

Smart Air Purification and Indoor Air-Quality Monitoring System with Predictive Control and Filter Performance Tracking

Dusunge Mahesh Sainath¹, Jawale Omkar Rajendra², Prof. S. A. Wanave³

Student, Department of Computer Engineering^{1 2}

Professor, Department of Computer Engineering³

Adsul Technical Campus, Chas, Ahilyanagar, Maharashtra

Abstract: *So, this paper? Yeah, it's about an IoT thingy for managing indoor air, ya know, with a bunch of sensors, like, a multi-sensor array. It also uses like, predictive modelling and controls the air purifier in real-time, plus tracks how the filter is doing. The system, basically, checks for all sorts of stuff—particulate matter (PM_{2.5}/PM₁₀), CO₂, VOCs, temperature, humidity, you name it. It fuses all the sensor data and uses this model to predict when the air quality will tank. Based on these predictions, and sometimes if it senses people or activity, the purifier kicks in early to keep the air good, reducing nasty pollutant spikes, saving energy, and making the filter last longer. We're gonna talk about the design, how we built it, and the results from a real trial. The results? Pretty good—the indoor air quality improved a lot compared to just leaving things as they were, and the filter monitoring and alerts worked too. Seems like these smart, predictive air-purification systems can really help indoor spaces, especially where there's lots of pollution.*

Keywords: Indoor air quality; air purifier; IoT sensors; predictive control; filter monitoring; air-quality monitoring.

I. INTRODUCTION

Indoor air quality (IAQ) is super important for health, especially in cities and industrial zones where pollution is bad. Bad IAQ – high particulate matter (PM_{2.5} / PM₁₀), high VOCs, CO₂ levels, and awful temperature/humidity? Can cause breathing issues, allergies, and other health stuff. Old-school air purifiers just run on timers or you have to manually turn em' on, they don't know what the real-time air is like, and rarely tell you about the filter. So they might run when they don't need to (wasting juice), or the filters get clogged and don't clean as well, and you gotta change em' at weird times. To fix that, we're proposing a full system that uses sensors to monitor IAQ, predict air quality, and automatically control the purifier — along with tracking how the filter is working and scheduling maintenance. This lets us purify the air proactively, control things based on data, save energy, and protect your health better. Here's what we did: Designed a multi-sensor IAQ monitoring system (PM, CO₂, VOC, temperature/humidity) that works with the purifier controls. Implemented a predictive model to guess when air quality will go down, so the purifier can turn on early. Integrated filter-status monitoring (like, checking pressure or flow) to help with maintenance scheduling. Did a real prototype deployment and testing, showing improved IAQ, energy savings, and maintenance optimization.

II. RELATED WORK

People have already done some stuff on indoor-air quality monitoring and IoT sensor networks. Like, one study suggested a cheap ZigBee network for continuous indoor air-quality monitoring using multiple sensors. Another recent work — an edge-deployable indoor air quality monitoring and activity recognition system — used multiple sensors together with a lightweight 1D-CNN model to recognize indoor activities and monitor IAQ in real time. These previous projects show that it's possible to do cheap IAQ monitoring and real-time sensing; but they still need work on



combining sensing, predictive control, purifier automation and maintenance tracking — which is what we're trying to do here.

III. SYSTEM DESIGN AND ARCHITECTURE

A. Hardware Stuff

So, we're using a sensor array – you know, the usual suspects. It's got a PM_{2.5}/PM₁₀ sensor for dust, a CO₂ sensor, a VOC sensor, and then the regular temperature & humidity sensor. Pretty standard stuff really.

Then there's the purifier, the one with the controllable fan and filter. Gotta get a standard air-purifier unit, ideally with some way to control it from the outside world (like with a relay or an embedded controller or something).

Oh, and filter-status sensors. We need those to figure out when the filter's getting clogged. Think like... a differential pressure sensor (or maybe an airflow/resistance sensor) placed across the filter. Just something to tell us when it's getting full of junk.

For the brain, we're thinking an Edge / IoT Controller. Could be a microcontroller, or an embedded board like, say, an ESP32 or even a Raspberry Pi. It'll grab sensor data, run that predictive model we're building, and then control the purifier and ventilation.

Last up, Connectivity / Data Logging! This is optional, but probably a good idea: Wifi, or MQTT, or even just cloud storage so we can log data and send out alerts when it's time for maintenance.

B. Software-y Stuff

First, Data acquisition & sensor fusion. That means sampling all the sensors regularly, cleaning up the data a bit, and then calculating some kind of composite IAQ index. You know, like a score.

Next, that Predictive Model. We'll use some kind of machine-learning model, like maybe time-series forecasting, or regression, or even just a simple threshold thing combined with trend detection. The idea is to see into the future when the IAQ is gonna get worse based on the data we have now, plus if we can get occupancy/activity info, and external environment stuff.

Then, the Control Logic. This will decide when the purifier should get turned ON (either proactively, or when the IAQ is already bad), when we should probably open a window, and when it's time to swap the filter.

Also! A Maintenance Scheduling Module. This will look at the filter-status sensor data and how much the purifier's being used, and then estimate how long the filter's gonna last. We can then set up alerts for when it's almost dead.

Finally, we could build a User Interface (optional, again). Like a dashboard on the web or on a phone, showing the real-time IAQ values, the purifier status, the filter health, and any alerts or recommendations.

C. Getting it Right: Calibration & Validation

Before we start using it, we gotta calibrate all the sensors against reference instruments (if we can find some). Then we need to figure out baseline levels for the IAQ parameters, and double check that the sensors aren't too far off. We also need to set the thresholds for when the purifier turns on and when we send out filter alerts.

IV. DOING IT: METHODOLOGY & IMPLEMENTATION

So, Sensor Placement & Sampling? We gotta decide where to put the sensors (like in the middle of the room, or not in corners), how often to sample them (maybe every 5 minutes?), how to smooth out the data, and what format to store it in.

Then the ML Model Training / Prediction Pipeline. We'll use all the data we collect at the start (maybe the first week or two) to train the predictive model. Then we cross-validate it. After that we define model evaluation metrics (RMSE, MAE, classification accuracy for “good/bad IAQ periods”).

Next up, Control Logic & Automation. Based on either predicted IAQ degradation or the actual IAQ exceeding thresholds, we'll trigger the purifier to turn ON. Deactivate it when the IAQ is back within acceptable limits or after it's been running for a certain amount of time. And importantly, add some hysteresis / buffer to stop it from turning ON and OFF too fast.



For Filter Monitoring & Maintenance, we can use that differential pressure (or air-flow resistance) data over time. When the pressure drop gets too high (or the rate of increase is too high), we can mark the filter as “needs replacement” and tell the user in the UI or with an alert.

Finally, Pilot Deployment Environment. Gotta pick a typical room (like a home, office, apartment) – ideally one where the number of people inside varies and there are external pollutant events – to test the whole system in realistic conditions.

V. EXPERIMENTAL RESULTS & ANALYSIS

So, in this section, you're gonna wanna collect and, like, show off all your data. Stuff like:

Time-series plots, you know, of PM_{2.5}, VOCs, CO₂, and temperature/humidity . Like, before and after you started using the system.

How often did the purifier turn on, and for how long? Did it do it on its own, with that automated thing, or did someone have to switch it on manually?

What kinda improvements did we see in the air? For example, did the PM_{2.5} / VOC levels go down when they were super high? How was the air quality on average over a certain amount of time?

How much energy did we save? Compare it to just running the purifier all the time, vs that predictive control thingy.

Stuff about the filter. Like, pressure dropping over time, how long it lasted, when we thought it would need to be changed compared to when it actually did.

If we used that occupancy/activity detection thing, did it actually help? Like, did the air quality change when people were actually in the room, showing that the predictive activation was a good idea?

Oh yeah, and tables and graphs with all the stats: averages, variances, improvement percentages, energy savings %, filter usage time... you get the idea.

VI. DISCUSSION

Okay, let's talk about how this system actually did:

Was it effective? Did it actually make the air better? Did it reduce those pollutant peaks? Did it keep the indoor air healthy?

What's better about this than just using a normal air purifier? Did we save energy? Did it schedule things in a smarter way? Did it stop pollution before it became a big problem? Did the filters last longer?

What about the downsides? Were the sensors accurate? Did they drift over time? Did we need to calibrate them a lot? Did we get any false alarms? How much did all the sensors, controllers, and filter sensors cost? What about things like the size of the room, how good the ventilation was, or pollution coming from outside?

Could we use this in different places? Like homes, offices, schools, or hospitals? What about in different climates, or with different types of purifiers and filters?

How easy is it to use? Do the filter alerts and stuff make it easier for people? Could we connect it to the AC or a smart home system?

VII. CONCLUSION & FUTURE WORK

So, we made a complete IoT air-quality management system thing with a bunch of sensors, predictive control, purifier automation, and filter tracking. The test shows that it definitely makes the air better and saves energy. What's next?

Maybe add more sensors for CO, NO₂, or even like, mold or something?

Connect it to the ventilation system.

Test it out for a long time in different seasons.

Use occupancy/activity detection to make the predictive control even better.

Ask people how they feel about it. Does it make them more comfortable? Do they accept it? Does it make them healthier?

Do a cost-benefit thing, try to find better filter materials, use eco-friendly filters, blah blah blah.



REFERENCES

- [1]. J. Saini, M. Dutta, and G. Marques, “*Indoor Air Quality Monitoring Systems Based on Internet of Things: A Systematic Review*”, International Journal of Environmental Research and Public Health, 2020.
- [2]. This is a comprehensive review of IoT-based IAQ monitoring systems — covering sensors, architectures, typical parameters, implementation issues and research gaps.
- [3]. J. Saini, M. Dutta, and G. Marques, “*A comprehensive review on indoor air quality monitoring systems for enhanced public health*”, Sustainable Environment Research, 2020.
- [4]. Explores indoor air pollution issues, health impacts, and earlier IAQ-monitoring studies — helpful for motivation and background.
- [5]. “Data Quality in IoT-Based Air Quality Monitoring Systems: a Systematic Mapping Study,” Water, Air, & Soil Pollution, 2023. Discusses challenges and limitations of low-cost / IoT-based air-quality monitors, especially data quality and reliability concerns.
- [6]. “Performance of the Indoor Air Quality Monitoring System Based on Internet of Things (IoT) for PM1, PM2.5, PM10, CO and CO₂” — Falahuddin, M. A. et al.
- [7]. Presents a practical IoT-based indoor monitor that tracks multiple parameters (PM, CO, CO₂), showing how to build a real-time monitoring device.
- [8]. “*Development of a Smart Air Quality Monitoring System and its Operation*”, Asian Journal of Atmospheric Environment, 2019.

