Microcontroller system for air quality monitoring

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Abstract

During this study, the element base was selected and the method for integrating a microcontroller system for air quality monitoring was developed, which made it possible to design and implement a microcontroller system for air quality monitoring that has the following advantages: compactness and portability; affordable cost at the level of 125 USD; low power consumption; collection and analysis of accurate data in real time; the ability to remotely monitor, control; the ability to integrate with other systems for various purposes; the ability to operate autonomously.

Keywords

Microcontroller system, air quality monitoring, Raspberry Pi 4B microcontroller, Waveshare MQ-135 sensor, Waveshare BME688 sensor, Waveshare Dust sensor.

1. Introduction & Literature Review

Air pollution is the presence of various harmful substances in the air that can be emitted as a result of industrial, transport, agricultural and other human activities [1, 2]. Air pollution is a serious environmental problem in our daily lives, as polluted air can have a harmful effect on human, animal and plant health, as well as the environment in general. Deteriorating air quality has a negative impact on public health and the environment [3, 4].

Air pollution can have serious consequences for human health, including respiratory diseases, cardiovascular diseases, allergic reactions, and other problems. In addition, it can lead to soil and water pollution and damage to ecosystems. To combat air pollution, it is necessary to implement effective measures to limit emissions of harmful substances, use environmentally friendly technologies and green solutions in all sectors of the economy, as well as increase public awareness and education about the problem of air pollution [5, 6].

The main sources of air pollution [7, 8]:

ITTAP'2024: 4th International Workshop on Information Technologies: Theoretical and Applied Problems, October 23-25, 2024, Ternopil, Ukraine, Opole, Poland

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1. Industrial emissions – emissions from enterprises, plants and factories, which include harmful substances such as hydrogen sulfide (H_2S), nitrogen oxides (NO_x), soot, hydrocarbons, toxic substances and others.
2. Transport – emissions from cars, airplanes, ships and other vehicles that use fuel containing harmful substances; for example, cars, trucks, buses, motorcycles and other vehicles running on diesel fuel or gasoline emit nitrogen oxides (NO_x), hydrocarbons, carbon dioxide (CO_2) and other harmful substances.
3. Agricultural production – the use of pesticides, fungicides and other chemicals in agriculture, which can cause emissions of harmful substances into the air; livestock production can lead to emissions of ammonia and methane, which can also contribute to air pollution.
4. Domestic sources – emissions from home heating systems, fireplaces, stoves, and smoke from landfills; the use of coal, wood, gas, or oil for home heating can cause emissions of carbon monoxides (CO and CO_2), as well as other harmful gases.
5. Natural sources – natural fires, which emit significant amounts of soot, smoke and other harmful substances; volcanic eruptions can emit significant amounts of ash, dust, gases and vapors, such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), water vapor (H_2O) and others; dust and sand storms can carry large amounts of dust, sand, ash and other particles into the air, which can lead to air pollution; some natural processes, such as decay of organic vegetation, emit gases, such as methane (CH_4), which can also affect air quality.
6. Thermal power plants – emissions from coal or gas-fired power plants contain large amounts of carbon dioxide, hydrogen sulfide and other harmful substances.

These sources can have a significant impact on air pollution, which affects human health and the environment.

Environmental pollution and air quality are becoming increasingly important topics in the areas of Smart Cities and government regulation [9, 10].

Air quality monitoring is an important process for determining the level of pollution and tracking changes in air composition, and plays a key role in ensuring the health and comfort of residents, as well as in preserving the environment [11, 12].

Air quality monitoring is extremely important for numerous reasons [13-15]:

1. Health – poor air quality can lead to serious health problems such as respiratory diseases, asthma, cardiovascular diseases, and even cancer.
2. Ecology – air pollution can have harmful effects on plants, animals and ecosystems in general, disrupting ecological balance and biodiversity.
3. Quality of life – clean air improves the quality of life of people by providing a comfortable and safe environment for living and working.
4. Economic impacts – air pollution can lead to economic losses due to lost productivity, increased medical costs, and loss of revenue from tourism and other industries.
5. Public debate – air quality monitoring provides the public with objective data on pollution levels, which facilitates public discussion and the adoption of effective measures to reduce the impact on health and the environment.

6. Overcoming crisis situations – air quality monitoring helps to detect crisis situations in time, such as fires, industrial accidents or emergencies that may pose a threat to public health and safety; timely response to these situations allows for the necessary measures to be taken to minimize the negative impact on health and the environment.
7. Scientific research – data collected from air quality monitoring is used to conduct scientific research on the relationship between air pollution and various types of diseases; this research helps to develop strategies for the prevention and treatment of diseases, as well as to improve environmental standards and policies.
8. International cooperation – air quality monitoring is an important element of international cooperation in the field of environmental protection and health; data exchange and joint monitoring programs allow countries to jointly address air pollution problems and carry out coordinated activities to reduce its impact.

Summarizing, air quality monitoring plays an important role in ensuring human health, environmental sustainability and sustainable development of society. In general, air quality monitoring is a key tool for ensuring the health, safety and sustainable development of society, and also promotes research and international cooperation in this area [16].

A real-time air quality monitoring system helps to track sudden changes in the atmosphere. Solving pollution problems is one of the main challenges facing cities today, as cities are the main sources of pollutant emissions, and on the other hand, they are also areas where the impact of pollution on human health (especially on the respiratory tract, cardiovascular system, and nervous system) is quite significant [17-19].

Let's consider the known real-time air quality monitoring systems [20-22].

AirVisual [23] is an innovative air quality monitoring platform that provides a wide range of real-time services for measuring, analyzing, and monitoring air pollution, including information on air quality in different regions of the world, including pollutant levels and air quality index, forecasts, and health tips. It offers sensors for indoor and outdoor use that provide real-time air quality data. The system is accessible through mobile apps and a website. The platform also provides air quality forecasts for the coming days, allowing people to plan their actions and choose strategies to protect themselves from air pollution. AirVisual provides users with tips and advice on how to protect themselves from air pollution and stay healthy, which helps reduce the negative effects of air pollution on the body. The cost of such an air quality monitor is about 400 USD.

PurpleAir [24-26] is a global air quality monitoring network implemented as a network of sensors located in different parts of the world that provides real-time data on the levels of pollutants in the air. This data can be accessed through an interactive map on their website and mobile application. PurpleAir uses two sensors on each device to measure levels of different air pollutants, such as PM2.5 and PM10, which allows for more accurate air quality data. PurpleAir also stores historical data, allowing users to track changes in air pollution levels over time. PurpleAir provides users with the ability to visualize air quality data on a map, where each sensor is labeled with its location. This network provides an API for developers to create applications and services that use air quality data for various purposes, including the development of mobile applications and interactive websites. The cost of such an air quality monitor is about 300 USD.

IQAir AirVisual Pro [27, 28] is a device that provides real-time information on the levels of pollutants in the air, including PM2.5, PM10, nitrogen oxide, and others. The information is displayed on the device's display and can also be synchronized with a mobile application. The platform can send users alerts about dangerous levels of air pollution, as well as provide advice on measures to reduce the impact of these pollutants on health. IQAir AirVisual Pro provides the ability to visualize air quality data on a map, allowing users to quickly assess the level of air pollution in different areas and analyze the situation in different regions. The cost of such an air quality monitor is about 400 USD.

Aeroqual Cloud [29, 30] is a monitoring system that provides real-time air quality data, including levels of nitrogen oxides, ozone, PM2.5, PM10, NO2, SO2, O3, and other pollutants, which allows you to get a complete picture of air quality in a particular region. The data can be viewed via a web portal or mobile application. The platform can automatically send notifications to users when dangerous levels of pollution are detected, and also provides the ability to analyze data and generate reports for further use. Aeroqual Cloud can be integrated with other monitoring systems or urban infrastructures to create integrated air quality and healthcare solutions.

Foobot [31] is a home air quality monitor that provides real-time data on pollutant levels such as PM2.5, VOCs, CO2, and others. The data can be viewed via a mobile app or web portal. Foobot automatically sends alerts to users when dangerous levels of pollution are detected and provides advice on how to improve air quality. Foobot has a user-friendly interface that allows you to track air quality trends and take the necessary measures to improve the environment. The cost of such an air quality monitor is about 1600 USD.

EPA AirNow [32] is an air quality monitoring system developed by the US Environmental Protection Agency (EPA). It provides information on air pollutant levels, such as PM2.5, PM10, ozone, nitrogen oxide, and others, for various locations in the United States through a website and mobile app. AirNow offers an interactive map where users can track the level of air pollution in their area using a color-coded air quality index scale. Users can sign up for air pollution alerts and receive advice on safety and health measures in the event of high pollution levels. AirNow provides users with access to a variety of informational resources about the health effects of air pollution and recommendations for reducing the environmental and health effects of air pollution.

Breezometer [33, 34] is an air quality monitoring platform that provides air pollution data based on the user's geolocation. It assesses the levels of various pollutants and provides useful tips for staying healthy. Breezometer uses advanced algorithms and models to analyze data from various sources, including sensor networks, weather stations and other sources, to provide users with the most accurate air quality information. The system provides data on the level of various air pollutants, including PM2.5, PM10, NO2, SO2, CO and O3, as well as other parameters such as temperature, humidity and pressure. Breezometer features an interactive map where users can view real-time air pollution levels in their area and receive updates via a mobile app or website. Users can subscribe to notifications about changes in air pollution levels and receive advice on safety and health protection measures according to the current situation. Breezometer provides users with in-depth data analysis, including reports on the duration, intensity, and health effects of air pollution.

Atmotube [35] is a portable air quality sensor that can be attached to a bag or keys. It provides information on the levels of various air pollutants such as PM2.5, VOCs, CO2 and others, as well as temperature and humidity via a mobile app. Atmotube notifies users of changes in air quality and provides advice on safety and health measures. Atmotube also has a community feature where users can share information about air quality and experience using the device. The cost of such an air quality monitor is about 200 USD.

The Lun City Air system is used in Khmelnytskyi. The stations are located around the city and scan the air quality every second. However, they measure only the amount of ultrafine particles in the air – the concentration of PM1, PM2.5, PM10. Real-time indicators are displayed simultaneously on several sources. The system is implemented quite well, but in Khmelnytskyi there are only 3 stations for data collection, which does not allow to see air pollution in all areas of the city, although the values can vary quite widely depending on the microdistricts.

Air quality monitoring systems allow users to monitor pollutant levels in the air in real time and take appropriate measures to protect health. They give users access to up-to-date information about air quality in their areas, allowing them to avoid polluted areas and take the necessary measures to maintain their health. Such systems are an important tool for informing the public about air pollution problems and contribute to the adoption of effective measures to reduce the impact of this pollution on health and the environment, however, the cost of ready-made systems is currently considerable, especially for citizens of Ukraine.

The main tasks of air quality monitoring [36-38]:

1. Measurement of pollutants – measurement of concentrations of various pollutants in the air, such as nitrogen oxides (NOx), sulfur oxides (SOx), hydrocarbons, soot and others.
2. Placement of monitoring sensors in different points of the city or region to obtain representative data on air quality in these places.
3. Data analysis – the obtained data are analyzed to determine the level of air pollution, identify sources of pollution and assess their impact on human health and the environment.
4. Ensuring the sufficiency [39, 40], security [41, 42] and quality [43, 44] of data, platforms, sites and mobile applications through which citizens receive information about the level of pollution.
5. Publicity of information – the results of air quality monitoring are made available to the public through special platforms, websites or mobile applications, which allows citizens to receive information about the level of pollution and take the necessary measures to protect their health.
6. Further actions – based on the monitoring results, strategies and measures are developed to reduce the level of pollution and improve air quality [45], such as the introduction of ecological technologies, regulation of emissions of industrial enterprises and vehicles, as well as other measures to reduce the impact on health and the environment.

Therefore, air quality monitoring is currently an *urgent task*, as it is a preliminary and necessary step for the development and further implementation of measures aimed at reducing air pollution in order to preserve the health of citizens. *The purpose of this study* is to design and develop a microcontroller system for air quality monitoring, which will be much cheaper than ready-made analogues, but will have no less accuracy and speed, will collect and analyze various air parameters (humidity, pressure, temperature, pollution level, dust content, concentrations carbon and other gases, etc.) in real time, will assess the level of air quality and safety, which will allow you to immediately react to changes in air quality and quickly take the necessary measures.

2. Design of microcontroller system for air quality monitoring

Considering the above criteria, we choose the following element base for designing a microcontroller system for air quality monitoring:

1. The Raspberry Pi 4B microcontroller (Figure 1) is one of the most common and affordable platforms for developing IoT projects; has a wide functionality and can be used to collect, analyze and transmit data about the environment; has an affordable price, which allows to reduce the cost of development and implementation of monitoring systems; consumes less electricity compared to traditional servers or computers; has a small size, which allows you to make monitoring systems compact and portable; has various ports and connectors, which allows you to easily connect various sensors and devices and, thus, expand the functionality of the monitoring system; allows you to create effective and flexible solutions for measuring and analyzing air parameters.
2. Waveshare MQ-135 sensor (Figure 2) can measure several types of gases, including ammonia, benzene, alcohol and carbon monoxide; known for its ease of use and low cost, which makes it attractive for budget projects; easily integrated due to its compatibility with popular microcontrollers and modules.
3. Waveshare BME688 sensor (Figure 3) combines the measurement of temperature, humidity, pressure and gases, which allows you to receive comprehensive data on air quality; has high accuracy and stability of measurements; supports artificial intelligence technologies to improve the accuracy of detection of different types of gases, which is especially attractive for modern applications; provides a comprehensive approach to air quality measurement, combines several parameters in one module, which simplifies integration and reduces the overall cost of the monitoring system.
4. Waveshare Dust sensor (Figure 4) has high accuracy thanks to laser scattering technology; measures the concentration of fine dust particles, which are one of the most harmful forms of air pollution, from 0.3 to 10 microns, which makes it particularly effective in monitoring air quality in conditions of high pollution; widely used to monitor air quality in urban environments, industrial areas and at home; has a compact size and can work with various microcontrollers or computers through the UART interface; is affordable; can stably and accurately provide data on the concentration of dust in real time, which allows prompt response to air pollution; is an important air quality monitoring tool that helps detect and control air pollution.

Figure 1: Raspberry Pi 4B microcontroller.

Figure 2: Waveshare MQ-135 sensor.

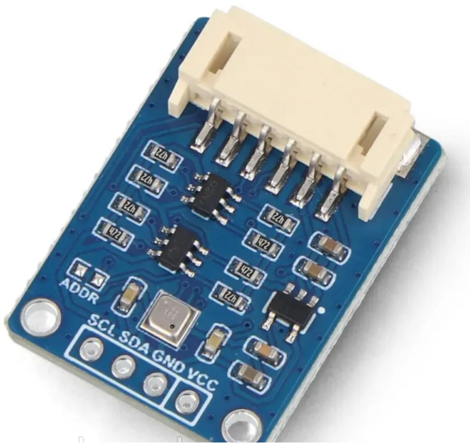

Figure 3: Waveshare BME688 sensor.

Figure 4: Waveshare Dust sensor.

Method of integration of the microcontroller system for air quality monitoring consists of the following steps:

1. Integration of modules – connection and integration to the main control unit of the Raspberry Pi 4B microcontroller of the Waveshare MQ-135 sensor, connection and integration to the main control unit of the Raspberry Pi 4B microcontroller of the Waveshare BME688 sensor, connection and integration to the main control unit of the Raspberry Pi 4B microcontroller of the Waveshare Dust sensor. Tables 1-3 show the connection diagrams of the Waveshare MQ-135, Waveshare BME688 and Waveshare Dust sensors to the Raspberry Pi 4V, respectively.
2. Preparation for the implementation of data collection and storage – installation and configuration of the operating system, validation of the sensor connection, verification of the stability of the sensors.
3. Creation of an interface for the interaction of remote administrators - providing the possibility of remote access to the microcontroller system; construction of safe infrastructure; ensuring scalability and fault tolerance; providing the possibility of remote administration and data retrieval.

4. Integration with the Internet of Things system – implementation of Internet of Things technology for real-time data transfer to cloud storage and other external devices.
5. Real-time data analysis and processing, preparation for data transmission via the Internet.

Table 1
Connection diagram of Waveshare MQ-135 sensor to Raspberry Pi (via Raspberry Pi Pico)

Output (pin) on the sensor	Output (pin) on the Raspberry Pi	Description
VCC	3.3V	Power, “+”
GMD	GND	Power, "-"
AOUT	GPIO 26	Analog output
DOUT	GPIO 22	Digital output

Table 2
Connection diagram of Waveshare BME688 sensor to Raspberry Pi

Output (pin) on the sensor	Output (pin) on the Raspberry Pi	Description
VCC	3.3V	Power, “+”
GMD	GND	Power, "-"
SDA	SDA.1	Information output
SCL	SCL.1	Synchronization output

Table 3
Connection diagram of Waveshare Dust sensor to Raspberry Pi (via Raspberry Pi Pico)

Output (pin) on the sensor	Output (pin) on the Raspberry Pi	Description
VCC	3.3V	Power, “+”
GMD	GND	Power, "-"
AOUT	GPIO 27	Data output
ILED	GPIO 21	LED control

Advantages of the designed microcontroller system for air quality monitoring:

- Compactness and portability.
- Affordable cost at the level of 5050 UAH (125 USD) – the Raspberry Pi 4B microcontroller costs about 3,000 UAH on average, the auxiliary Raspberry Pi Pico microcontroller used as an analog-to-digital data converter is about 250 UAH, the Waveshare MQ-135 sensor is about 150 UAH, the Waveshare BME-680 sensor is about 1000 UAH, Waveshare Dust sensor is about 500 UAH, LCD display for displaying test values is 150 UAH.
- Low power consumption.
- Collection and analysis of accurate data in real time.
- Ability to remotely monitor, control.
- Ability to integrate with other systems for various purposes.

- Ability to operate autonomously.

3. Development and testing of microcontroller system for air quality monitoring

As a result of the implementation of the method of integration of the microcontroller system for air quality monitoring, the following system prototype was developed – Figure 5.

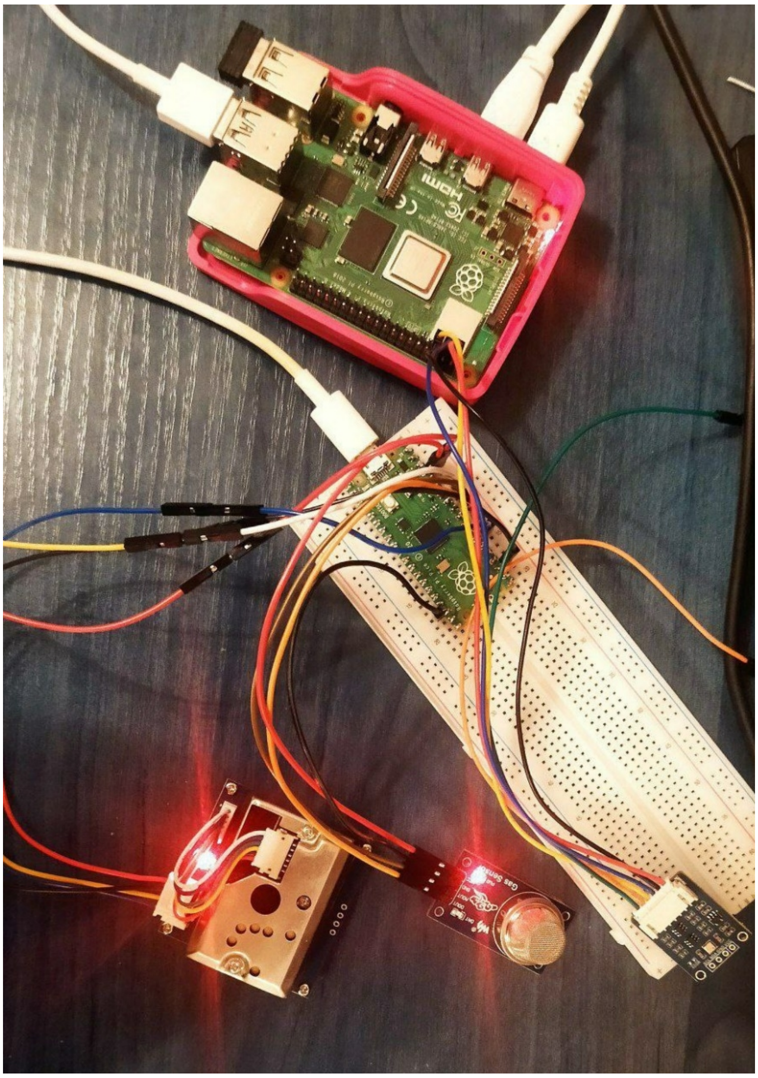

Figure 5: Microcontroller system for air quality monitoring.

In addition to the hardware presented in Figure 5, to access the developed microcontroller system for air quality monitoring, the software of microcontroller system for air quality monitoring was also developed in the form of a mobile application for the Android operating system.

After starting the mobile application, can immediately see the main screen, where the last read data will be displayed, provided that the connection with the remote server is present. Figure 6 shows the main screen of such a mobile application.

If go to the graph display screen, the user will see 5 graphs with data for a 5-day period. Figure 7 shows the screen for displaying graphs of collected in a 5-day period data by air quality monitoring mobile application.

This screen has two modes – displaying information for a certain period of days (5, 10 and 30 days) and displaying data for a certain day hourly. Screen for displaying hourly graphs of air quality monitoring mobile application data collected for the current day is shown in Figure 8.

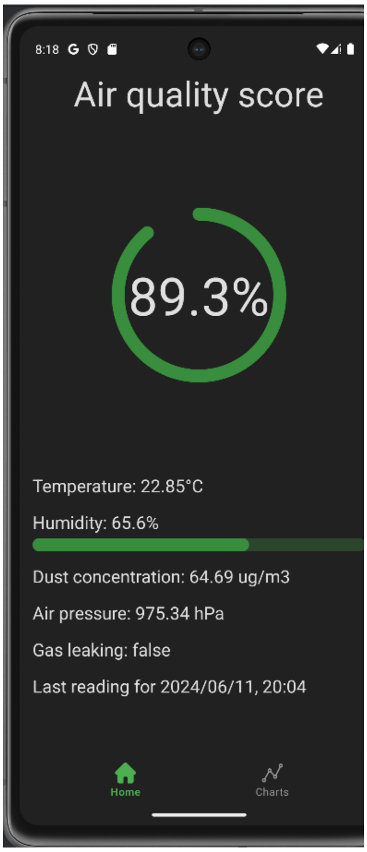

Figure 6: The main screen of the air quality monitoring mobile application.

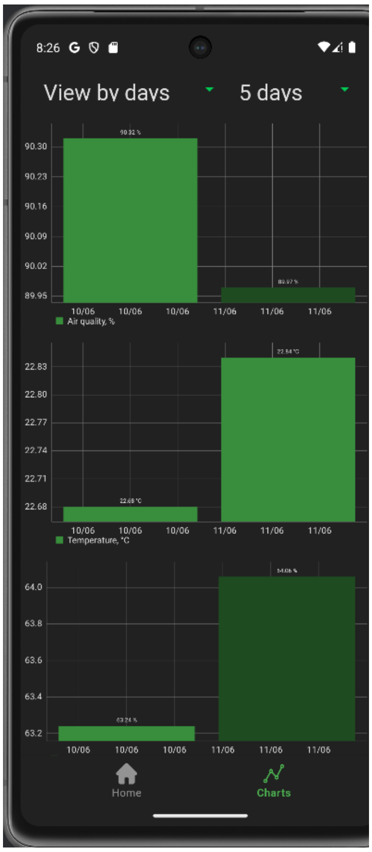

Figure 7: Screen for displaying graphs of collected in a 5-day period data by air quality monitoring mobile application.

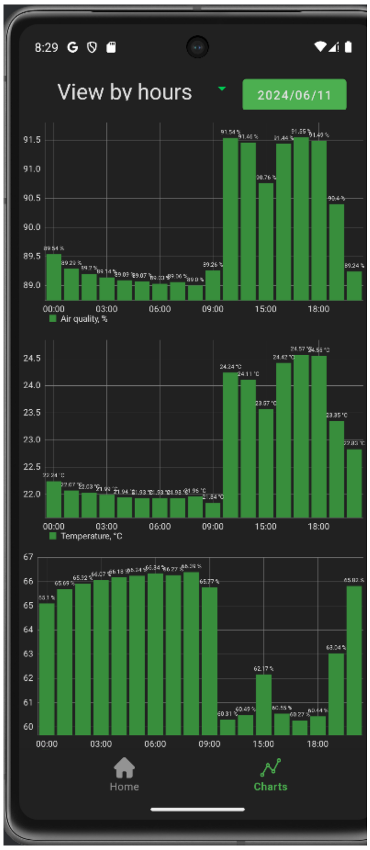

Figure 8: Screen for displaying hourly graphs of air quality monitoring mobile application data collected for the current day.

4. Conclusions

Air quality monitoring systems allow users to monitor pollutant levels in the air in real time and take appropriate measures to protect health. They give users access to up-to-date information about air quality in their areas, allowing them to avoid polluted areas and take the necessary measures to maintain their health. Such systems are an important tool for informing the public about air pollution problems and contribute to the adoption of effective measures to reduce the impact of this pollution on health and the environment, however, the cost of ready-made systems is currently considerable, especially for citizens of Ukraine.

Air quality monitoring is currently an urgent task, as it is a preliminary and necessary step for the development and further implementation of measures aimed at reducing air pollution in order to preserve the health of citizens. The purpose of this study is to design and develop a microcontroller system for air quality monitoring, which will be much cheaper than ready-made analogues, but will have no less accuracy and speed, will collect and analyze various air parameters (humidity, pressure, temperature, pollution level, dust content, concentrations carbon and other gases, etc.) in real time, will assess the level of air quality and safety, which will allow you to immediately react to changes in air quality and quickly take the necessary measures.

During this study, the element base was selected and the method for integrating a microcontroller system for air quality monitoring was developed, which made it possible to design and implement a microcontroller system for air quality monitoring, that has the following advantages: compactness and portability; affordable cost at the level of 125 USD; low power consumption; collection and analysis of accurate data in real time; the ability to remotely monitor, control; the ability to integrate with other systems for various purposes; the ability to operate autonomously. In addition to the hardware, to access the developed microcontroller system for air quality monitoring, the software of microcontroller system for air quality monitoring was also developed in the form of a mobile application for the Android operating system.

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