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Design and implementation of Internet of Things-enabled long-range autonomous surveillance bot for LPG leak detection and environmental safety monitoring

Rajesh Singh[1], Anita Gehlot[1], Rahul Mahala[2], Vivek Kumar Singh[3]
[1]Uttaranchal Institute of Technology, Uttaranchal University, Dehradun, Uttarakhand, India
[2]Law College Dehradun, Uttaranchal University, Dehradun, Uttarakhand, India
[3]Amazon Web Services, Dallas, Texas, United States

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ABSTRACT

Liquefied petroleum gas (LPG) accidents pose significant safety risks, requiring continuous monitoring and Internet of Things (IoT) technology to prevent gas leakage and ensure human safety. This work proposes distributed field-oriented IoT gas sensing robots for detecting dangerous flammable gases like Ammonia, Sulphur Dioxide, Nitrogen Dioxide, and Carbon Dioxide. The SnoLURk solution enables cost-effective IoT gas leak detection in indoor and outdoor robots using budget-friendly casings and sensors. The study also discusses a robotic system for gas leak detection, aiming to detect and combat burglary using ZigBee and GSM modules. Cloud support allows Wi-Fi zone residents to receive alerts and send investigators via email, enabling remote data analytics monitoring. The IoT-based Worker's Health Monitoring System improves health and safety practices in industrial environments by monitoring workers' health 24/7. It allows on-site and off-site monitoring, enabling quick intervention and avoiding complications. The system's applications include construction, mining, manufacturing, and healthcare. Future versions may include improved sensors and machine learning.

Corresponding Author:

Rahul Mahala
Law College Dehradun, Uttaranchal University
Dehradun, Uttarakhand, India
Email: rahulmahala98@gmail.com

1. INTRODUCTION

Liquefied petroleum gas (LPG) accidents are a significant societal issue, affecting the use of highly pressurized and cold LPG gas, primarily used for cooking and as fuel in generators and water heaters [1]. LPG, a flammable mixture of propane and butane, poses significant safety risks, necessitating continuous monitoring and Internet of Things (IoT) technology to prevent gas leakage and ensure human safety [2]. Home security is a major concern due to Liquid petroleum gas leaks, posing a threat to commercial and residential use. Technology is crucial for preventing explosions and fires, and using LPG gas detectors can help [3]. The IoT's MQ-2 sensor, when integrated with an automatic gas leak detection system with a self-regulating valve, ensures safety and minimizes gas wastage [4]. This work proposes distributed field-oriented IoT gas sensing robots for detecting dangerous flammable gases like ammonia, sulphur dioxide, nitrogen dioxide, and carbon dioxide in the environment [5]. The IoT is a rapidly evolving technology that connects social environments through interconnected sensors, enabling data communication via internet connectivity [6]. IoT connects physical devices with sensors, enabling data exchange and expanding internet reach. It extends beyond personal devices and prioritizes safety in projects [7]. The SnoLURk solution enables cost-effective IoT gas leak detection in indoor and outdoor robots by using budget-friendly casings and sensors [8]. The proposed system ensures sufficient LPG availability in cylinders, mitigating gas leak risks due to its low CO2 emissions and high energy efficiency [9]. This paper discusses a robostatic system for gas leak detection, which emits an alarm and takes precautionary measures to prevent dangerous incidents such as asphyxiation in homes and factories [10]. The study defines design requirements for gas leak detection and monitoring systems, distinguishes between data collection and event detection solutions, and discusses existing wireless sensor network approaches [11]. Cloud support allows Wi-Fi zone residents to receive alerts and send investigators via email, enabling remote data analytic monitoring using secure data locations [12]. The study aims to create a cost-effective wireless security system using ZigBee and GSM modules to detect and combat burglary, utilizing the PSO routing optimization algorithm [13].

2. REVIEW OF LITERATURE

LPG, a flammable gas, can ignite and explode, potentially damaging workers in hazardous areas. The industrial sector lacks efficient warning systems and equipment for gas leak detection [14]. LPG gas is highly inflammable, prone to fire or explosion if leakage occurs and is unmonitored. It is challenging to order gas when it runs out at odd times [15]. The project utilizes SDG principles for resilience and sustainability, enhancing countries' ability to respond to environmental changes. Real-time updates are provided through sensor nodes, local control centers, and functional monitoring units [16]. The innovation involves developing IoT applications to monitor people counting devices and send alerts when a limit is exceeded, primarily for rural areas to efficiently track occupancy statistics [17]. IoT technology is transforming the way we communicate, ensuring security and reducing risks like gas leakage and fire incidents. Adopting appropriate devices can help prevent accidents [18]. IoT-based LPG leak detection systems revolutionize detection and alert mechanisms, addressing the challenge of human monitoring, high costs, and complicated installation processes in homes, businesses, and industries [19]. Good standards are needed for LPG usage in household cooking due to potential gas leakage from devices like regulators, pipes, and burners [20]. Devices combine ordinary sensors with LPG gas leakage detection systems to detect hazardous gases, ensuring user safety in all situations [21]. This report has a focus on the design of a robot for the examination and detection of blockages within the sewer system, and performs an assessment by application of image recognition [22]. This document aims to enhance safety measures on a smart security robot by utilizing tagging and other sensors to monitor gas flow [23]. The research aims to integrate IoT devices into the automatic LPG cylinder gas level monitoring system to prevent gas exhaustion and ensure timely replacement [24]. The system monitors LPG levels in cylinders and prevents damage during gas leakage by cutting off the power supply and activating an exhaust fan [25].

3. METHODOLOGY

The design of the LoRa LPG detector bot is such that the different LPG sensing, communication, and alerting elements have been combined as shown in the block diagram of LoRa LPG detector bot in Figure 1, allowing it to perform a multitude of functions. The system is coordinated by blocks, a microcontroller that is above all responsible for the transmission of data and the control of the bot. This unit is the primary control center from where all the input information derived from the sensors is collected, processes, and sends it to other modules in the system. Additionally, due to its design, its integration into the bot is simple, and its power requirements are minimal.

The sensor block has two components, which include an MQ2 gas sensor and an environmental sensor. The MQ2 sensor is capable of detecting LPG in the air and sends an analogue signal that is directly proportional to the concentration of gas it detects. To determine if there is a gas leak in the area, this signal is followed by the microcontroller until it overtakes a set value. At the same time, the environmental sensor provides temperature and humidity values, which help enhance the bot's monitoring functions for the detection of gas leaks and sources and the conditions under which they occur. Using these sensors, the microcontroller gets essential signals that make it possible for the bot to take action when the environment is harmful and hence ensure its safety. In order to propel the bot, there is a motor control block that serves as the mobilizing element. The block is constructed by a motor driver that allows the bot to navigate and reposition itself after receiving a signal from a microcontroller. The motor driver received and executed the control commands and moved the bot appropriately. This mobility feature is a real bonus for situations when the bot requires self-traversing over the examined area or moving towards the suspected leak location. The communication block integrates the LoRa RF module for mobility purposes, which is capable over large distances with less power consumption. In the event that the sensors detect gas leaks or other strange environmental changes, the information has to be transmitted by the microcontroller through a LoRa module to some remote unit or a base station. With LoRa, Bots can communicate over greater distances than conventional wireless systems would allow. This is important when it is necessary for the bot to operate autonomously in isolated places and to receive commands from an operator or monitoring station in a different location. A buzzer is part of the alert system block and is set off when the bot's gas concentration reading is above the safe level register. The buzzer performs this task of warning since the alarm is on when a perilous situation is prevailing in the environment. This is particularly important when there is a need to alert the distant authorities as well as people at the site simultaneously. And the entire system has a self-sustaining system with a rechargeable battery fitted, so there is no need for manual intervention.

The primary system communication and control node is designated as the router node, and the component's structure accomplishes its task of processing the information received from the LoRa LPG detector bot and passing it over to the cloud, as illustrated in Figure 2. The NodeMCU microcontroller is incorporated within the router node, which in this case is the router node, and it does most of the computations. He is a powerful LoRa cyber network satellite, intelligent and able to integrate, process, and send information into cyberspace. Its connection to the internet is done easily thanks to its built-in Wi-Fi unit, simplifying access to the cloud platform for monitoring and control. The configuration of data captured from the LoRa with the NodeMCU is processed to enable it to be sent to Blynk Cloud, and later be displayed on a smartphone or web-based dashboard. Also in the communication block, there is a LoRa RF module for transferring information over a long distance from the detector bot. The data signals sent by the bot are captured by the LoRa RF module integrated in the router node for further processing. The data integration combines the localized sensors with the remote sensors. LoRa provides an edge in range and power efficiency in communication with the detector bot because it enables connection at long range and in weak Wi-Fi areas. The LoRa module allows the NodeMCU to receive data and process that information to transmit it to the accessible cloud after the module is utilized. The router node can be operated by an alphanumeric keypad input block that is built into the system. Without going online, users can access basic local control, which enables them to perform commands like setting the threshold limits for alerts, issuing alert acknowledgments, and issuing commands. This option is beneficial when users want to execute instructions or when they want to alter a setting at the node without navigating through the menus. It also allows greater functionality because the router node does not have to rely on communication to the cloud to be used.

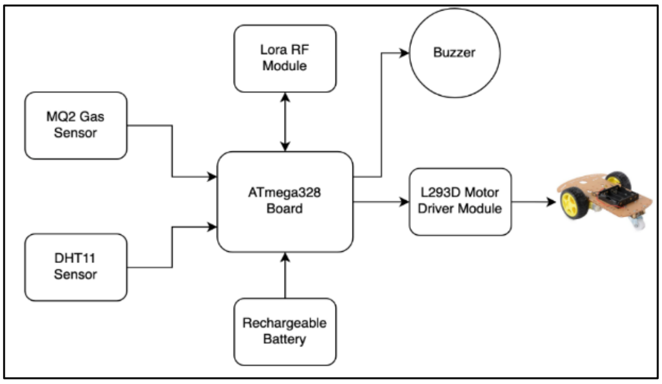

Figure 1. Block diagram of the Lora LPG detector bot

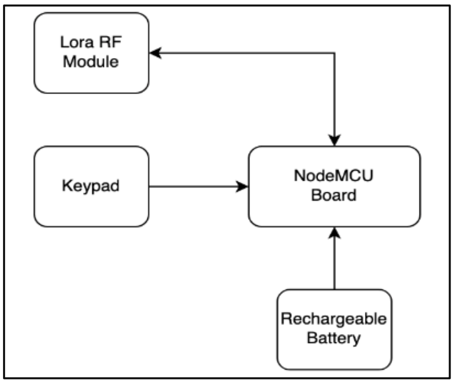

Figure 2. Block diagram of router node

The hardware connections of the LoRa LPG detector bot have the following elements in Figure 3. The MQ-2 Gas Sensor receives information from the Arduino Uno to sense combustible gases present in the environment. The power supply is needed for the sensor to work, so its Vcc pin connects to the 5V of Arduino Uno, and the pin GND connects to the GND of the Arduino. The sensor produces an analog signal corresponding to gas concentrations and feeds the information to the Arduino through the OUT pin A0. This allows the unit to control air quality and execute the necessary pre-programmed routines if harmful gases are detected in the environment. The DHT11 Temperature and Humidity Sensor is used for measuring the environmental conditions and supplying the Arduino Uno with up-to-the-minute temperature and humidity information. To make sure it works properly, the Vcc pin comes from the 5V pin of the Arduino Uno, whereas the GND pin goes to the GND of the Arduino unit. The Data pin of the sensor is linked to digital 2, which provides the microcontroller with the needed data to process the environmental readings. This configuration enables temperature and humidity control, which is vital for weather monitoring, home automation, and industrial safety.

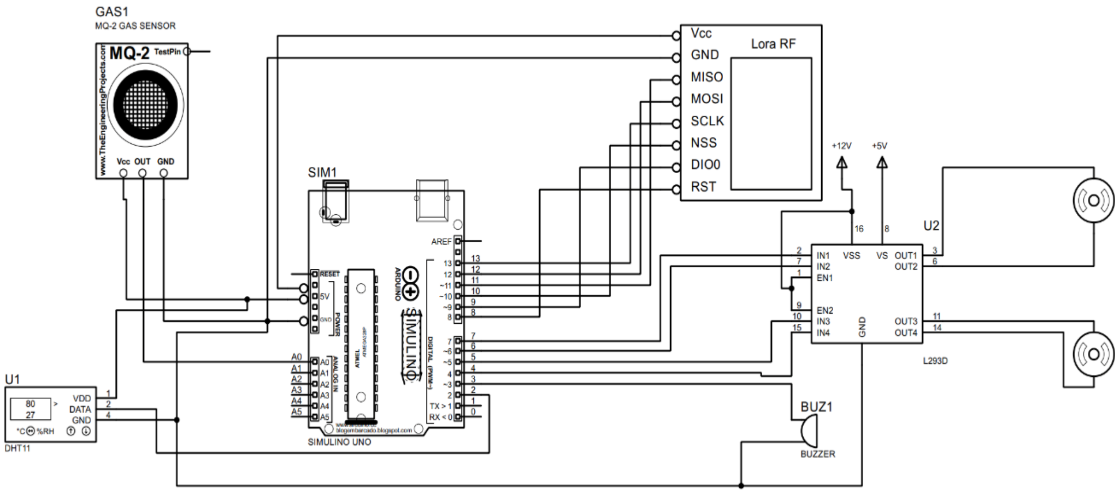

Figure 3. Connection diagram of Lora LPG detector bot

The software logic includes setting specific LPG concentration thresholds, beyond which the system sends an alert to notify users about a potential leak. Interrupt handling is employed to ensure that sensor data is processed in real-time, enabling immediate response to changes in gas levels. Additionally, data filtering techniques are used to minimize noise and smooth sensor readings, ensuring accurate and reliable leak detection. Environmental factors like ventilation and humidity can affect the accuracy of the sensors, but compensation algorithms are used to adjust readings for reliable performance under varying conditions. In this system, communication over a long distance is done using the LoRa RF Module. The module receives power from 3.3 V, which is why its Vcc pin is connected to the 3.3 pin of the Arduino Uno. The ground pin is connected to the Arduino GND pin, so they will have the same ground point, and signals can be transmitted properly. The module is connected to the Arduino through the SPI protocol; therefore, MISO, MOSI, and SCLK pins are connected to digital pins 11, 12, and 13. Digital pin 10 is used to connect the NSS; digital pin 9 connects the DIO0 pin, and digital pin 8 connects the RST pin. This connection configuration enables the LoRa module to transmit and receive data over large distances; thus, it is ideal for remote monitoring, controlling, and automating systems so far away. Motor movement is facilitated through two DC motors with the help of the L293D motor driver. This driver type integrates control logic and output power in a single IC. When using the driver IC, one must provide two sources of power, which are Vss to pin 16 and Vs to pin 8. In this case, the first source is connected to +12V to operate the motors, while the second is connected to +5 volt to operate the IC logic. To ensure a stable ground connection, the GND pins 4, 5, 12, and 13 are all connected to the GND of the Arduino Uno. IN1, IN2, IN3, and IN4 input pins of the L293D (which are connected to digital pins 4, 5, 6, and 7) control the motor's movement. The first DC motor is driven by OUT1 and OUT2, while OUT3 and OUT4 are used for the second DC motor. This step makes it possible to control the motors bidirectionally and make them turn both forward and backward. The alarm system is built into the system. It is connected to the Arduino Uno in such a way that the positive terminal is connected to digital pin 3, and the negative pin is connected to the GND. When specific configurations are triggered, including gas concentration detection, temperature or humidity changes, or specific messages from the LoRa module, the Arduino turns on the alarm, and the sound can be heard from the connected speakers. The hardware connections of the router node have the following elements in Figure 4. In this circuit, the main microcontroller is the NodeMCU V3, which is powered by a 9 V battery. The battery's positive terminal is properly connected to the Vin pin of the NodeMCU, and the negative terminal is attached to the GND pin. This arrangement allows for appropriate powering of the board. Furthermore, NodeMCU also takes charge of communication with the LoRa RF module alongside processing the input signals received from the keypad. The LoRa RF Module allows for wireless communication via long-distance signals. With this, the communication range is significantly increased. The module requires a 3.3 V power supply, so its Vcc pin is attached to the 3.3 V pin of the NodeMCU. The GND pin of the LoRa module is then connected to the GND of NodeMCU. The communication between the module and the board is performed using the SPI protocol. The pins MISO, MOSI, and SCLK are connected to D9, D8, and D7, and the NSS pin is connected to D6. The DIO0 pin is connected to the D5, and the RST pin is connected to the D4.

In this system, a keypad is also included in the circuit for user input. Each of the buttons is attached to separate digital input pins of the NodeMCU. The first button connects to D0, the second button connects to

D1, the third button to D2, and the last button to D3. By pressing the button, it forms contact with GND, and the NodeMCU was able to determine the input signal. This configuration makes it possible for the end-user to issue commands and control functions remotely using the LoRa module.

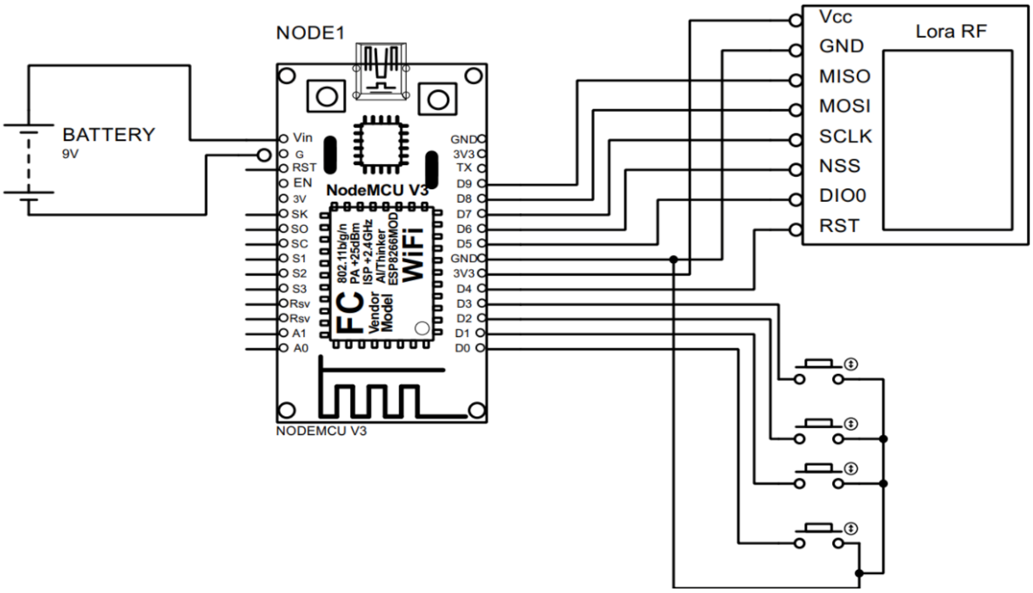

Figure 4. Connection diagram of router node

4. RESULTS AND DISCUSSION

LoRa LPG detector bot's working principle revolves around gas leakage detection and alarming relevant personnel, which is achieved through a set of sequential tasks. Some environmental conditions that need to be monitored are captured by the sensors mounted on the bot. Most importantly, the system has been designed to function with a greater degree of autonomy, which means that the system does not require constant monitoring with regard to information collection or sending, therefore, broadening the scope of the system to areas that can be classified as semi-hostile. It starts with the phase of acquiring data that is carried out by the sensors, which measure the concentration of LPG, temperature, and humidity in the vicinity. The MQ2 sensor gases specifically measure the concentration of LPG vapor in the air, and an electric current is generated in direct proportion to the volume of gas present. This signal gets transmitted to a microcontroller mounted onboard. This microcontroller is programmed to continually compare these values to preset limits. Furthermore, temperature and humidity sensors provide more data regarding the setting, which is important for the assessment of a risk environment because the gas and its detection are affected by certain environment conditions. Figure 5 illustrates the hardware arrangement used in the LoRa LPG detector bot.

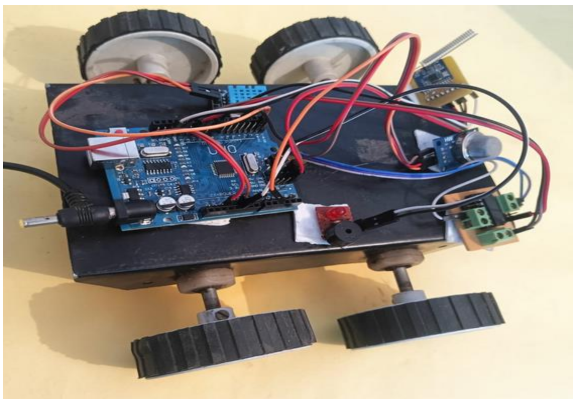

Figure 5. Hardware setup used in Lora LPG detector bot

As soon as the information is collected, the system moves on to the stage of processing the data, making decisions, and taking actions. At this point, the microcontroller processes the available information and establishes whether the levels of LPG have increased beyond the desired markers. If the concentration of gases is under parametric limits, the bot remains passive and goes on observing the situation. However, in the event that the gas level exceeds the limit, the microcontroller is programmed to react to a series of events. First, the microphone is used to set off the buzzer in a vicinity, which causes a loud sound in the presence of people, informing them of the danger immediately. The local alert system guarantees that there is no need to stay connected over a distance in order for people close to the area to be warned about possible threats. At the same time, the microcontroller goes on to the communication stage as the information has been sent via the LoRa RF chip to a remote unit, which is the router node. With the LoRa communication standard, it is possible to build particular networks of devices with considerable distance between each other, with low power in transmitting the information which is required in regions that are not close to the areas where the bot is situated. Thus, all monitoring stations obtain information instantaneously, even though there are great distances or barriers that would obstruct typical wireless connections. The system's communication range varies from 500 m to 15 km, depending upon the conditions, where 15 km is in ideal conditions, but in urban environments with obstacles, it may drop to 500 m. Latency typically ranges from 1 to 2 seconds, ensuring near-real-time response. Detection accuracy reaches up to 95%, though it may decrease to 85% in challenging conditions or with sensor calibration issues.

The LPG detection system comprises the router node as the central control and communication center, which in this case is the LoRa LPG detector bot, and relays this data to the hosted platform. This includes receiving commands, processing them, or relaying them further while still permitting limited interactivity from the user via the keypad. The functional router node characteristic is aimed to facilitate ease in the integration of sensor data from the user into the cloud for easy remote access, as well as provide a sustainable and self-contained safety monitoring system. The process starts from the data reception stage, whereby the router node cellular module is able to receive signals from the detector bot. Ordinarily, this data comprises the LoRa and numerous environmental and LPG concentration readings, which are performed by one of the sensors incorporated on the bot. So, with LoRa technology, the router node can conduct long-range communication and is able to interface with the detector bot over great distances. Figure 6 depicts the hardware configuration of the router node.

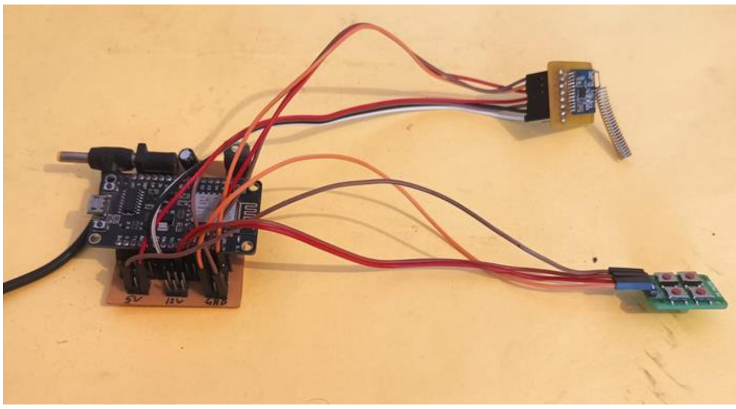

Figure 6. Hardware setup used in router node

The next step involves the router node transferring to data processing upon acquisition of the information. The node microcontroller unit mounted within the node actively assists with the relevant information uploaded to the cloud. Modify the content for proper integration with the Blynk cloud interface by the node microcontroller unit, which in this case acts as a data processor and integrations with the Blynk cloud. Router node enables the clients' monitoring interface with the aid of cloud computing technology to be updated and integrated to close to real-time performance. The next step will be the lawn engine head data upload. The next step for the resource center is to use the node microcontroller unit wireless transmission module to upload the information to the cloud. Through the router node, the concentration of liquefied petroleum gas Eluc's and relevant environmental parameters can be sent remotely by a user using a mobile phone or web interface. Images of the information are uploaded to the clouds for advanced state notification. This feature is crucial in allowing users to act quickly and counteract any threats that may arise. The router node uploads the images in real time, which allows effective permanent monitoring to be achieved. Because of this, it enables the users to be further removed from the system without losing control of it. Users who are locally near the system can do some communicator activities such as changing the worth of the alarm, accepting the alarm, or getting summary info. This feature is crucial because it allows the system to be locally exposed even in the absence of an internet connection. In cases where the internet is completely unavailable, the system nodes can still allow users to change parameters, access information, and operate the system effectively. Because of this, ordinary users won't be helpless and will be able to circumvent the problems with the internet connection. The capability of the LoRa module to communicate over long distances made it possible for the detector bot to work efficiently over distances without any difficulty in data transmission to the router node. Connections between the device and the Blynk cloud make it remotely accessible, with an easy-to-use platform for users to monitor gas concentration, temperature, and humidity, as Blynk dashboard in Figure 7.

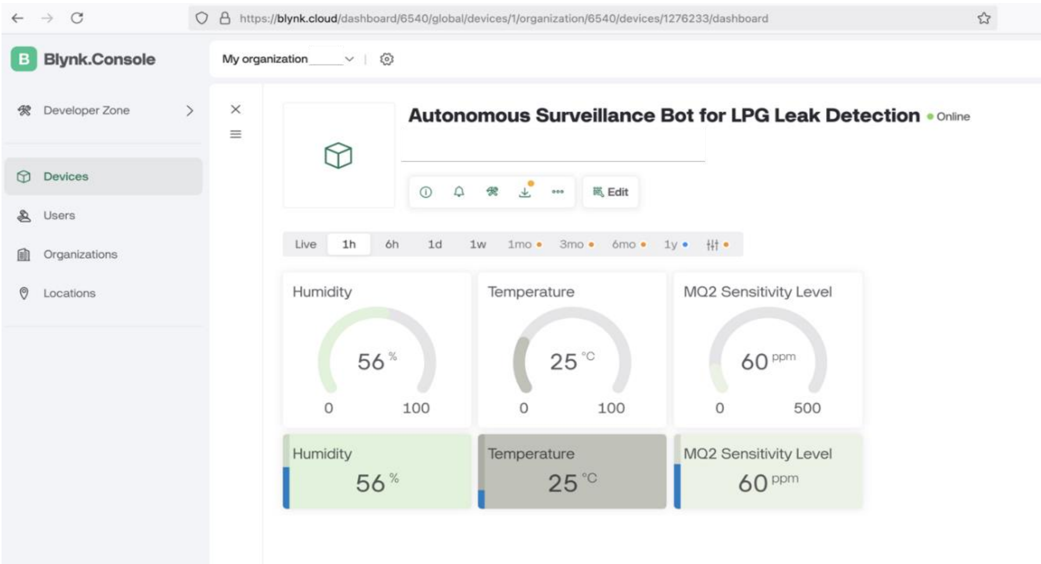

Figure 7. Blynk dashboard used for this system

5. CONCLUSION

The IoT-based worker's health monitoring system is a really interesting method of improving health and safety practices in industrial and large-scale environments. Such a system makes use of IoT technologies, wireless communications to gather and process data in real time, and ensures that the health of workers is monitored 24/7 to almost eliminate the risk of unmonitored health incidents. This system improved health in anticipation of the health needs of the workers, with particular attention to the industries with environmentally hazardous or physically demanding jobs. The system also allows for both on-site and off-site monitoring of the employee's health, enabling quick intervention by the supervisors and the health practitioner's day complications are avoided. Additional benefits of this system, like integration of cloud for storage and complete tracking of the user's location, make this a fully autonomous health monitoring system. The applications and advancement of this technology have a wide scope in the long and short terms. Since safety and health are still a big diva in any industry, this system can be applied and adapted in a number of areas like construction, mining, manufacturing, and even healthcare. The later versions of this system may contain better sensors which would be able to monitor more parameters, such as blood oxygen saturation and respiratory rate, work any time of the day. Moreover, the system itself could also incorporate machine learning, where consistent changes in the analyzed health data could activate alarms warning the person of potential adverse health conditions. Another really fascinating direction to pursue is the production of devices that could be worn by employees and used to monitor their health parameters during the entire duration of the work shift.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Rajesh Singh	✓	✓			✓				✓	✓				
Anita Gehlot	✓	✓			✓				✓	✓				
Rahul Mahala		✓			✓			✓		✓				
Vivek Kumar Singh		✓			✓					✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest relevant to this study.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Rajesh Singh is currently associated with Uttaranchal University as professor & director (R&I) with more than seventeen years of experience in academics. He has been featured among the top ten inventors for ten years, 2010-2020, by Clarivate Analytics in "India's Innovation Synopsis" in March 2021 for filing 358 patents. He has published more than 100 research papers in SCI/Scopus journals. He has published thirty-four books in the area of embedded systems and Internet of Things with reputed international publishers. He can be contacted at drrajeshsingh004@gmail.com.

Anita Gehlot is currently associated with Uttaranchal University as Professor and Head (R&I) with more than fifteen years of experience in academics. She has been featured among the top ten inventors for ten years, 2010-2020, by Clarivate Analytics in "India's Innovation Synopsis" in March 2021 for filing two hundred and sixty-three patents. She has published more than a hundred research papers in SCI/Scopus journals. She has published thirty-four books in the area of embedded systems and Internet of Things with reputed international publishers. She can be contacted at dranitagehlot@gmail.com.

Rahul Mahala has completed B.Sc., LL.B., LL.M., and is currently a Ph.D. Scholar of Law at Uttaranchal University, Dehradun, Uttarakhand, India. He can be contacted at Rahulmahala98@gmail.com.

Vivek Kumar Singh his currently working at Amazon Web Services, Dallas, Texas, United States of America. He can be contacted at wiweq05@gmail.com.