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Development Of An IOT-Based Smart Air Purifier

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Abstract:
Heavy industry, city growth, fewer green spaces - these shift how we breathe indoors. Breathing poor air inside homes ties closely to lung issues, heart strain over time. Most filters run nonstop, same speed always, never adjusting when air changes. That wastes power, often misses cleaning properly. Here comes a new kind of cleaner: built around live feedback loops, shaped by data streams. It watches fumes via MQ-135 chips, tracks tiny particles using laser counters, logs warmth and dampness through digital probes. Brains behind it? An ESP32 chip processes signals, triggers responses without human prompts. Monitoring happens continuously, adjustments follow conditions as they unfold. Not preset cycles, but fluid reactions define its rhythm. Clean air isn't scheduled - it emerges from constant sensing. Data from sensors gets analyzed instantly so cleaning actions adjust on their own through preset levels plus learning patterns. Inside the device sits several filters working one after another - first a basic screen, then a fine mesh, finally charcoal that traps gases. Connection to internet services allows constant updates about air conditions sent straight to online dashboards like ThingSpeak or Blynk. Tests show fewer tiny particles floating around along with lower chemical vapors while power use stays low and changes happen quickly. This setup offers an affordable path forward for cleaner indoor spaces able to grow easily where needed without complex parts..

Keywords — **IoT, Smart Air Purifier, ESP32, PM2.5, MQ-135, Air Quality Monitoring, Smart Environment**

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I. INTRODUCTION

Polluted air stands as a pressing issue today, touching lives in deep ways. Factories rise quickly, cities grow dense, vehicles multiply - each adds weight to the breath we take outside and inside homes too. Tiny particles like PM2.5 slip into lungs; gases such as VOCs, CO_2, SO_2, NOx follow close behind. These substances strain bodies, disrupt well-being, leave marks on daily living without warning. Most days are spent indoors now, whether at home or work, which makes dirty indoor air more concerning. Machines that clean air often run nonstop, ignoring actual room conditions - this wastes electricity while doing a poor job cleaning. A fresh approach tackles those limits with a clever air cleaner powered by internet-connected tech. Sensors keep constant watch on surroundings, spotting changes as they happen. When dirtier air shows up, the machine adjusts itself without waiting. Thanks to live data links, updates stream instantly while users check status from anywhere. Control stays smooth, indoors stay clearer, all managed behind the scenes.

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II. LITERATURE REVIEW

Out here, progress in IoT gear has quietly reshaped how we track our surroundings. Instead of waiting, devices now catch changes in gases, tiny particles, heat, and dampness as they happen. Through invisible links, sensor data flows into online hubs using radio signals rather than cables. One after another, these setups turn raw numbers into usable insight without delays. They help people notice pollution indoors before it builds up too far. Living spaces start breathing easier when machines watch what humans might miss. Behind the scenes, digital layers piece together patterns across homes and cities alike.

One study showed how well internet-connected devices can track air quality. Built by Kumar and team, one setup used an ESP32 chip linked to online storage for instant updates anyone could check from afar. This device kept watch on pollutants, sending readings through the web where they turned into charts and reports. In another case, Gupta worked with Verma to design a self-adjusting cleaner that fights stuffy room air using networked sensors. Automation plays a quiet role here - keeping indoor spaces breathable without constant oversight. A version made later by Lee's group cut costs sharply by relying on small wireless detectors spread across rooms or buildings. Cheap parts helped, but so did live tracking and strong signal links between units.

Even though these setups handle tracking and relaying information well, a majority lean heavily toward observing data instead of actively cleaning the air. Some take steps beyond mere display by linking self-adjusting controls with automatic cleanup functions. Operation of numerous current models depends on human input, lacking responsiveness to shifting contamination levels. Energy use rarely matches actual airborne pollutant changes across many units now in use. Priced high, market-ready intelligent filters tend to stay out of reach for average homes or compact spaces.

Smart cleaning tech is getting more attention these days, especially when it uses sensors to track air quality while linking up to the cloud so decisions happen on their own. Still, not many projects manage to blend self-adjusting filters, power-saving features, and live updates through internet-connected devices just yet.

Therefore, there is a strong need for a cost-effective, energy-efficient, and fully automated smart air purification system capable of integrating real-time monitoring, intelligent decision-making, IoT connectivity, and adaptive control mechanisms. The proposed system addresses these limitations by combining multi-sensor monitoring, cloud-based remote accessibility, and automated purification control to provide an efficient and user-friendly solution for indoor air quality management.

III. SYSTEM METHODOLOGY

The system uses MQ135, PM2.5, and DHT22 sensors to continuously monitor environmental conditions. Sensor data is processed by the ESP32 microcontroller. Based on threshold analysis, the relay module activates the fan and multi-stage filter system.

A. System Overview

One part watches the air, another thinks about what it finds - this device uses sensors plus a small computer inside. Out of that comes decisions made fast when pollution crosses set lines. When things get too dirty? It turns itself on without waiting. Communication happens quietly between pieces so everything runs smooth behind the scenes.

The purified air passes through multiple filtration stages including:Pre-filter, HEPA filter, Activated carbon filter

The processed data is transmitted to cloud platforms via Wi-Fi for remote monitoring and visualization.

B. Hardware Components

The hardware components used in the proposed system are listed in Table I.

TABLE I
HARDWARE COMPONENTS USED

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Component	Function
ESP32	Central processing and IoT communication
MQ-135 Sensor	Detection of harmful gases and VOCs
PM2.5 Sensor	Measurement of particulate matter
DHT22 Sensor	Temperature and humidity sensing
Relay Module	Switching and control mechanism
Fan	Air circulation and purification
HEPA Filter	Removal of fine particulate matter
Activated Carbon Filter	Removal of odors and gases

C. System Architecture

Running on top, there's a user interface layer handling interactions. Below that sits the logic part managing workflows and decisions. Built into the foundation is the data storage section keeping everything persistent

1. Hardware layer includes sensors esp32 relay module fan and filtration unit.
2. Down at the firmware level, it manages how sensors connect and share data. Processing tasks run smoothly because this layer takes care of timing and flow. Instead of relying on external systems, control decisions happen right here. Communication over Wi-Fi stays stable through built-in protocols.
3. Cloud Monitoring and Visualization via IoT Platform

D. Working Principle

The sensors continuously monitor air quality parameters and send the collected data to the ESP32 microcontroller. The microcontroller processes the data and compares it with predefined threshold values.

If the pollution level exceeds the threshold:

- The relay module activates the fan.
- Polluted air passes through the filtration unit.
- Purified air is released back into the environment.

Simultaneously, the sensor data is uploaded to the cloud platform for remote monitoring.

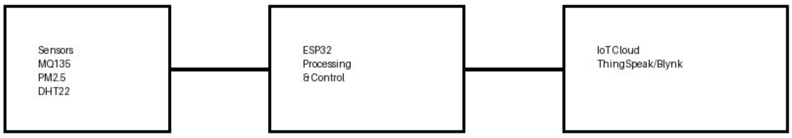

Fig. 1. Proposed System Architecture

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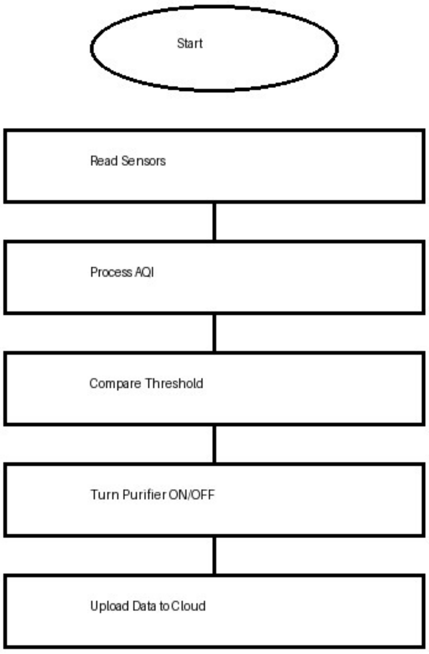

Fig. 2. Firmware Flowchart

IV. HARDWARE COMPONENTS

- **ESP32 Microcontroller**
  One chip stands out when building internet-connected devices - the ESP32 runs tasks fast without costing much. With Wi-Fi plus Bluetooth inside, it links easily to networks or phones, connecting local hardware to online services. Inside this air cleaner design, the processor gathers readings from detectors watching temperature, dust, or gases. After checking those numbers, it decides how fast fans should spin or if filters need adjusting. Live updates on pollution levels flow through the web, landing on dashboards like ThingSpeak or Blynk automatically. Running long hours on little energy, its brain handles quick calculations while offering plenty of ports for add-ons. Wires speak between parts using standard ways: some lines whisper serial messages, others pass chunks via SPI or I2C lanes.

- **MQ135 Gas Sensor**

When it comes to checking what's floating in the air, the MQ135 steps in as a solid pick. Not limited to just one type of gas, it sniffs out things like CO_2, NH_3, even fumes from paint or cleaning products. Smoke? Benzene? Yeah, those too - it picks up several common contaminants without much fuss. Its readings come through as voltage signals that shift when pollutant levels change. Inside devices like smart purifiers, this little detector keeps watch nonstop, feeding live updates straight to the ESP32 chip. What makes it stick around in so many setups isn't flashiness - just affordability, decent responsiveness, and how smoothly it links into circuits. Plenty of environmental tools rely on it simply because it does its job quietly and well.

- **PM2.5 Sensor**
  Tiny bits float in air, too small to see - these are called PM2.5 when smaller than 2.5 micrometers across. Deep inside your lungs they go, possibly leading to breathing trouble over time. To catch them in motion, a special tool counts how light bounces off each speck drifting by. Readings show up as micrograms packed into one cubic meter of air. This gadget talks straight to an ESP32 chip without delay. Clean air decisions happen faster because

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numbers arrive live, second after second. Purifier adjusts itself based on what it learns right now. The sensor plays a critical role in evaluating indoor air quality and ensuring healthy environmental conditions.

- **DHT22 Temperature and Humidity Sensor** The DHT22 is a digital sensor used for measuring temperature and relative humidity with high accuracy and stability. It consists of a capacitive humidity sensing component and a thermistor for temperature measurement. The sensor provides calibrated digital output, which makes interfacing with microcontrollers simple and reliable. In the proposed system, the DHT22 monitors environmental conditions that influence indoor comfort and purifier performance. The collected temperature and humidity data are also displayed on the cloud platform for real-time monitoring. Compared to other sensors, the DHT22 offers better accuracy and a wider operating range.
- **Relay Module & Fan** The relay module acts as an electrically operated switch that allows the ESP32 microcontroller to control high-power devices safely. Since the ESP32 operates at low voltage and current levels, the relay module provides isolation between the control circuit and the fan. The fan is responsible for drawing polluted air into the purifier and circulating it through the filtration system. When the air quality exceeds predefined threshold values, the ESP32 sends a signal to the relay module, which activates the fan automatically. This automated operation ensures efficient purification while minimizing unnecessary power consumption.
- **HEPA and Activated Carbon Filters** The filtration unit of the smart air purifier consists of a HEPA filter and an activated carbon filter arranged in multiple stages for effective purification.

  HEPA Filter :- HEPA (High Efficiency Particulate Air) filters are designed to capture extremely fine particles such as dust, pollen, smoke, bacteria, and PM2.5 particles. These filters can remove up to 99.97% of airborne particles as small as 0.3 micrometers. In the proposed system, the HEPA filter plays a major role in removing particulate pollutants from indoor air.

  Activated Carbon Filter :- Activated carbon filters are used to absorb harmful gases, smoke, odors, and volatile organic compounds (VOCs). The filter contains porous carbon material with a large surface area, enabling efficient adsorption of chemical pollutants. In this project, the activated carbon filter helps improve air freshness and removes unpleasant odors and toxic gases from the environment.

  Together, the HEPA and activated carbon filters provide efficient air purification by removing both particulate and gaseous pollutants, resulting in cleaner and healthier indoor air.

V. AIR QUALITY ANALYSIS AND CONTROL ALGORITHM

A. Air Quality Evaluation

The proposed IoT-based smart air purifier system uses real-time environmental sensing and intelligent analysis to evaluate indoor air quality continuously. The system collects data from the MQ135 gas sensor, PM2.5 sensor, and DHT22 temperature and humidity sensor. These sensors provide information regarding harmful gas concentration, particulate matter levels, temperature, and humidity.

The collected sensor data is processed by the ESP32 microcontroller to determine the severity of air pollution and to control the purification mechanism automatically. The system uses both threshold-based analysis and adaptive weighted evaluation for accurate and energy-efficient operation.

The adaptive air quality evaluation parameter is defined as:

$$S = w_1(PM2.5) + w_2(VOC) + w_3(Humidity)$$

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where:

- (w_1, w_2, w_3) are weighting coefficients assigned to each environmental parameter.
- (S) represents the overall pollution score of the indoor environment.

This weighted analysis enables the system to evaluate multiple environmental conditions simultaneously and improves the accuracy of pollution assessment compared to conventional fixed-threshold systems.

B. Threshold-Based Purification Control Logic

The purifier operation is controlled using predefined threshold values based on standard indoor air quality guidelines:

- PM2.5 Threshold = 100 µg/m³
- VOC Threshold = 1.0 ppm
- Humidity Threshold = 60%

The ESP32 continuously compares sensor readings with these threshold values. When pollution levels exceed the safe limits, the purifier is activated automatically through the relay-controlled fan mechanism.

The basic control logic is implemented as follows:

IF (PM2.5 > 100 OR VOC > 1.0)
→ Turn Purifier ON
ELSE
→ Turn Purifier OFF

To enhance system performance and energy efficiency, adaptive control logic is also incorporated. Based on the calculated pollution score (S), the purifier operates at different levels:

- ($S < T_1$) → Purifier OFF
- ($T_1 \leq S < T_2$) → Low-Speed Operation
- ($S \geq T_2$) → High-Speed Operation

This adaptive control mechanism ensures efficient purifier operation by adjusting fan speed according to pollution severity. As a result, the system reduces unnecessary power consumption while maintaining effective air purification performance.

C. Firmware Operation

The firmware of the proposed system is developed using Arduino IDE and Embedded C/C++ programming. The ESP32 microcontroller executes the entire monitoring and control process in a continuous loop.

The firmware performs the following operations:

1. Sensor initialization and calibration
2. Wi-Fi connection establishment
3. Real-time sensor data acquisition
4. Air quality analysis and threshold comparison
5. Automatic purifier control using relay module
6. Transmission of sensor data to cloud platforms

The processed environmental data is transmitted to IoT platforms such as ThingSpeak or Blynk for remote monitoring and visualization. This enables users to access real-time air quality information through mobile or web applications. The continuous monitoring and intelligent control algorithm ensure reliable, automated, and energy-efficient operation of the smart air purifier system.

VI. IMPLEMENTATION AND TESTING

A. Hardware Implementation

Wires link each piece - sensors plug into the ESP32, one by one. Power flows where connections meet, kept steady on purpose. The MQ-135 feeds data through an analog path straight to the chip. Communication hums along via UART for the PM2.5 detector. A single digital line carries signals from the DHT22. Relays switch the fan when needed, tied into the loop. Filtration runs only when triggers align just right. Each part has its place, none left loose.

B. IoT Integration

The ESP32 transmits environmental data to cloud platforms such as ThingSpeak and Blynk through Wi-Fi communication. The cloud platform provides:

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* Real-time monitoring
* Data visualization
* Historical data analysis
* Remote accessibility

C. Experimental Testing

The developed system was tested under different environmental conditions to evaluate detection accuracy, response time, and purification efficiency.

The system successfully detected:

* Smoke
* Dust particles
* VOC concentration
* Temperature and humidity variations

The purifier responded automatically whenever pollution levels exceeded threshold limits.

VII. RESULTS AND DISCUSSION

Out of nowhere, cleaner air appeared once the machine kicked in. When dust particles and fumes were measured afterward, numbers dropped sharply. Speed mattered - changes happened quicker than expected. Less gunk floated in the air within minutes.

Purification seems to have made indoor air noticeably cleaner, based on what the tests showed.

TABLE II

PERFORMANCE ANALYSIS OF THE PROPOSED SYSTEM

Parameter	Before Purification	After Purification	Improvement
PM2.5 (µg/m³)	165	48	70.9%
VOC (ppm)	1.8	0.6	66.6%
Temperature (°C)	32	30	—
Humidity (%)	68	55	—
Response Time	—	4.2 sec	—

The Down to 48 micrograms per cubic meter from 165 - that's where the PM2.5 landed after just minutes. VOCs dropped too, starting at 1.8 parts per million then settling near 0.6. Quick reaction stood out - about four point two seconds before changes showed up. Right away it responded, almost like it knew what was coming. Connected through IoT, data flowed into the cloud without noticeable lag. Monitoring happened smoothly, running in the background like a quiet observer. Because of smart switching logic, power use fell off sharply. Operation wasn't constant - it paused when things stayed stable. Efficiency rose simply by waiting until needed.

TABLE III

COST ANALYSIS OF THE SYSTEM

Component	Cost (INR)
ESP32	300
MQ135	150
PM2.5 Sensor	800
DHT22	200
Relay	100
Total	**~1550**

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The proposed system provides a low-cost alternative to commercially available smart air purifiers.

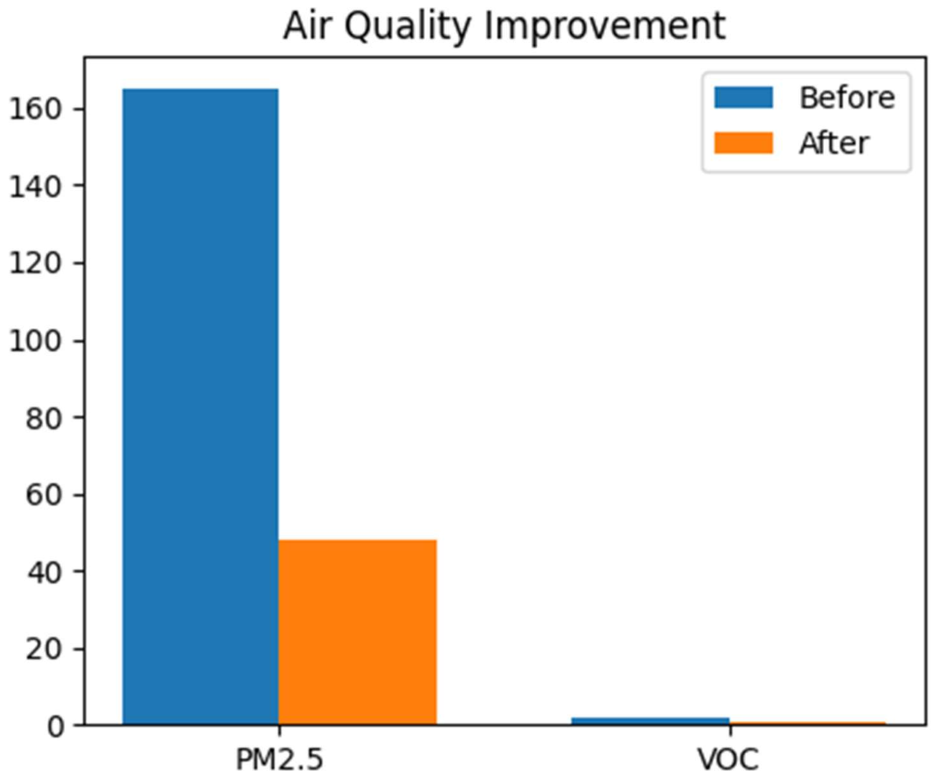

Fig. 3. Air Quality Improvement Performance

Parameter	Before	After
PM2.5 (µg/m³)	165	48
VOC (ppm)	1.8	0.6
Humidity (%)	68	55

VIII. CONCLUSION

One big thing here shows how clean air gets tracked by a gadget using internet links. It fixes pollution levels without someone needing to step in every time. Cost stays low while working across different places like clinics, work desks, or living rooms. Built around a small brain called ESP32, it pulls data from detectors watching humidity, dust, and gas. Messages travel online so updates appear far away just as fast as nearby. Automation kicks fans on or off through electric switches tied to real conditions. From start to finish, pieces fit together allowing constant checks indoors with little delay. Each part plays role when air needs correction right then. From tests, lower levels of PM2.5 and VOCs show up fast, using less energy along the way. Because it adjusts thresholds on its own, the air cleaner runs smarter without wasting electricity. Built to be affordable and flexible, it works well in homes, workplaces, schools, hospitals - wherever clean air matters. Down the road, features like prediction through AI, better sensors, and links to household systems could become part of it.

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