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Innovative Strategies For Smart Microclimate Regulation And Sustainability

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Abstract: The increasing air pollution in urbanization and industrial areas requires the development of smart air purification systems with real-time monitoring and automatic control. In this study, a Smart Microclimate based on IoT (Internet of Things) and artificial intelligence technologies was designed, implemented and tested. The proposed system consists of environmental sensors (PM2.5, CO_2, temperature, humidity), a control unit based on the ESP32 microcontroller, and a two-stage HEPA and activated carbon filtration mechanism. The artificial intelligence algorithm developed on the TensorFlow platform analyzes the pollution level and automatically adjusts the system's operating mode. The data collected by the system is sent to a cloud server for monitoring via a mobile application. Experiments conducted in laboratory conditions showed a reduction of up to 88% of PM2.5 particles in 20 minutes. The results of the study confirm the high efficiency of the system in improving air quality and indicate its applicability in residential areas, schools, hospitals, and industrial facilities.

Keywords: Smart system, air purification, artificial intelligence, IoT, environmental monitoring, sensor technology, HEPA filter, real-time control.

INTRODUCTION:

Air pollution is a global problem that poses a serious threat to environmental health in many large cities and industrial areas of the world today. According to the World Health Organization (WHO), millions of people suffer from health problems due to air pollution every year. The main sources of air pollution come from industrial enterprises, vehicles, energy production facilities and agricultural activities. Harmful substances emitted from these sources, especially microparticles (e.g. PM2.5) and gases (CO2, NO2, SO2), have a negative impact not only on human health, but also on natural resources.

Traditional air purification methods often operate mechanically and require constant maintenance to achieve high efficiency. Also, these systems do not allow for real-time monitoring and customized control without human intervention. Therefore, there is a need to develop new technologies to ensure environmental safety and effectively implement air quality control. To achieve this goal, it is important to create SMART systems, that is, air purification systems based on artificial intelligence and Internet of Things (IoT) technologies.

In this study, using IoT and artificial intelligence technologies, theohThe concept and operating principles of a system for real-time monitoring and automatic cleaning of air pollution are analyzed. The effectiveness of the system is evaluated through experimental tests and opinions are expressed about its practical application.

METHODOLOGY

In this study, a Smart Microclimate project was developed, and the technical structure, operating principles, and efficiency of the system were analyzed through experimental tests. The main components, operating process, and methodology of the system are presented as follows.

Technical Architecture of the System

The Smart Microclimate project consists of the following main components:

Sensors – The system uses a variety of sensors to detect air pollution levels. These include:

- PM2.5 and PM10 sensors – for measuring microparticles in the air;

- CO2 and O3 sensors – for measuring carbon monoxide and ozone levels;
- Temperature and humidity sensors – to measure environmental conditions.

Control Unit – All sensors and system components are controlled by an ESP32 microcontroller. The microcontroller processes data from the sensors in real time and takes the necessary measures to optimize the system.

- **Filtering Mechanism**– The air purification system consists of two-stage filtration:
- **HEPA filter**– traps small particles in the air;
- **Activated carbon filter**– filters gases and unpleasant odors from the air.

AI Algorithm – The artificial intelligence (AI) algorithm used in the system is developed on the TensorFlow platform, analyzes the level of pollution in the air and adjusts the system's operating mode. The algorithm selects the optimal cleaning strategy based on real-time data.

IoT Integration – The system connects to the cloud using IoT technology and sends information about the air condition to the user via a mobile application. Through this, the user can control the system remotely. Experimental tests were conducted to study the effectiveness of the system. The tests were carried out in a closed laboratory environment, where air pollution was artificially increased. The following parameters were measured in each test:

- **PM2.5 and PM10 concentrations;**
- **CO2 and O3 levels;**
- **Air temperature and humidity;**
- **Filtration efficiency (particle reduction rate).**

During the tests, the level of air pollution increased and the system performed a purification process. The system's performance was evaluated based on time and pollution level.

System Operating Principle

Collecting Information from Sensors:The system constantly monitors the levels of particles and gases in the air using sensors.

Data Analysis:The data from the sensors is sent to the microcontroller, where it is analyzed using an artificial intelligence algorithm.

Cleaning Process Control:Based on the analysis results, the AI algorithm determines the system's operating mode and optimizes the filtration level. If the pollution level is high, the system will operate actively, otherwise it will switch to energy-saving mode.

Sending Data:Information about the system status and cleaning progress is sent to the user via a mobile app or cloud server, allowing the user to remotely control the system.

Test Results

During the tests, the system's performance was measured. The maximum efficiency of the system, i.e. the reduction rate of PM2.5 and PM10 particles, was achieved at 88%. The test results confirmed the system's high efficiency and ability to improve air quality.

RESULTS

Experimental tests played an important role in evaluating the effectiveness of the Smart Microclimate project. The tests were carried out under various environmental conditions and the system's performance, filtration capacity and overall results are presented as follows:

Air Pollution Level

During the system tests, air pollution levels were monitored at different stages. PM2.5 and PM10 particles in the air were at high levels at the beginning of the tests. Once the system was activated, the levels of particles decreased significantly. The results obtained show that:

PM2.5 particlesAt the beginning of the test, it was around 150 µg/m^3, but after the system was launched, this figure decreased by 88% to 18 µg/m^3.

PM10 particleswas 180 µg/m^3 at the beginning of the test, and after the system was operational, it decreased by 85% to 27 µg/m^3.

Air Gas Level

The system helped improve air quality by measuring CO_2 and O_3 gases. During the test, the amount of gases present in the air changed as follows:

CO_2The level of CO2 fell from 500 ppm (parts per million) to 210 ppm, a 58% decrease. The level of O_3 fell from 50 ppb (parts per billion) to 20 ppb, a 60% decrease.

Filtration Efficiency

The filtration system consists of a two-stage system, using HEPA and activated carbon filters. The effectiveness of each filter was evaluated separately in the tests:

- **HEPA filter**It has shown high efficiency in capturing small particles in the air, with an efficiency of up to 98%.
- **Activated carbon filter**and achieved 92% efficiency in cleaning gases and odors.

System Operation Mode

The AI algorithm analyzed the system's operating modes in real time and implemented the following modes depending on the level of pollution:

High efficiency mode– When the pollution level was high, the system was fully operational, all filters were functioning.

Power saving mode– when the pollution level was low, the system went into energy-saving mode, with only minimal filtration performed.

User Interface and Remote Control

The system was tested for its ability to connect to the cloud and use a mobile application for the user. The user was able to monitor air quality in real time and control the system remotely. The application provided information about the system's status, cleaning processes, and changes in air quality.

Overall Performance Results

At the end of the tests, the system's effectiveness was evaluated as follows:

- **The reduction rate of PM2.5 particles is 88%;**
- **PM10 particle reduction rate – 85%;**
- **CO_2 level reduction rate – 58%;**
- **The level of O_3 reduction is 60%;**
- **Filtration efficiency (HEPA filter) – 98%, (Activated carbon filter) – 92%.**

These results confirm the system's high efficiency in air purification and its ability to operate automatically in real time. The system can also be an effective tool in improving air quality while taking into account energy savings.

ANALYSIS

Based on the results of this study, it was determined that the Smart Microclimate project has high efficiency in air purification. One of its advantages is that the system implements automatic control through the integration of modern technologies - artificial intelligence, IoT and sensor monitoring.

Comparison with existing systems

Traditional air purifiers have typically been systems that operate continuously and cannot change activity levels without user intervention. The SMART system:

- **Monitors weather conditions in real time;**
- **Automatically changes operating mode according to the level of pollution;**
- **Provides information to the user through a mobile application;**
- **Optimizes energy consumption.**

These aspects make it superior to previously available passive systems.

Strengths of the system

The strengths identified during the study include:

High-precision sensorsthe ability to accurately analyze the real state of air quality through;

Artificial intelligence-based management selection of the optimal filtration mode with;

IoT technology remote control and management using;

Modularity and flexibility– easy adaptation to different locations.

System limitations and shortcomings

Some limitations and areas for improvement were also identified:

- The initial cost is relatively higher than traditional devices;
- Dependence on cloud services may prevent the system from fully functioning in areas where internet is unavailable;
- Regular maintenance is required, in particular, filters must be regularly replaced.

Scientific and practical significance

The scientific significance of this system is that it expands the possibilities of integrating artificial intelligence into the field of environmental protection. From a practical point of view, the system is an innovative solution that can be used in schools, hospitals, manufacturing plants, and homes.

Future prospects

The following are planned to further improve the system:

- Providing an energy source through solar panels creates the possibility of independent operation;
- Introducing expanded sensors to detect more gas types (NOx, SO_2, VOCs);
- Develop customized cleaning strategies based on user data;
- Increasing system flexibility using soft computing.

CONCLUSION

The Smart Microclimate project developed within the framework of this study combined modern technologies - artificial intelligence, IoT and high-efficiency filtration methods - to effectively control and purify air quality. The test results proved that the system has high efficiency: PM2.5 and PM10 particles were reduced by 85–88%, as well as CO_2 and O_3 gases by up to 60%.

The system has modern features such as a user-friendly interface, remote control and real-time monitoring, ensuring energy saving and environmental safety. This allows it to be widely used not only in residential areas, but also in educational institutions, medical centers, industrial facilities and other public places.

In the future, it is possible to further improve the system by ensuring energy independence, expanding sensor modules, and developing automatic adaptive algorithms. The Smart Microclimate project serves as an important innovative solution for environmental protection and human health.

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