Remote Air Pollution Monitoring System Based on Internet of Things

Andriy Palamar[a], Mikolaj Karpinski[a,b], Mykhaylo Palamar[a], Halyna Osukhivska[a] and Mykola Mytnyk[a]

[a] *Ternopil Ivan Puluj National Technical University, Ruska str., 56, Ternopil, 46001, Ukraine*
[b] *University of Bielsko-Biala, Willowa st. 2, Bielsko-Biala, 43309, Poland*

Abstract

Air pollution influences human activities, leads to global warming, poses a hazard to the ecosystem and life quality on the Earth. To avoid such adverse instability in nature, increasing the efficiency of air pollution monitoring means and methods is extremely important. In this paper the development and implementation of an effective solution for remote air pollution monitoring based on IoT is proposed. The system is developed using the Arduino Leonardo module and Raspberry Pi microcomputer. The concentration level in the air of the LPG, carbon monoxide, methane, and carbon dioxide using MQ2, MQ7, MQ9, and MQ135 gas sensors are measured. These sensors can reveal many hazardous gases and can be used for measuring their quantity very precisely. The air pollution monitoring system measures air quality parameters and transfers them to a cloud server in real-time in order to provide remote access. Experimentation results performed using the designed computerized air quality monitoring system show that it provides a reliable source of real-time air pollution data. The essential aspect of this work is to produce a low-cost infrastructure to enable data aggregation and proliferation to all users.

Keywords

Internet of Things, remote monitoring, microcontroller, Raspberry Pi, microcomputer, ThingSpeak, sensor, air pollution.

1. Introduction

In the last decades, due to urbanization, there has been a large quantity of drastic forest loss, construction waste, major growth in polluting industries and vehicles on roads that has increased the environment pollution level. Current trends in industrial production are characterized by the widespread use of hazardous technologies that cause significant impairment of environmental performance in some regions. In large industrial cities, the air pollution level can significantly exceed sanitary and hygienic standards. According to the World Health Organization, Ukraine was ranked as the country with the highest number of human deaths from air pollution in Europe [1].

Nowadays the environment is harmed due to the bombarding, which leads to explosions, fires, industry and infrastructure destruction, because of the war in Ukraine. The situation may deteriorate due to the high risk of chemical attacks.

The information availability about the air pollution level, as well as trends in its change is extremely important to achieve the desired air quality. Widespread utilization of remote monitoring tools is an effective approach for identifying air pollution sources. Its essence is to determine the concentration level of harmful air substances in real-time. Hence, it is significantly important to continuously monitor

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EMAIL: palamar.andrij@gmail.com (A. Palamar); mkarpinski@ath.bielsko.pl (M. Karpinski); palamar.m.i@gmail.com (M. Palamar); osukhivska@tntu.edu.ua (H. Osukhivska); mytnyk@networkacad.net (M. Mytnyk).
ORCID: 0000-0003-2162-9011 (A. Palamar); 0000-0002-8846-332X (M. Karpinski); 0000-0002-8255-8491 (M. Palamar); 0000-0003-0132-1378 (H. Osukhivska); 0000-0003-3743-6310 (M. Mytnyk).

the air quality, analyze the obtained data and predict the future air pollution level [2] in order to reduce its hazardous impacts on the environment and human health.

The importance of monitoring the air pollution level in the environment is justified by the results of theoretical and experimental studies using physical and mathematical modeling methods. This approach allows us to assess the air quality level in a large city or other facility where there are movable or stationary pollutant sources.

Each year the locations of pollution sources vary and their quantity rises [3]. Due to determining the air pollution level by various harmful substances, and identifying relevant trends in the impurities distribution in time and territory, it will be possible to decide on the necessity to install stationary observation posts in the area and schedule their work. Such observation points will provide monitoring data on the general air condition, check emission sources in their responsibility area.

In order to decrease the environment pollution, scientists and governments have made many efforts for monitoring air pollution and its analysis [4, 5]. However, existing technical means in Ukraine do not fully meet the requirements of air quality monitoring in terms of data acquisition speed and opportunities for their analysis and processing in real time.

On the other hand, nowadays the air pollution level is significantly increasing which demands a more cost effective and portable solution. Therefore, the development of a computerized system for remote air pollution monitoring with small size and low cost is an important task that has determined the direction of this research.

The goal of the work is research and practical implementation of system for remote air pollution monitoring based on Internet of Things.

2. Related works

Many efforts were made by engineers and researchers in the air pollution monitoring domain in order to improve environmental quality. Over the last several decades, there have been published results of many researches on the air quality monitoring approaches. During the scientific literature sources review and analysis, it was found that many scholars conducted research using wireless sensor networks. A number of researches concerning air pollution monitoring using the IoT approach have been established.

The paper [4] presents a comparative review of modern air pollution monitoring systems. The authors reviewed stationary and dynamic monitoring systems as well as methods that are used for pollution data analysis. The systems were compared by the following parameters: gases types that are measured using sensors, transmission data techniques, and methodologies analysis. The benefits and drawbacks of the reviewed systems were discussed.

In [5] has proposed an air pollution monitoring system based on IoT and edge computing concepts. A system hardware prototype using the Arduino module was developed. The measured data is transmitted to the cloud service IBM Watson IoT platform using ESP8266 WiFi module.

The authors in [6, 7] present a system for air pollution monitoring, which was designed using the Arduino platform. The considered system has a possibility of storing the received data on the remote server in real time. The disadvantages of this system are the limited channels number for connecting sensors and the microcontroller low computing power of the Arduino Uno module.

The paper [8] describes a system for air quality monitoring based on IoT. The system uses temperature, humidity and gas sensors to detect and send this data to ESP8266 module, which transfers the obtained data into the web server. The proposed system uses a Recurrent Neural Network based on Long Short Term Memory in order to predict the pollution level in the future. However, the microcontroller of the ESP8266 module has only one channel for connecting analog sensors. This limitation reduces the system functionality.

In [9] the development of an air pollution monitoring system based on Arduino has been described. The authors propose to use fuzzy logic functions implemented in the Arduino microcontroller software, in order to increase the efficiency of determining the air pollution level by the CO and CO_2 gases. However, the system is not able to transmit the monitoring results to a remote web-server, but only displays them on the LCD.

Another interesting implementation is the air quality monitoring system for Smart Cities based on IoT described in [10]. This system uses a Raspberry Pi microcomputer with the MCP3208 analog to digital converter (ADC) to gather data about the air pollution level from the sensors. The Raspberry Pi provides communication with the IoT cloud platform ThingSpeak in order to visualize monitoring results using graphs. Moreover, the data can be displayed using an Android application in a tabular format.

The paper [11] presents a system developed for air pollution monitoring to determine the concentration of NO_2, SO_2, CO_2, CO gases using semiconductor sensors and the Nucleo F401RE board. The authors used the Raspberry Pi platform as a base station for collecting data from the sensors and for creating the web server, designed to display monitoring results.

The authors in [12] have developed an IoT based system, which provides an effective solution to monitor air pollution level using gas and dust sensors. The MCP3008 ADC converts data from the sensors to a digital format and sends them to the ESP8266 microcontroller through the SPI interface. The system uses WiFi and GPS modules to transfer the monitoring results to an IoT-based cloud platform. Furthermore, the various pollutant values have been displayed on Google Map.

The research [13] presents the design and implementation of a vehicular pollution monitoring system based on IoT. The hardware is based on the Arduino platform. RFID technology is used for finding, detecting and tracking vehicles' location. The proposed system also transfers the data of pollutant level to the server for future analysis.

The paper [14] proposes an intelligent and multifunctional IoT-based platform for air pollution monitoring. To improve air quality, a comprehensive network communication infrastructure using NB-IoT technology, a cloud decision-making system, a tracking information system and an online management system have been developed.

The authors in [15] have proposed a solution based on IoT in order to monitor air quality. The system hardware includes the MCP3008 ADC, which is responsible for measuring data using the MQ-3 gas sensor. The Raspberry PI board receives measured data in real time. It is used as a web-server in order to provide remote access to monitoring results through the Internet

Research published in [16] outlines the implementation results of a microprocessor-based air quality monitoring embedded system. The authors propose to use a fog computing approach for collected data processing. The IoT cloud platform is responsible for storing gathered data from end devices, making analysis and providing analytic results.

The research [17] presents a three-level air pollution monitoring system based on IoT, which receives data using gas sensors connected to an Arduino board and transfers them to the cloud using a WiFi module. The authors developed the Android application "IoT-Mobair" in order to provide relevant information about air quality to the customers.

The paper [18] describes a system for pollution monitoring which has the possibility to reduce traffic in highly polluted locations on roads. The PIC16F877A microcontroller and the ESP8266 module are used for measuring and transmitting data to the remote server for traffic control purposes. A mobile application, which displays information about air quality, is developed.

In [19] a system for monitoring carbon monoxide and carbon dioxide level in the air has been proposed. The BeagleBone Black module is used to measure the data and their transferring to the Microsoft Azure cloud service using IoT. The designed system can predict the air pollution level using machine learning in order to reduce the pollution effect on the environment.

The authors in [20] have described a monitoring air pollution system that has the ability to create awareness among the public by using IoT and android application. The proposed system uses an Arduino module, which receives data from the sensors and sends them to the cloud using an Ethernet shield. However, such a hardware solution has a significant limitation of the inability to transfer data using a wireless approach directly to the cloud.

The paper [21] presents an air pollution monitoring system, which operates in real-time. The proposed system can significantly decrease the hardware cost by using IoT. Unfortunately, the authors did not describe in detail hardware features of the system in the article. The designed system has the ability to make forecasts using artificial neural network. However, it requires a large number of measurement results from recent years as the input data.

The literature review and analysis on the topic revealed that existing air quality control systems still have a number of limitations and disadvantages. Existing air monitoring systems have relatively high cost, complex equipment technology, unstable operation, and require laboratory analysis. These factors make it impossible for their large-scale deployment. Consequently, the task of further development and implementation of new modern solutions for improving an air pollution monitoring process is relevant.

3. System structure

To overcome the problems and limitations of the existing systems, the authors of the paper propose a remote air pollution monitoring system based on the Internet of Things. The significance of the Internet of Things (IoT) has been increasing rapidly in the last decade. IoT is a global concept of “smart devices” that can measure and connect with their environment and interact with other systems and users [8]. IoT nowadays generates a great data amount by the myriads of connected devices, including microcontrollers and sensors, that are commonly accumulated and stored on cloud platforms [22]. The proposed system architecture for remote air pollution monitoring system based on the IoT concept is shown in Figure 1.

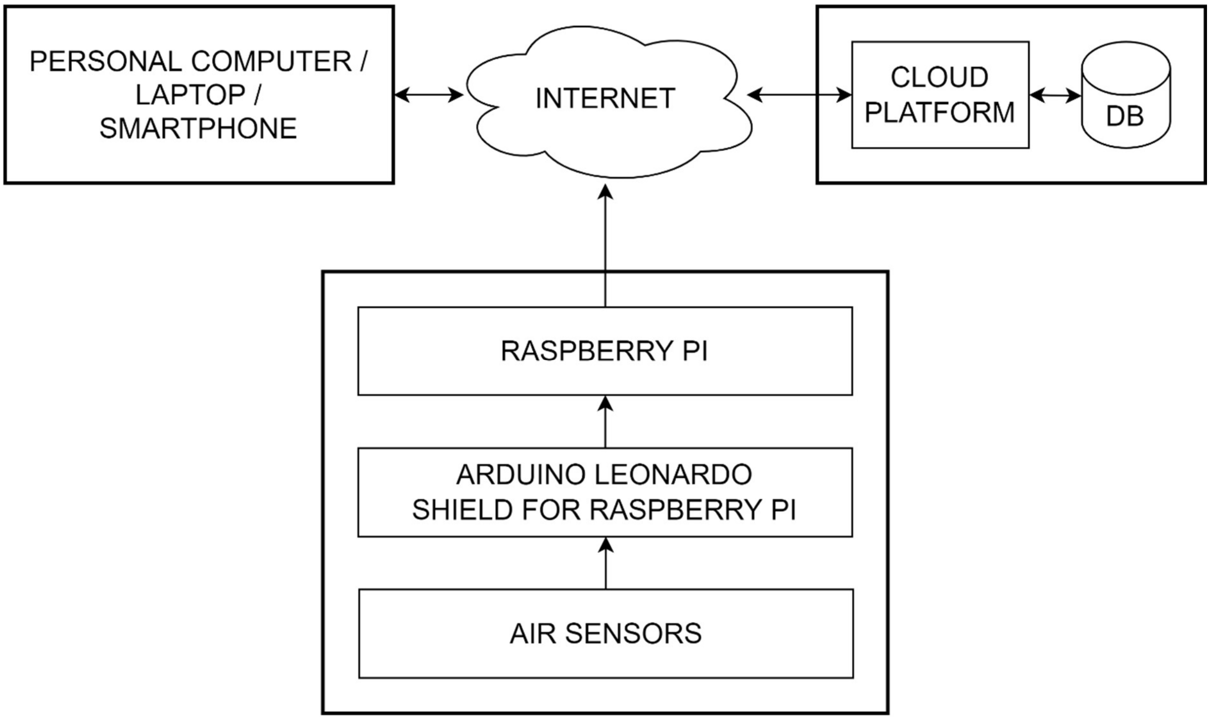

Figure 1: Air pollution monitoring system architecture

The proposed system includes the following main components:

- gas sensors
- microcontroller-based Arduino Leonardo shield
- microcomputer Raspberry Pi
- cloud platform

The gas sensors are responsible for measuring the harmful gases concentrations in the air. They are connected to the Arduino Leonardo shield, which is based on the Atmega32u4 microcontroller. The Raspberry Pi module is used as the gateway of the computing node in the designed IoT system. It receives the measured results from the microcontroller and transmits them to a remote server. The cloud IoT-based platform is used to store the measurement results for further processing and analyzing and display them in the form of graphs.

4. System implementation

4.1. Hardware prototype

A block diagram of the proposed information-measuring system for air quality monitoring is depicted in Figure 2.

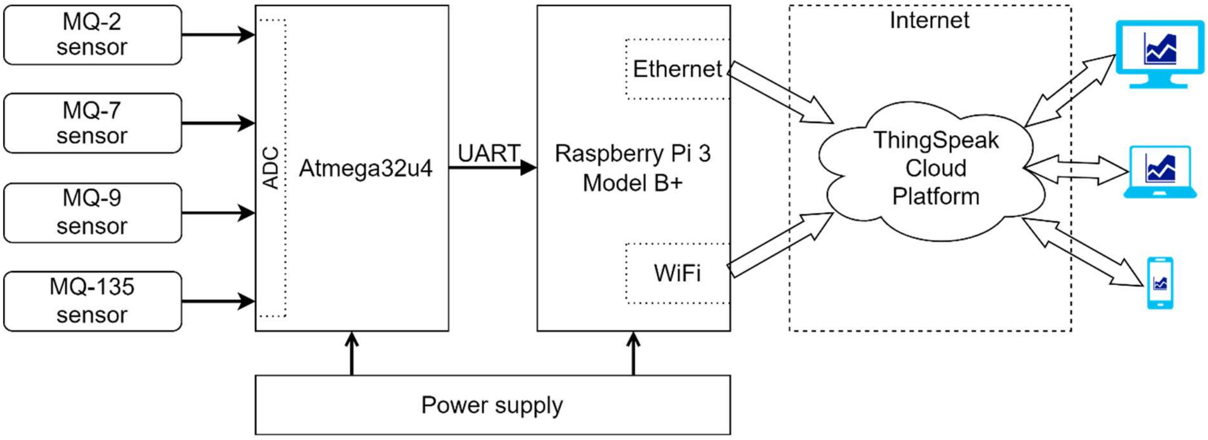

Figure 2: Structure of air pollution monitoring system

The main component of the air pollution monitoring system is the IoT-based measuring device, which obtains data from the gas sensors and transfers it via Ethernet or Wi-Fi to the cloud platform. Sensors are one of the IoT system key components that are used to detect changes in the environment and collect relevant data [23].

The device uses gas sensors MQ-2, MQ-7, MQ-9, and MQ-135 that are responsible for measuring the concentrations of the following gases in the air:

- liquefied petroleum gas (LPG)
- carbon monoxide (CO)
- methane (CH_4)
- carbon dioxide (CO_2)

The choice of these sensors was determined by the optimal ratio of their cost and measurement accuracy. In addition, they provide high performance and calibration capability. The proposed system obtains inputs from the sensors that measure the gases concentrations. These received input signals are converted to the digital form using inbuilt ADC with 10-bit resolution of the Atmega32u4 microcontroller.

The microcontroller transmits the measured data to the Raspberry Pi via UART interface. The microcomputer sends them through the IP network (WiFi or Ethernet) to the IoT cloud platform ThingSpeak for storing and online monitoring.

The Arduino Leonardo shield in this project is responsible for measuring air pollution level by using analog gas sensors. The Raspberry Pi microcomputer is used as an IoT gateway to provide the measurement results transmission to a remote cloud server. It provides general management of all system operation modes related to data transmission. The Raspberry Pi is responsible for receiving information from the Arduino Leonardo shield and for the data sending process to a remote cloud platform using the TCP / IP protocol.

The Raspberry Pi is a credit card-sized microcomputer that runs on a Linux-based operating system. It provides affordable solutions for wireless monitoring. In the project, authors use the Raspberry Pi 3 model B+, which has a quad-core 64-bit ARM Cortex A53 microprocessor with 1.2 GHz, 1 GB of SDRAM, and built-in Bluetooth and Wi-Fi modules. Micro SD memory card of 16 GB is used as a ROM for the microcomputer.

An electrical scheme of the monitoring unit based on the Raspberry Pi microcomputer and the Arduino Leonardo module has been developed. The device was prototyped based on the electrical scheme. A connection diagram of hardware components is shown in Figure 3.

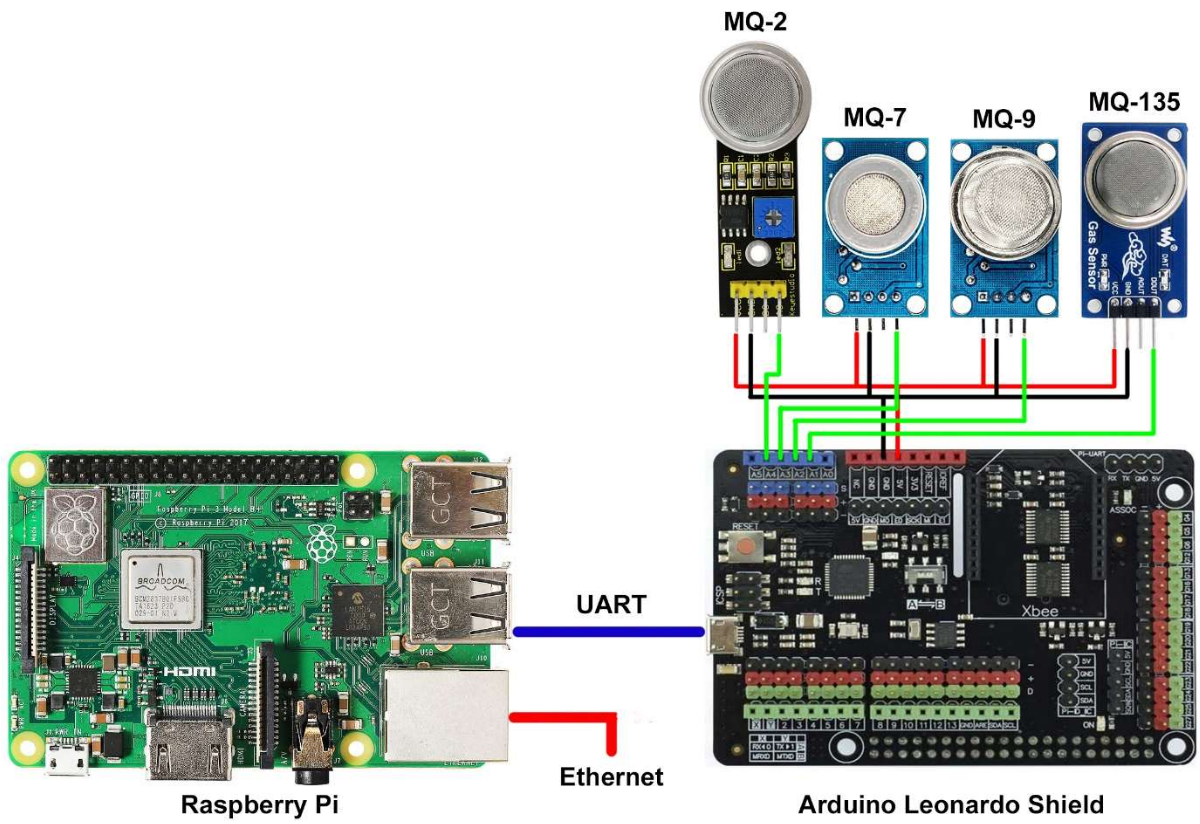

Figure 3: Connection diagram of hardware components

The Raspberry Pi 3 has a connector consisting of forty general-purpose digital pins. It is used to connect the Arduino Leonardo shield. The microcomputer provides the possibility to transfer data using Ethernet or WiFi technology, which is one of the main requirements for the designed system.

The Arduino Leonardo module is one of the most important hardware components of the air quality monitoring system based on the Atmega32u4 microcontroller. The design of the system assumes that the Arduino Leonardo module will be connected to the Raspberry Pi and communicate with it via a UART interface. The Raspberry Pi connects to an external AC/DC adapter that generates a power of +5 V, which is connected via the microUSB.

The air quality sensor modules are installed on the solderless breadboard. They are connected to the analog inputs of the Arduino Leonardo shield. During the development of the proposed system, the challenge was to combine the Arduino Leonardo and Raspberry Pi in one device to take advantage of both platforms. This prototype includes the microcontroller-based Arduino module using its real-time capabilities. On the other hand, the data processes and transfers via the Internet by the Raspberry Pi using its computing and networking capabilities. Thus, computational and communication tasks performed by the Raspberry Pi and monitoring tasks performed by the Arduino Leonardo will be separated in order to use the benefits of the both platforms.

4.2. Software implementation

In the designed system the software consists of two parts. The first part is the firmware designed to manage the Atmega32u4 microcontroller, which is the core of the Arduino Leonardo module. It is written by using the C++ programming language in the Arduino IDE. The second software part of the designed system is written for Raspberry Pi microcomputer using Python programming language in the Thonny IDE. It is responsible for receiving data from the Arduino, converting them to a convenient form, and transferring them to a remote cloud server using REST API. A flowchart of the algorithm for obtaining and transmitting data to the IoT platform is presented in Figure 4.

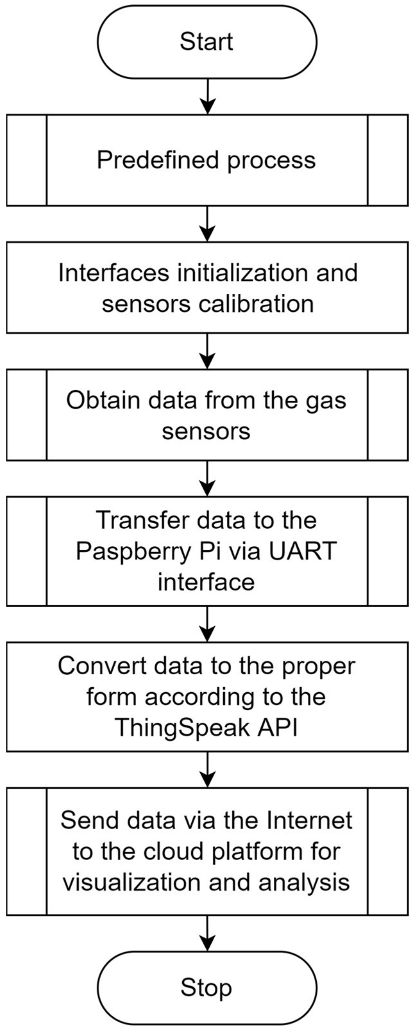

Figure 4: Flowchart of the algorithm for obtaining and transmitting data to the IoT platform

After turning on the device, the first step is to connect libraries, configure interfaces, and microcontroller pins, and initialize variables and constants. During the second step, the gas sensors calibration functions execute. The microcontroller receives data from the sensors in a loop, obtaining information on the concentration level of LPG, carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), and other harmful gases in the air. The measured data are multiplied by the appropriate coefficients to obtain real numerical values in parts per million (ppm). In the next step, the data is sent to the Raspberry Pi module using the UART interface via USB cable.

The Arduino module sends data through the serial port in string format, after which numeric values are extracted from it by Raspberry Pi. At the same time, the microcomputer is trying to connect to the Internet by using WiFi or Ethernet. Once the connection is successful, data is transferred to the cloud server ThingSpeak using the REST API methods. Thus, the device operates cyclically until the power supply stops.

ThingSpeak is a cloud platform for the Internet of Things that allows to collect, display and analyze streaming data. It has the ability to retrieve data from a variety of computing devices, such as ESP, Arduino, Raspberry Pi, and other similar modules. ThingSpeak is a free of charge service with a powerful IoT functionality, which provides the possibility to display data in real-time. Hence, it is the best choice for the designed air pollution monitoring system. Once the data is received on the ThingSpeak channel, it can be visualized, processed, and analyzed using the capabilities of MATLAB functions.

The Python code fragment for Raspberry Pi, which is responsible for receiving measurement data from the Arduino and transferring it to the ThingSpeak cloud platform is shown in Figure 5.

```python
import time
import serial
from time import sleep
from urllib.request import urlopen
#connect to read data from Arduino module
ser = serial.Serial('/dev/ttyACM0', 9600, timeout=1)
ser.flush()
baseURL1 = 'https://api.thingspeak.com/update?api_key=EI3MU9PVGK0HP4TW&field1=0'
baseURL2 = 'https://api.thingspeak.com/update?api_key=EI3MU9PVGK0HP4TW&field2=0'
baseURL3 = 'https://api.thingspeak.com/update?api_key=EI3MU9PVGK0HP4TW&field3=0'
baseURL4 = 'https://api.thingspeak.com/update?api_key=EI3MU9PVGK0HP4TW&field4=0'

while 1:
    try:
        #receiving data from the Arduino and divide the tape
        line = ""
        if ser.in_waiting > 0:
            line = ser.readline().decode('utf-8').rstrip()
            print(line)
            arr = line.split()
            #if the tape consists of 2 words, continue to process the data
            f1 = urlopen(baseURL1 + str(arr[1]))
            f1.read()
            f1.close()
            time.sleep(2)
```
Figure 5: Python code fragment for Raspberry Pi

5. Experimental results and discussion

The hardware implementation of the designed information-measuring system for air quality monitoring is shown in Figure 6.

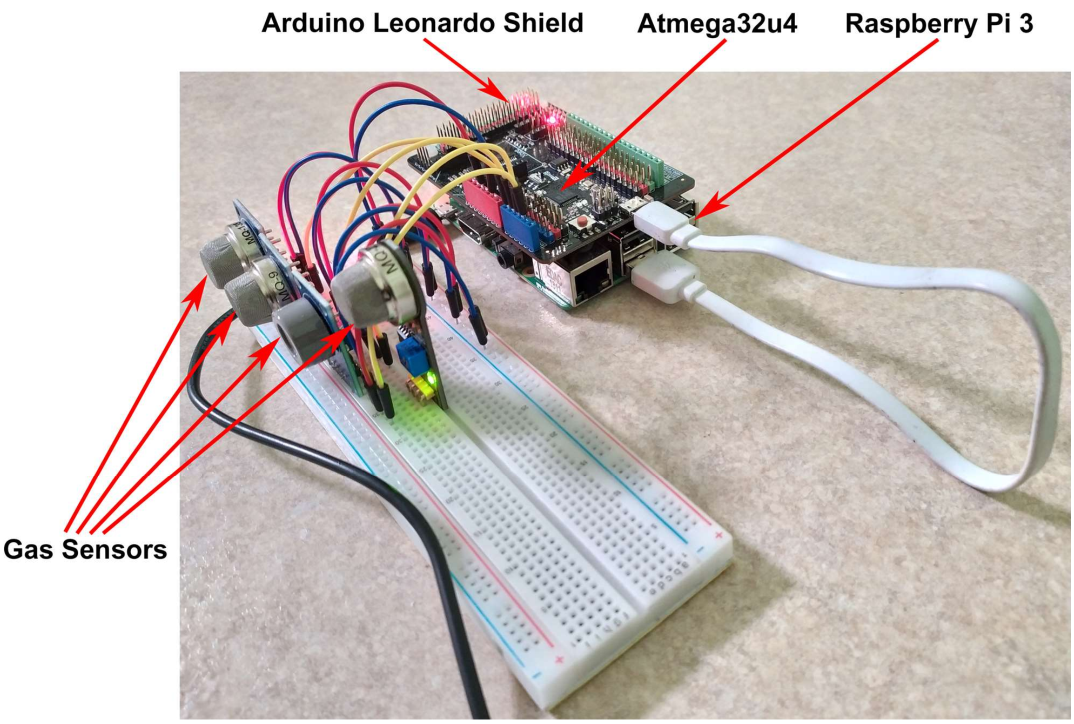

Figure 6: The hardware implementation of the designed system

The measurement results of air quality parameters are shown in Figure 7.

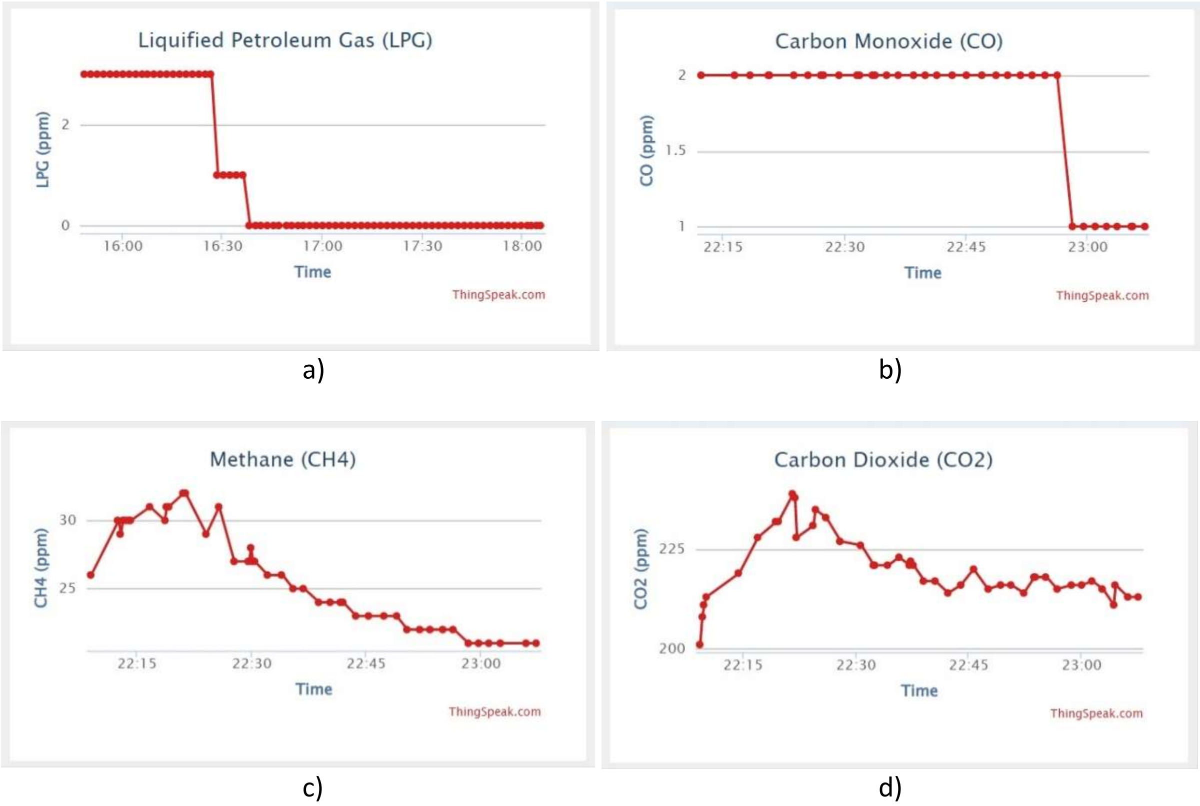

Figure 7: The monitoring results of the harmful gases concentration in the air: a) liquefied petroleum gas (LPG); b) carbon monoxide (CO); c) methane (CH_4); d) carbon dioxide (CO_2)

Air pollution measurements were taken based on the parts per million metrics. The ThingSpeak cloud platform provides a wide range of opportunities for visualizing the data obtained from sensors. The graphical representation of monitoring results visualizes on a web page to display real-time data. This data can also be accessed using a mobile application. The ThingSpeak platform allows the storage of the accumulated data on the server throughout the year. Data can be exported to any program for further processing. This provides many opportunities for statistical data processing, additional calculations, and in-depth data analysis.

The designed remote air pollution monitoring system was tested using different measurements in various conditions and situations from common and normal to uncommon and abnormal air states. These various test results show high accuracy and minimum error rate in measuring LPG, CO, CH_4, and CO_2 concentrations in air.

6. Conclusions

Air quality is a substantial problem that directly influences human health. This paper proposed a computerized remote air pollution monitoring system that provides access to the measurement results of air quality in real-time. The system based on the Raspberry Pi and Arduino Leonardo shield was prototyped. The firmware for the Atmega32u4 microcontroller and software for the microcomputer were created. The system transfers and stores the measured data to the ThingSpeak IoT cloud platform.

The successfully developed and implemented monitoring system visualizes the air pollution data in real-time on a web page. This system is being used to collect data for an in-depth analysis of various parameters' mutual influences. The implementation results show that the designed system is simple to use, has a relatively low cost, and provides a real-time online access to precise information about the pollution concentration in the air. The use of the IoT concept allowed the air pollution monitoring system to be scalable, flexible, and smart.

Increasing the input data flows by connecting additional sensors to the monitoring unit can significantly expand the capabilities of the system. Implementation of this scheme is possible because the Arduino Leonardo shield has free ADC input channels. It will be implemented in future research.

7. Acknowledgements

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