, and the average methane ppm of the pipeline. By selecting any of the pipelines from the overview tab, the user will be presented with a new screen which contains the details for each individual node along that specific pipeline. This information will include whether the node has detected a leak, if the node has been disconnected from the network, how many data packets have been sent by the node, and the average methane ppm at that node.



LA to SF

Node 1
Connected.
Average Methane PPM: 29.2
4,654 Packets Sent.

Node 2
Connected. Leak Detected!
Average Methane PPM: 2,347.5
4,654 Packets Sent.

Node 3
Connected.
Average Methane PPM: 24.8
4,654 Packets Sent.

Node 4

Figure 6: Screenshot of the pipeline details tab of the proposed mobile application.

Lastly, the mobile application will also consist of a settings tab. From this tab the user will be able to alter some of the general characteristics of the application such as the language of the text. The settings tab will also provide the user with an opportunity to temporarily remove pipelines from surveillance as well as an option to add removed pipelines back into the app. An official prototype of the application may reveal the need for more tools that would be included under this tab.

4 SUMMARY

The Aliso Canyon gas leak was the worst gas leak in United States history (McGrath, 2016). As a direct solution to this event and events like it, we are designing a low-cost, deployable-anywhere gas monitoring system that can be installed densely around gas pipelines. For gas storage facilities, our system can work in tandem with existing gas monitoring systems to provide localized high concentration measurements around potential leakages, while the existing systems provide high sensitivity measurements around the entire storage facility. Our Natural Gas Pipeline Monitoring System seeks to streamline the process of finding and fixing gas leaks, thereby preventing the negative effects of major gas leaks.

ACKNOWLEDGEMENTS

This project/publication was made possible through the support of a grant from the W. M. Keck Foundation.

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