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SYSTEM FOR MONITORING THE PARAMETERS OF POLLUTION FACTORS IN INDUSTRIAL AREAS WITH APPLICATION IN THE JIU VALLEY AREA

NICOLAE PĂTRĂȘCOIU[1], COSMIN RUS[2], CECILIA ROȘULESCU[3], NICOLETA NEGRU [4]

Abstract: In this paper, we propose a solution for monitoring environmental parameters in terms of air quality. Once the data is acquired using air quality sensors, it is sent using a higher-level LoRa radio communication, where it is processed and potential alerts can be issued to exceed certain critical value thresholds. Monitoring environmental parameters in industrial assets which are potential sources of pollution, especially in the mining decommissioned or closed, it is very important to prevent environmental accidents and to ensure a good working environment for workers in a factory located in that area. The entire autonomous system can be located in an industrial hall and in the testing phase has an autonomy of about eight hours.

Keywords: environmental pollution, data acquisition, LoRaWAN, LoRa, air quality

1. INTRODUCTION

For most people, it can be a surprise to find out that the air on an urban street with a level of average car traffic might actually be cleaner than the air at work or home. Most studies indicate that certain air pollutants may exist in higher concentrations indoors than outdoors. Until recently, significantly less attention has been paid to indoor air pollution, compared to outdoor air pollution, especially that produced by industrial emissions and transportation, but in recent years, however, the threats posed by exposure to indoor air pollution have become more visible [8]. For example, a newly painted house, with new furniture or a workplace where the smell of cleaning products is very strong, draws attention to the harmful health factors. The air quality in our homes, workplaces or other spaces varies considerably, depending on the materials used for the construction of the place, the products used for cleaning and the purpose of the room, as well as the way we use and ventilate the space. Poor indoor air quality can be particularly harmful for vulnerable groups, such as children, the elderly, and those with cardiovascular and chronic diseases, such as asthma. Major indoor air pollutants include, among others, radon (a radioactive gas formed in the ground), cigarette smoke, gases or particles from the combustion of fuels, chemicals and

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[1] *Associate Prof. Eng. Ph.D. at the University of Petroşani, nicolaepatrascoiu@upet.ro*

[2] *Eng.,Ph.D. student at the University of Petroşani, cosminrus@upet*

[3] *Professor, Grigore Geamănu School*

[4] *Ph.D. student, Systems engineering, University of Petrosani, nicoletanegru@upet.ro*

allergens. Pollutants such as carbon monoxide, nitrogen dioxide or volatile organic particles and the like the compounds can be found both outside and inside any place of production. Nowadays, unfortunately, we spend most of our time indoors, in our homes, at work, in schools or in shops. Many atmospheric pollutants can exist in high concentrations in indoor spaces and can cause health problems, such as:

1) Tobacco Smoke

Prolonged exposure to cigarette smoke aggravates respiratory problems, irritates the eyes, in addition to the fact that smoking can cause lung cancer.

2) Allergens

Allergens, including pollen, aggravate respiratory problems and can cause coughing, eye irritation and rashes.

3) Carbon monoxide (CO) and nitrogen dioxide (NOx) can be lethal in high doses in addition to the fact that in low doses can cause headaches, dizziness and nausea. Exposure to NOx causes eye and throat irritation and respiratory distress.

4) Humidity

Exposure to the hundreds of species of bacteria, fungi and mold that can grow indoors when there is high humidity can cause respiratory problems, allergies and asthma.

5) Chemicals

Certain synthetic chemicals used in cleaning products can affect the liver, kidneys and nervous system.

6) Radon

Prolonged exposure to this radioactive gas can affect the lungs and cause lung cancer [2].

As with outside pollution sources, the impact of indoor air pollutants is not limited to the health of factory workers or people in a home. These effects are accompanied by high economic costs. Exposure to tobacco smoke in working environments in the EU was estimated at over 1.5 billion euros direct medical costs and over 1.3 billion euros indirect costs related to productivity losses but for some time some regulations have been legislated that I prohibit smoking in confined spaces. Unfortunately, smoking is not the only source of indoor air pollution. According to several specialized studies, most of the pollutants from outside penetrate our homes and workplaces (offices, production rooms), where we spend most of our time. In addition to the influence of external pollution factors, indoor air quality is also affected by other factors, including cooking, heating using wood stoves, scented candles, use of chemical cleaning products, wax and lacquers for cleaning and maintenance of surfaces, use of materials such as formaldehyde plywood and flame retardant plywood. In addition, radon comes from the soil and is found in a small percentage in the building materials. Workers inside a production facility near a source that emits pollution of any kind will have to suffer both because of workplace-specific pollution factors and because of external pollution factors. According to some EU directives, European countries are trying to eliminate some of these sources of indoor air pollution. Attempts are being made to replace toxic substances with non-toxic equivalents and to find technological processes that reduce emissions, such as reducing formaldehyde emissions resulting from plywood processing. Radon-emitting building materials have been widely used in the past, but their use has been gradually restricted. The adoption of laws against pollution by all the states of the world is not the only way to improve the quality of the air we all breathe, because we can take measures to control and reduce the particles and chemicals in the air in the interior spaces where we are. Small actions, such as ventilation of enclosed spaces or elimination of obvious pollution sources, can help to improve the quality of the air at home or in the workplace. However, some of our well-intentioned actions can have negative effects. Ventilation is necessary, but not excessive, because it means a substantial loss of thermal energy from the inside, which leads to increased use of heating equipment, which leads indirectly to pollution. Another idea that needs to be emphasized is that of electric cars. It is true, electric cars do not emit any pollutant emissions, but it is known that a large amount of pollution results in the production of electricity if the entire process is made with fossil fuels [9].

2. PROBLEM FORMULATION

Indoor air quality - is a term that refers to the air quality inside the buildings, with an emphasis on the health and comfort of the people in those areas. The air quality inside any production facility can be affected by both different harmful gases and microbial contaminants (mold, bacteria). Source control, proper filtration and efficient and intelligent use of ventilation contribute to the reduction of harmful factors to the limits provided by local and international regulations. Also, the daily, periodic and periodically cleaned operations increase the quality of the indoor air, significantly reducing the presence of pathogens on and from areas with heavy traffic, carpets, carpets or sanitary spaces. Determining indoor air quality involves collecting air samples, monitoring human exposure to polluting substances, collecting samples from various surfaces and areas of buildings, receiving consistent support from computer modeling of air flows inside buildings. In this context, the correct maintenance, complete and well periodized of the thermal equipment, air conditioning and ventilation - are extremely important, and the rhythmic cleaning and disinfection of them, of the segments of pipes, of the fan-convectors, etc. they become essential in ensuring the comfort of the employees working in the respective spaces [4].

Petrosani municipality of Hunedoara, Romania, located in the coal basin of the Jiu Valley is recognized as a polluted city to a lesser or greater extent due to the use of coal as a thermal agent. Against the background of the mining closures, few are beginning to appear, companies that have other fields of activity and carry out their technological chain in the halls near the former mining operations, the workers of these companies are subjected to the interior spaces of the work places to the external pollution that inevitably enter the interior. On the other hand, the inhabitants of the area still use a lot of coal for heating their homes and this fact together with the pollution produced by the mining activities combined with the atmospheric pollution due to the increase of the number of vehicles in the city produces significant pollution that not only affects the exterior but also the interior spaces specific to a industrial buildings. The problem of setting up systems for monitoring the temperature, humidity and air quality in an industrial premises, especially in its interior spaces, is posed. This system must be cheap and reliable, having a modular structure. Once installed the system for monitoring the parameters of the air must be able to realize an alarm system in case of exceeding certain safe thresholds for the instructors in an industrial hall for example. Thus, an algorithm for the control of some fans can be made based on the data collected with the monitoring system. And just the presence of a monitoring system that only collects data on air quality and emits alarms especially from inside an industrial hall is better than nothing at least so the workers can go outside the production hall until the concentration values drop.

3. PROBLEM SOLUTION

It is proposed to create a wireless network of sensors that communicate with each other and together to send the collected data to a central device which in turn sends the data to an application server, where to manage this data and to issue any decisions. This type of wireless communication is best suited to LoRa technology.

LoRa is a technology that puts at the disposal of intelligent solution developers a long-range and secure data transmission, with low energy consumption. Public and private networks using LoRa technology may provide greater coverage than existing cellular networks. It is an easy-to-connect technology to any existing infrastructure. LoRa uses unlicensed gigahertz radio frequency bands, such as 433 MHz, 868 MHz and 915 MHz. LoRa operates within the LoRaWAN network. LoRaWAN is a radio transmission protocol through which networks of intelligent objects are formed, with Media Access Control (Mac) level for managing communication between LPWAN gateways and end node devices, and defines the communication protocol and system architecture for a network of the Internet of Things, while the physical components of LoRa allow long-distance communication [1].

A generic LoRaWAN network architecture [1] consists of:

1. Nodes: It are the parts of the LoRa network that monitor and control the supervised infrastructure (parking sensors, smart meters, remote management devices for lighting systems, etc.). These are usually remote [1].
2. LoRa Gateway: This is the access gateway through which data is received from nodes through the LoRaWAN protocol and then transferred through a TCP / IP connection to the network server. The connection to the LoRa network server can be ethernet, cellular or any other wired or wireless telecommunication connection that provides internet connection. Because a LoRa network resembles a telephone communication network, LoRa central stations can be mounted near the base of a telephone base station. Thus, they

can use the backup capacity of the cellular station to transmit data to the network server [1].

3. Network server: The LoRa network server manages the entire network. The network server removes duplicate packets and controls the data transmission speed. Given all these aspects, the complexity of implementing a LoRa network is very low [1].
4. Application server: The application server can access applications that show data from nodes and display them to provide the information most relevant to the client. LoRa allows bidirectional communication between nodes and the network server, remote commands can be sent to nodes, these commands can help manage nodes, but also control elements in a system with other specific commands [1]. In figure 1 is presented the LoRaWAN architecture.

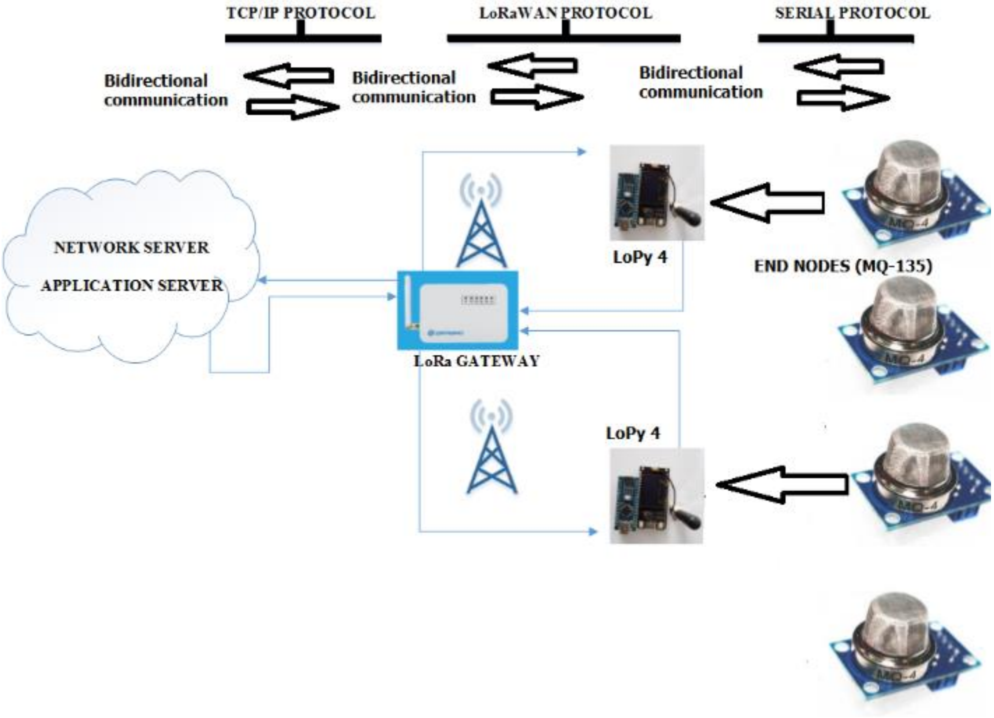


Fig. 1 LoRaWAN architecture

LoRaWAN is a technology that deals with the management of communication frequencies, data transmission rate and transmission power for all network devices that transmit information from connected sensors only when they have data available for transmission. The data transmitted by an end-node device can be received by several gateways that transmit the data packets to a central network server. The network server filters data by removing duplicate packets, performs security checks, and manages the entire network. The data is then transmitted to the application servers.

LoRaWAN has three different classes of end devices to meet the different needs of each application:

- Class A, bidirectional: The final devices of class A can program the transmission upstream based on their own needs, with a small error. This class of devices allows two-way communication. Class A devices have the lowest power consumption.
- Class B, bidirectional with scheduled reception slots: The final devices in class B initialize the reception sequence at scheduled times. Therefore, it is necessary to have a base synchronized with the gateway device, so that the network server knows when listening to the final device.
- Class C, bidirectional with maximum reception slots: The final devices of class C have almost continuous reception windows. Therefore, they have a maximum energy consumption [1].

An Arduino Uno development board, a Dragino gateway and a LoPy 4 shield equipped with an 868MHz LoRa radio module were used to achieve the IoT system. The LoPy 4 (fig. 2) is a miniature development board dedicated to connected objects, based on the Python language, low consumption and having WiFi, Bluetooth (BLE compatible), LoRa and Sigfox connectivity. This module is an evolution of LoPy 1.0. It increases the communication possibilities for all connected object projects by adding a Sigfox module with UFL connector for external antenna. This board works autonomously by executing a MicroPython program stored in its internal memory or can be controlled by command line (REPL) via the WiFi link. The LoRa and Sigfox protocols make it possible to establish wireless, low-speed, long-range links dedicated to connected objects. They use a frequency of 868 MHz in Europe, are easier to configure and consume less energy than a conventional WiFi connection. The LoPy 4 has 24 input / output pins (I2C, UART, PWM, etc.) allowing the realization of connected projects with different sensors and modules [5].

Fig. 2 LoPy 4 development board used

Like one WiPy module, the LoPy 4 board works in several modes:

- by Wifi by directly sending command lines in Python to be executed via a serial terminal (via Telnet or with PuTTY software for example).

- by Wifi by manually choosing the Python program to run via the terminal.
- in standalone by executing the Python program boot.py then main.py stored in internal memory.

It will be further exemplified by taking the temperature data from an enclosure using a DHT11 sensor connected to the end-node device. The DHT11 sensor is a sensor that can measure temperature and humidity. The temperature data is obtained with a thermistor and the relative humidity with a capacitive sensor. All these elements are pre-calibrated and the output is analog. The DHT11 temperature and humidity sensor, although very convenient, does not provide good accuracy but is easy to use and small in size. Even if this type of sensor does not present a particular accuracy it can be used for testing different monitoring and control systems especially in spaces where it is necessary to know these parameters in real time. An air quality sensor MQ-135 was used to check the air quality [3]. An MQ-135 type sensor was used to monitor air quality. The principle of catalytic measurement is very appropriate and very often used for the detection of volatile organic compounds (VOC), represented by gases and combustible vapors. One of the techniques used for VOC detection involves passing the gas sample onto the surface of a semiconductor material, which is maintained at a constant temperature. Adsorption of gas molecules on the surface of the semiconductor changes its electrical conductivity. Although this type of sensor does not present an extremely high accuracy, it can be used successfully to implement any kind of monitoring system due to the low price and ease of use. In fig. 3 is represented the catalytic solid-state sensor.

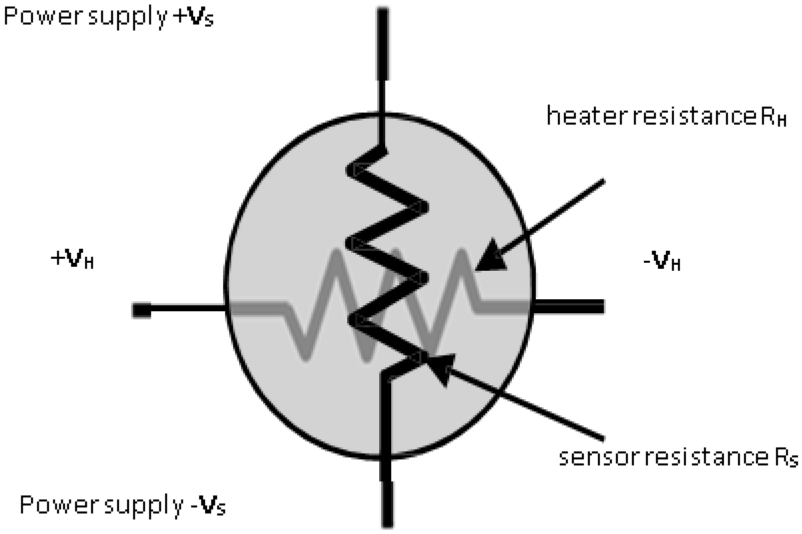


Fig. 3 Catalytic solid-state sensor

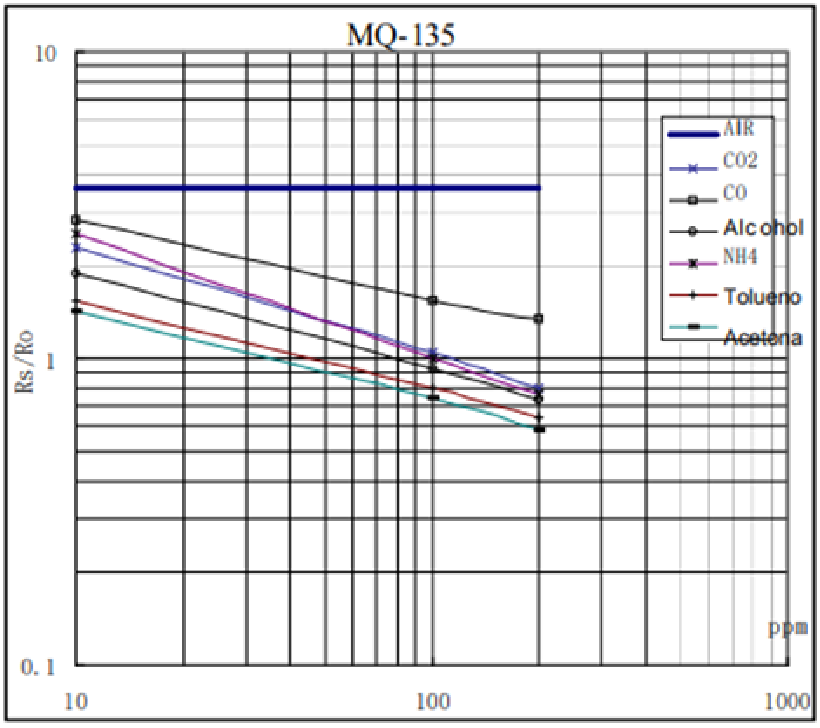


Fig. 4 Sensitivity characteristics of the MQ-135

The selectivity of the gas to be detected can be achieved by choosing the semiconductor and the operating temperature. However, filters are needed to avoid interference or alteration of results due to other airborne pollutants. The relationship between sensor resistance and gas concentration can be expressed by the following equation (1):

$$R_S = A * [C]^{-a} \tag{1}$$

where: R_S represent electrical resistance of the sensor, [C] represent gas concentration, A represents a sensor construction constant and a is the slope of R_S curve.

The MQ-135 gas sensor is commonly used in air quality control equipment and is suitable for detecting or measuring concentrations of NH_3, NO_x, alcohol, benzene, smoke, CO_2. The MQ-135 sensor also features a digital pin that makes it possible for this sensor to work even without a microcontroller and can be used even when trying to detect only a particular gas. If the air pollutant concentration is measured and this value is expressed in parts per million (ppm), the analog pin must be used. The MQ-135 gas sensor uses SnO_2 which has a higher air resistance as a sensitive material. When there is an increase of polluting gases, the electrical resistance of the gas sensor decreases with increasing concentrations. In order to measure using ppm units, the PPM graph (Rs/Ro) explained in the sensor data sheet must be analyzed. The graph shown in fig. 4 shows the typical sensitivity characteristics of the MQ-135 for several gases at 20 degrees Celsius, humidity of 65%, O_2 concentration 21% and load resistance (R_L) 20kΩ [3].

The Ro value represents the value of the resistance in the fresh air (or the air with which we compare - the sensor resistance at 100 ppm NH3), and the value of Rs represents the value of the resistance in the gas concentration. First, the sensor must be calibrated by finding the Ro value in the fresh air and then using this value, Rs can be calculated using a specific formula. Once Rs and Ro are calculated, the ratio of the two values is then calculated and then using the graph shown in fig. 5, the equivalent value of ppm for the respective gas can be calculated.

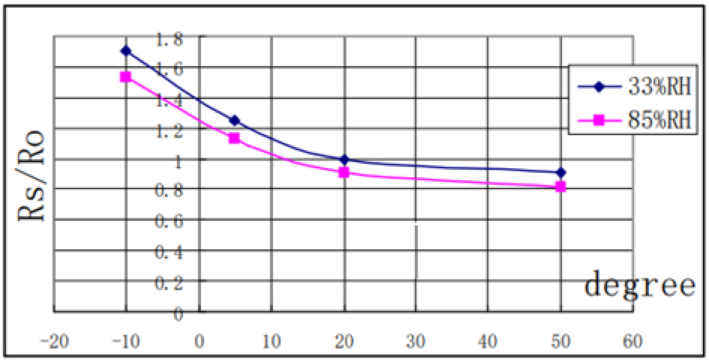
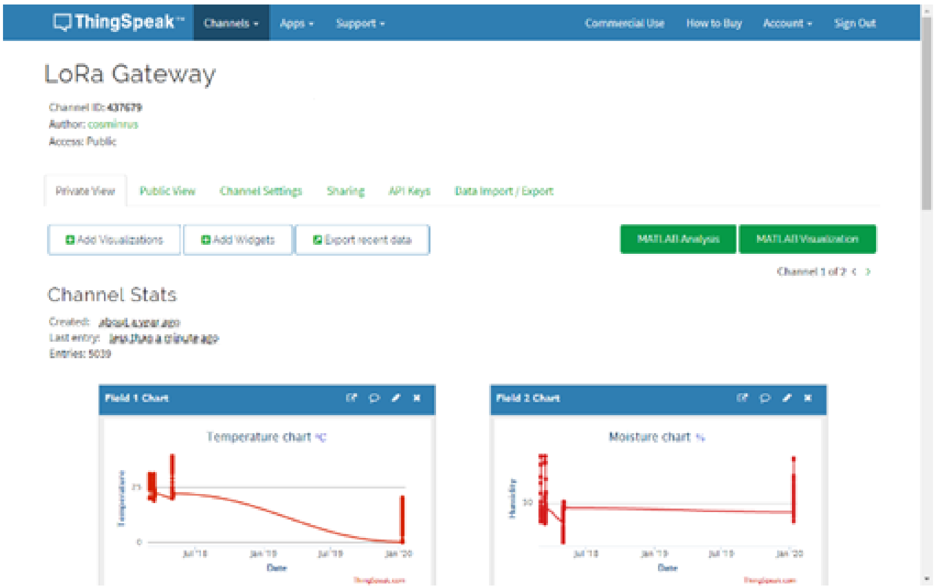


Fig. 5 The dependence of the MQ-135 on temperature and humidity

The Arduino IDE with the Dragino Yun extension installed as well as the specific LoRa libraries were used to perform and test the system. LoPy 4 development boards have been programmed into Python. The system will report to the IoT ThingSpeak service the purchased values (temperature, humidity and the concentration of the polluted compounds monitored) as well as the battery voltage supplying the system. The Arduino program implements both the acquisition part and the network transmission part through the LoRa communication. Within the source code the value of the key parameter that is obtained from free registration on the ThingSpeak site must be customized. The acquisition and the reporting are done at an interval that can be modified according to preference, in the interval of inactivity the LoRa module is in low consumption mode. Our system is a typical IoT system that uses the ThingSpeak online platform. This device is connected using a serial connection to observe that the data collected by the sensors reaches the gateway device in the first phase and then to the ThingSpeak platform.

The ThingSpeak platform is one of the most popular IoT platforms that offers data storage, processing and visualization services. One of the major advantages of the platform is the possibility to execute programs written in the Matlab language [6].

LoRaWAN protocol is designed to meet the basic requirements that characterize an IoT system: two-way communication, mobility and location services. This standard allows uninterrupted operation without complex installation, providing freedom and flexibility in the development of IoT applications [7]. In fig. 7 is represented the public ThingSpeak channel created for this monitoring system. The channel id is 437679. This channel has been operating since June 2018 and has been used for several IoT applications in research conducted at the University of Petrosani. It can also see in fig. 6 the graphs of temperature and humidity in the test location during a period that over a year [10]. This indoor air quality monitoring system is implemented and has been functionally validated for over 1 year. It is a reliable and simple to manage system.


LoRa Gateway

Channel ID: 437679
Author: cosminrus
Access: Public

Channel Stats

Created: about a year ago
Last entry: less than a minute ago
Entries: 5039

Fig. 6. ThingSpeak channel with ID 437679 [9]

This monitoring system proved effective in October 2019, more precisely on 26.10.2019, when it detected in an incipient form a fire that appeared in a laboratory of the University of Petrosani, minimizing the damages. The fire had as a starting point a power supply of a computer server, the monitoring system detected the incipient gas emission resulting from the combustion and issued an alert notification after which it could intervene quickly limiting the material damages. Figure 7 shows the collected data that presents the moment of the beginning of the fire from 26.10.2019 in a laboratory of the University of Petroșani following the overheating of a computer power supply. One can see the sudden increase of the concentrations of pollutant emissions from the inside (the emission value reached 200 ppm but at that time no person was in the laboratory), their reduction then gradually, but only after a few hours the reduction was close to zero. It can be concluded that the harmful factors resulting from the release of gases in the absence of adequate ventilation can affect the personnel working inside a production hall many hours after the first detection. Of course, the LoRa system can serve both acquisition systems (temperature, humidity, pressure in various pipes, electricity consumption, level of solar radiation, etc.) but also actuation systems, it is possible to remotely control the various closing / opening mechanisms, engines, ventilation systems, pumps, CO2 tanks in fire extinguishing installations, etc. With the help of the IoT ThingSpeak service (figure 8), a program has also been created that sends commands to close or open a relay that commands a ventilation system inside the enclosure, when large levels of pollutant particle concentrations are detected.

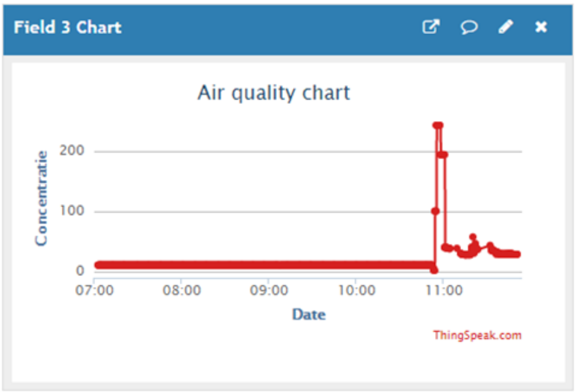


Fig. 7. Air quality chart

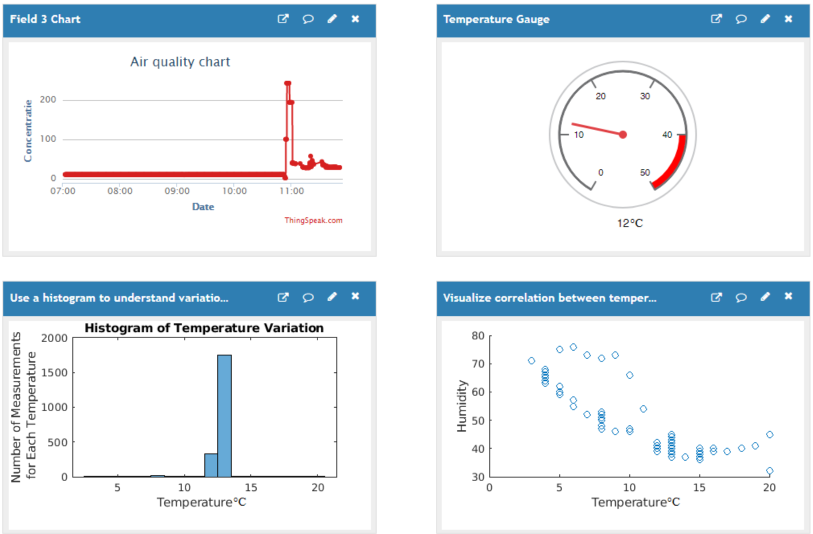


Fig. 8. Monitoring system software interface

Regarding the signal coverage of the LoRa communication network, it can be said that good results were obtained taking into account the resistance structure of the buildings (iron, concrete) and their positioning within a metropolitan area. Following the tests performed in the test laboratories of the University of Petroșani, it was established that the maximum distance up to which end-node devices can communicate with the gateway device is over 250 m, taking into account the internal infrastructure of the building and the density specific to the urban area. A second test was then performed. This experiment aimed to test the coverage of LoRa equipment in the field. The tests were carried out near Petroșani municipality, in an area with residential housing. The temperature was 8°C and the ambient humidity was 55%. The gateway device was located on the second floor of a house and was positioned outside the window. The end-node device was in a vehicle during testing. The transmit power of the end-node device was set to 14 dBm. As with other tests in different works, in order to test the performance of the different scattering factors, the options for confirming and relaying the packages were deactivated. The spread factor did not change, even if there were packet losses. Propagation factors of 7, 9 and 12 were chosen for testing. With reference to other tests published in specialized works [1], 100 packages were sent to the network server for each of the spreading factors used. It was found that the larger spread factors have a much better coverage, for a spread factor of 12, over 80% of the packets were received at a distance of 550 m, while for a spread factor of 7 it did not no package was received (figure 9). These data have been validated by comparison with the data obtained in other specialized works and have obtained approximately the same results [1]. It is worth noting that the gateway device was located on the second floor of the University of Petrosani, which is about 5 m above the ground, although normally such a base station is located at a higher altitude for a better coverage. The test point was 550 meters away just behind a seven-story building. It is important to mention that the purpose of the above tests is to test the coverage of the LoRa physical layer using different spreading factors in the Petroșani area, Hunedoara, Romania (figure 9).

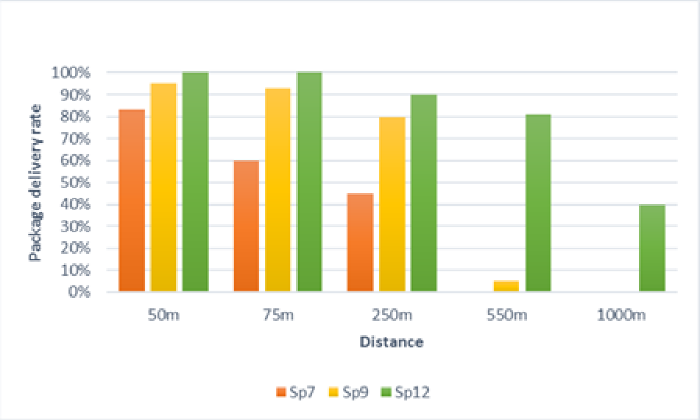


Fig. 9. Package delivery report of different spreading factors at different distances

Typically, in a LoRa type network with the LoRaWAN protocol, end devices can automatically increase the propagation factor if the transmission with the smaller spreading factor fails. Also at the test level was obtained an autonomy of about 8 and a half hours of the monitoring system mounted inside the production hall. Figure 10 shows the test hardware assembly of the monitoring system.

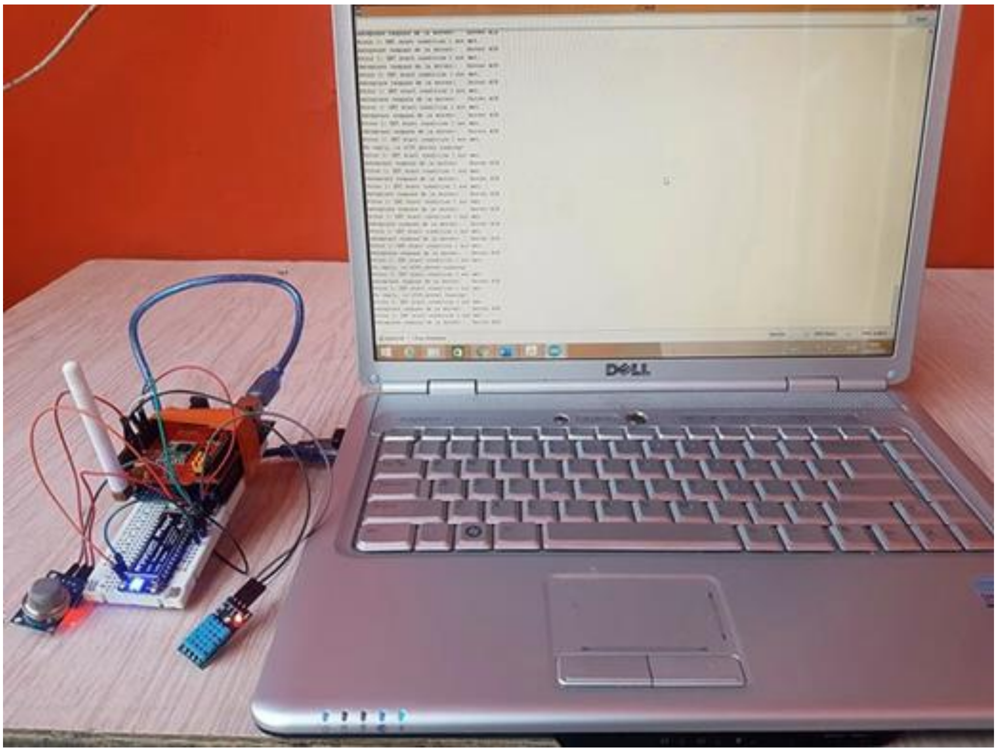


Fig. 10. The end-node device with the sensors connected

This value is very satisfying considering that the system's power supply was made from a cheap 2000mAh battery. This value of autonomy covers the monitoring of air quality during the shift of the working personnel.

4. CONCLUSIONS

Modern technology for data collection and transmission, which does not require cable connections in the served areas is represented in this paper. The system is scalable to a large number of nodes. The communication nodes are independent of classical electricity, which makes them independent of the operating condition of other equipment in the production room or the monitoring site. This feature is very useful for production equipment status monitoring applications. The proposed solution allows the personalization of the received information according to the visualization and format requirements of the content considered optimal. Typically, in a LoRa type network with the LoRaWAN protocol, end devices can automatically increase the propagation factor if the transmission with the smaller spreading factor fails. Also at the test level was obtained an autonomy of about 8 and a half hours of the monitoring system mounted inside the production hall. This value is very satisfying considering that the system's power supply was made from a cheap 2000mAh battery. This value of autonomy covers the monitoring of air quality during the shift of the working personnel.

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