AirGuard: Innovations in Embedded Systems for Optimal Indoor Air Quality and Human Well-Being

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***Abstract*—In light of escalating concerns over indoor air quality and its profound impact on human health and well-being, coupled with the advancements in embedded systems technology, there arises a pressing need to explore innovative solutions. This paper delves into the realm of Embedded Systems for Optimal Indoor Air Quality and Human Well-Being. It provides an overview of the current challenges and explores potential avenues for improvement. Furthermore, it presents a novel approach through the integration of embedded systems, emphasizing their role in monitoring, analyzing, and regulating indoor air quality parameters.**

***Index Terms*—Embedded Systems, Indoor Air Quality, Human Well-Being, Sensor Technology, Automation.**

I. Introduction

Life in the 21st century is intricately intertwined with the quality of indoor air we breathe, a factor profoundly influencing human health and well-being. The significance of maintaining optimal indoor air quality has become increasingly apparent, particularly in the wake of recent events prompting a reevaluation of our living environments. In this era of burgeoning technological advancements, embedded systems emerge as pivotal tools in addressing the complexities of indoor air quality management. However, despite their potential, the exploration of embedded systems for enhancing indoor air quality and human well-being has been relatively nascent until now. By harnessing the power of embedded systems technology, we embark on a journey towards revolutionizing indoor air quality management, mitigating health risks, and fostering environments conducive to human flourishing. This paper delves into the realm of Innovations in Embedded Systems for Optimal Indoor Air Quality and Human Well-Being, shedding light on emerging solutions and envisioning a future where technology serves as a catalyst for healthier living spaces.

II. The Impact of Air Quality on Human Health

Air pollution, comprising various contaminants like dust, fumes, gas, and smoke, poses a threat to human health by entering the respiratory system. Inhaling these pollutants triggers inflammation, oxidative stress, and cell mutagenicity, affecting organs such as the lungs, heart, and brain, ultimately causing diseases [2].

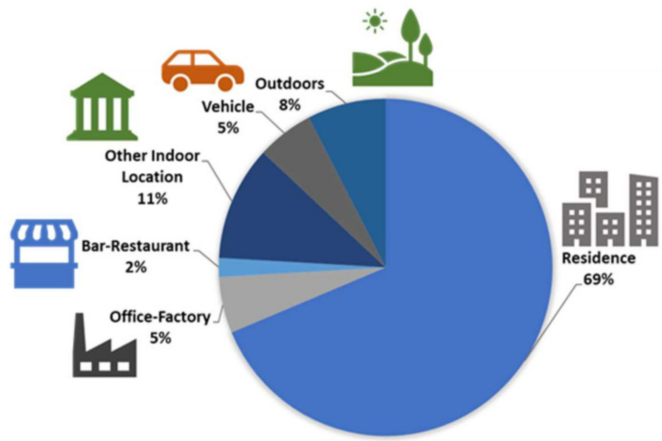

Fig. 1. Pie chart of the percentage of time spent in indoor and outdoor environments. Data were collected from the United States Environmental Protection Agency (US EPA) sponsored National Human Activity Pattern Database (NHAPS). The total number of participants was 9196, and approximately 87% of the time spent in indoor environments was in residential buildings, office buildings, restaurants, and other indoor places, such as malls, stores, schools, churches, public building, salons, health clubs, parking garages, auto-repair shops, and laundromats. [1]

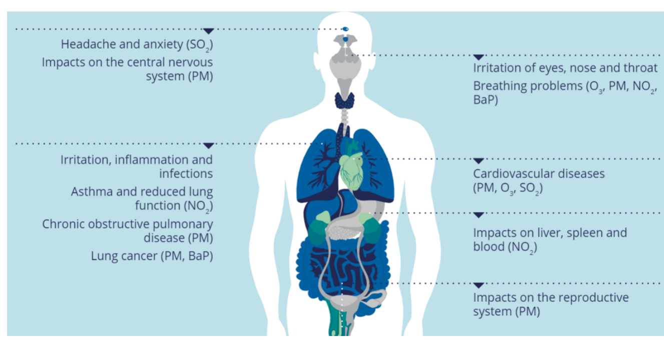

Fig. 2. Health impacts of air pollution [3]

A. What are the health effects of PM?

PM10 and PM2.5, which consist of inhalable particles, pose significant health risks, particularly affecting respiratory and cardiovascular health. Short-term exposure can exacerbate asthma, respiratory symptoms, and increase hospital admissions. Long-term exposure is associated with higher mortality rates from cardiovascular and respiratory diseases, including lung cancer. PM2.5, in particular, poses a stronger risk factor for mortality than PM10. Vulnerable groups such as those with pre-existing lung or heart conditions, the elderly, and children are most affected. Exposure to PM can also impair lung development in children. There is no safe level of exposure, and even low levels can have adverse health effects. While evidence regarding different particle compositions and sources is not conclusive, combustion-related PM, especially black carbon, is consistently linked to health hazards. Components like PAHs, metals, and inorganic salts contribute to these risks, with diesel engine exhaust classified as carcinogenic. [4]

B. The Effects of Humidity on Humans

Relative humidity (RH) is often overlooked but is crucial for maintaining healthy indoor and outdoor environments. It refers to the amount of water vapor in the air relative to the maximum possible at a given temperature. RH impacts respiratory health and allergies, with studies showing its importance.

Maintaining RH within the 40–60

RH extremes affect indoor air quality, with high RH increasing off-gassing from materials and low RH promoting indoor ozone formation. RH also influences allergen levels and pollution dynamics, impacting respiratory health.

Understanding RH's effects on health is crucial for developing preventive measures and policies. Maintaining optimal indoor RH levels can mitigate health risks by reducing irritants and microorganism proliferation. [5]

C. Health Effects of Ozone

Ozone, particularly on hot, sunny days, can adversely affect our health, even at low levels. Exposure to ozone may lead to coughing, sore throat, difficulty breathing deeply, and lung inflammation. It can also increase susceptibility to lung infections and worsen existing lung conditions like asthma, emphysema, and chronic bronchitis. Even healthy individuals can experience these effects, but those with lung diseases may face more severe consequences, including increased hospitalizations and medication use.

Long-term exposure to ozone is associated with worsened asthma symptoms and may contribute to the development of asthma. Studies suggest that areas with high ozone levels have higher rates of respiratory-related deaths. Understanding these health risks is crucial for developing strategies to mitigate ozone exposure and protect public health. [6]

D. The impact of oxygen levels on human health

Oxygen levels significantly impact human health, with an optimal level of around 21 [7] Low Oxygen Levels (Hypoxia):

- Hypoxia, or low oxygen, can cause symptoms like shortness of breath, rapid heart rate, and fatigue.
- Severe hypoxia may result in confusion, cyanosis, loss of consciousness, and organ damage.
- Prolonged exposure can lead to tissue damage, especially in vital organs like the brain and heart.

High Oxygen Levels (Hyperoxia):

- Hyperoxia, or high oxygen, can be beneficial in short-term medical settings but harmful with prolonged exposure.
- Therapeutic benefits include improved oxygenation in patients with respiratory distress.
- However, prolonged exposure can lead to oxygen toxicity, causing respiratory discomfort, chest pain, and lung damage.

Individual health factors and exposure duration influence the effects of oxygen levels on health. Maintaining optimal oxygen levels is crucial for overall well-being. Proper monitoring and management are essential to prevent adverse health effects.

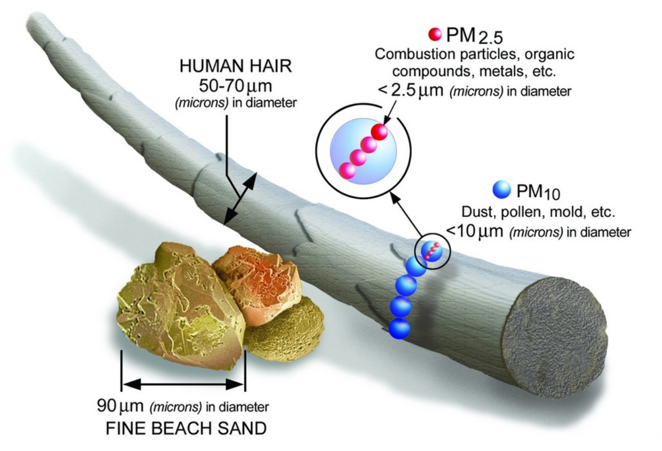

Fig. 3. Indoor air quality [8]

III. Building AirGuard

Firstly, let's start with a short overview of the parts used for this project, which are:

- 3 x Arduino uno: For the project, three Arduino Unos, each powered by the ATmega328P IC, collectively manage input data and control output devices.
- DHT11: The DHT11 sensor measures temperature and humidity levels in the environment.
- Air Quality: This sensor is designed for comprehensive monitor over indoor air condition. It's responsive to a wide scope of harmful gases, as carbon monoxide, alcohol, acetone, thinner, formaldehyde and so on.
- DSM501 dust sensor: The DSM501 dust sensor is capable of detecting particulate matter in the air, including PM10 particles. It provides valuable data for monitoring air quality and assessing potential health risks associated with elevated levels of PM10 pollution.
- Oxygen Sensor: The Gravity: I2C Oxygen / O2 Sensor is based on electrochemical principles and it can measure the ambient O2 concentration accurately and conveniently.
- Ozone Sensor: IIC Ozone Sensor is based on electrochemical principles and it can measure the ambient O3 concentration accurately and conveniently.

- UV sensor: The UV sensor for Arduino detects ultraviolet light, providing valuable data for monitoring UV exposure levels.
- Light Sensor: The Grove Light Sensor is a module that is used to measure light intensity.
- Stepper Motor: In the project, a stepper motor is employed to shield plant growth from excessive light by controlling the movement of shades or blinds.
- TDS sensor: TDS (Total Dissolved Solids) indicates how many milligrams of soluble solids are dissolved in one liter of water. In general, the higher the TDS value, the more soluble solids are dissolved in water, and the less clean the water is.
- Photoelectric High Accuracy Liquid Level Sensor: This is a photoelectric water liquid level sensor that is operates using optical principles.
- Moisture Sensor: This Moisture Senor can be used for detecting the moisture of soil or judge if there is water around the sensor.
- Water Flow Sensor: The Water Flow Sensor for Arduino measures the flow rate of water in a system, providing crucial data for monitoring and controlling water usage.
- TEC1-12706 Heatsink Thermoelectric Cooler Peltier: The TEC1-12706 Heatsink Thermoelectric Cooler (Peltier) used to dehumidify air by creating a temperature difference that causes moisture to condense on its cold surface.
- Plant heater: A plant heater is a device that provides warmth to plants during cold weather to maintain optimal growth conditions.
- Plant lamp: A plant lamp is a light fixture that provides artificial light to plants for growth when natural sunlight is insufficient.
- Water Level Sensor: The Water Level Sensor detects the water level in the dehumidifier.
- 5 Cooler:5 coolers serving for air circulation.
- 3 filters: Three air purification filters significantly improve indoor air quality.
- One battery, one solar panel, and two adapter: One battery, one solar panel, and two adapter power the entire system.

The project comprises three Arduino Uno boards interconnected for seamless communication. Communication is facilitated via serial ports through which they exchange necessary information. Among the Arduino units, one integrates a built-in WiFi module responsible for gathering data from all units and transmitting it to a dedicated server. This server processes the data, subsequently displaying it on a Django application tailored explicitly for this system.

The application facilitates comprehensive monitoring of all system parameters and enables adjustment of system settings with ease.

The first Arduino board hosts a suite of sensors including a air quality sensor, DHT11, and DSM501 dust sensors. Additionally, relays are interfaced to regulate the purification system, effectively eliminating harmful particles such as PM10 dust. A relay system is implemented to modulate indoor air humidity, ensuring an optimal environment for human habitation. Controlling the TEC1-12706 Heatsink Thermoelectric Cooler Peltier, embedded within the air dehumidification mechanism, is achieved through a dedicated relay. This cooler utilizes water collected from the air to irrigate plants, thus contributing to comprehensive air quality management.

Fig. 4. The final project look

The second Arduino unit is equipped with an ozone sensor, essential for the primary Arduino's functionality. Moreover, it integrates sensors for UV light, light intensity, and a stepper motor governing solar energy absorption to foster proper plant growth. Maintaining ideal conditions for plant growth indoors, the stepper motor safeguards against harmful UV radiation, ensuring the plant's oxygen production. Additionally, a relay linked to the second system controls a supplementary lamp, activating if sunlight levels are insufficient during the day, thereby managing the plant's daylight requirements effectively.

The third Arduino unit is tasked with managing plant watering and monitoring water quality. It features TDS sensors for soluble solids measurement, liquid level sensors to monitor reservoir levels, and moisture sensors to assess soil moisture content. A water flow sensor ensures the plant receives an optimal watering volume during each cycle. This Arduino collates data from all units via a serial connection, transmitting it to the server for user visualization.

Although the Arduinos are interconnected via serial connections, each unit can operate independently. Collectively, they function to optimize indoor air quality for human comfort. Power is supplied to the entire system through a battery, rechargeable via a solar panel for autonomy. Alternatively, the battery can be charged from a power outlet if solar energy production proves insufficient. A dedicated adapter powers the heater and the TEC1-12706 Heatsink Thermoelectric Cooler Peltier, requiring 12V 12.5A 150W of electricity. The battery outputs at 12V and 5V, while the solar panel generates a current of 16V.

Fig. 5. Project look how is working

IV. FUTURE IMPROVEMENTS

Enhanced Connectivity: Upgrade the communication system to incorporate more advanced protocols such as MQTT or WebSocket for improved reliability and efficiency in data transmission between Arduino units and the server. This can help reduce latency and streamline data exchange.

Integration of Machine Learning: Implement machine learning algorithms to analyze the collected data more intelligently. By leveraging historical data and real-time sensor readings, the system can learn patterns and make predictive adjustments to optimize air quality management and plant growth conditions.

Expand Sensor Capabilities: Integrate additional sensors to monitor parameters like CO2 levels, volatile organic compounds (VOCs), and pH levels of the water reservoir. This expanded sensor suite can provide a more comprehensive understanding of indoor environmental conditions and plant health, allowing for more precise adjustments and interventions.

Remote Control: Implement a mobile app or web interface that allows users to remotely control the indoor air quality and plant care system. This would enable users to adjust settings from anywhere, enhancing convenience and accessibility.

Energy Optimization: Optimize energy usage by incorporating energy-efficient components and implementing power-saving strategies. This could include optimizing relay activation schedules, using low-power microcontrollers, and integrating energy harvesting technologies to maximize autonomy and reduce reliance on external power sources.

Integration with Smart Home Systems: Integrate the indoor air quality and plant care system with existing smart home systems and platforms (e.g., Google Home, Amazon Alexa) for seamless integration into the user's home automation ecosystem. This would enable voice control, integration with other smart devices, and enhanced interoperability.

V. CLOSING THOUGHTS

In conclusion, the integration of three Arduino Uno boards into a cohesive system demonstrates a sophisticated approach to indoor air quality management and plant cultivation. Each Arduino unit plays a specific role, from monitoring air quality and regulating environmental parameters to facilitating plant growth and watering.

The seamless communication between the Arduinos via serial ports ensures efficient data exchange, allowing for real-time monitoring and control. The utilization of various sensors, relays, and actuators enables precise adjustment of air purification, humidity levels, plant lighting, and watering, contributing to an optimal indoor environment for both humans and plants alike.

The inclusion of renewable energy sources, such as solar panels, not only provides autonomy to the system but also aligns with sustainable practices. The flexibility of power sources, including rechargeable batteries and conventional outlets, ensures continuous operation even in variable conditions.

Overall, this project exemplifies a holistic approach to environmental management, leveraging technology to create healthier and more sustainable living spaces. By combining innovative hardware with intelligent software, it offers a glimpse into the future of smart indoor environments, where human comfort and ecological balance are seamlessly integrated.

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