Smart indoor air quality monitoring system: implementation and analysis

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***Abstract* —This paper presents the design and development of an intelligent air quality monitoring system that utilizes the widely adopted and versatile Arduino Uno microcontroller as its foundational platform. The system underwent comprehensive testing procedures to ensure its adherence to specified requirements. Moreover, a series of experiments were conducted in diverse areas of a residential environment to generate datasets for various air quality indicators. The research findings showcase the potential of the developed system in accurately monitoring and assessing indoor air quality in real-time. Enhancing indoor air quality plays a crucial role in mitigating the transmission of common airborne viruses and pollutants, thus significantly benefiting respiratory health.**

***Keywords* - air quality, analysis, health, humidity, monitoring, temperature**

I. Introduction

Indoor Air Quality (IAQ) is a multifaceted topic that demands continuous research and action to safeguard human well-being [1-3]. As we become more aware of the impact of IAQ on our health, it becomes evident that addressing this issue is of paramount importance. Not only do people spend a significant portion of their lives indoors, but the consequences of poor IAQ can be severe, affecting both short-term comfort and long-term health.

While the adverse health effects of poor IAQ, such as headaches, respiratory tract irritation, fatigue, asthma, and allergies, are well-documented, the link between prolonged exposure to low IAQ and the increased risk of cancer serves as a stark reminder of the urgent need for better indoor air management [1]. Consequently, understanding and mitigating the sources of Indoor Air Pollution (IAP), particularly Volatile Organic Compounds (VOCs), becomes imperative in our pursuit of a healthier indoor environment [3-5].

VOCs, which emanate from common household items like paints, waxes, and pesticides, contribute significantly to the degradation of IAQ. The off-gassing of organic chemicals from these products introduces a variety of harmful compounds into the air, posing potential risks to respiratory health and overall well-being [3]. Consequently, strategies to reduce VOC emissions and promote eco-friendly alternatives have emerged as key components of sustainable indoor air management.

The field of air quality management has gained momentum in recent years, with extensive research focusing on air quality monitoring and the development of specialized equipment to detect and alleviate pollutants. While these efforts are commendable and have led to valuable insights, there is still untapped potential for further advancements. Researchers and practitioners should collaborate to explore innovative solutions that address the complexities and challenges inherent in managing IAQ effectively.

One promising area of exploration lies in leveraging cutting-edge technology, such as Internet of Things (IoT) devices, to create intelligent and adaptive indoor air quality systems. These systems could constantly monitor IAQ parameters and respond dynamically to fluctuations in pollutants, allowing for real-time interventions to maintain healthier indoor environments. Additionally, the integration of AI algorithms in air quality management could facilitate more accurate predictive models, aiding in the early detection of potential IAQ issues and preventing health risks proactively.

Education and awareness campaigns are equally crucial in the endeavor to improve IAQ. Empowering individuals with knowledge about the sources of indoor air pollution and the steps they can take to reduce their exposure can make a significant difference in promoting healthier habits and fostering a culture of air quality consciousness.

Furthermore, policymakers should take heed of the significance of IAQ and implement stringent regulations to limit the use of VOC-emitting products and encourage the adoption of eco-friendly alternatives. Financial incentives and tax breaks for businesses and individuals investing in IAQ improvements could also accelerate the transition towards healthier indoor environments.

So, Indoor Air Quality is an ever-evolving domain that necessitates continuous efforts and collaborative initiatives from various stakeholders. By acknowledging the far-reaching implications of poor IAQ on human health and the environment, we can drive research, innovation, and policy changes to create safer and healthier indoor spaces for everyone. Only through concerted action and a holistic approach can we tackle the challenges of IAQ effectively and secure a better, cleaner future for generations to come.

II. Related works

A multitude of air quality monitoring systems have been documented in the scientific literature, as evidenced by various studies [1, 6-7]. These studies underscore the potential of leveraging Internet of Things (IoT) technology to enable indoor air quality monitoring through the utilization of low-cost sensors. The development of such systems was driven by the backdrop of the global pandemic in 2020, which highlighted the critical importance of well-ventilated indoor environments. The significance of maintaining optimal air quality in these spaces emerged as a primary concern, as it serves as the foremost line of defense in safeguarding human health [8-10].

Researchers primarily focus on evaluating environmental quality in diverse indoor spaces across multiple buildings, offering insights through various measurement indicators. However, studies specifically examining air quality monitoring in contrasting rooms within residential households are relatively scarce. This article addresses this research gap by introducing a developed monitoring tool to assess residential spaces' surrounding environment and explore the relationship between room properties and air quality in such settings.

III. METHODOLOGY

When examining the implementation and testing of intelligent air quality monitoring systems, several key issues come to light:

- Insufficient number of measured indicators;
- Measurement errors;
- Lack of sufficiently complex experiments;
- High cost.

Enhancing the accuracy of data collection plays a pivotal role in improving the outcomes of subsequent data processing in the context of air quality monitoring. Real-time air quality readings enable timely measurements, allowing for monitoring at any given moment.

This study aims to develop an air quality monitoring system using low-cost sensors to measure fundamental indicators. It will conduct comprehensive experiments with household chemicals and scented products to assess their impact on indoor air quality. Additionally, the study plans to generate ten-day datasets from contrasting residential rooms to evaluate air quality variations over an extended period.

IV. IMPLEMENTATION OF THE SYSTEM AND RESULTS OF THE EXPERIMENTS

The system utilizes Arduino Uno microcontroller for computational power and versatile port support. It features two sensors - BME680 and CCS811 - for measuring vital air quality indicators: temperature, humidity, atmospheric pressure, CO_2, VOCs, and IAQ. Fig. 1 shows the system's external appearance and design.

Fig. 2 shows the functional electrical circuit diagram of the system, representing the interconnections and functions of its components. It provides a clear understanding of the system's operational mechanism and internal processes.

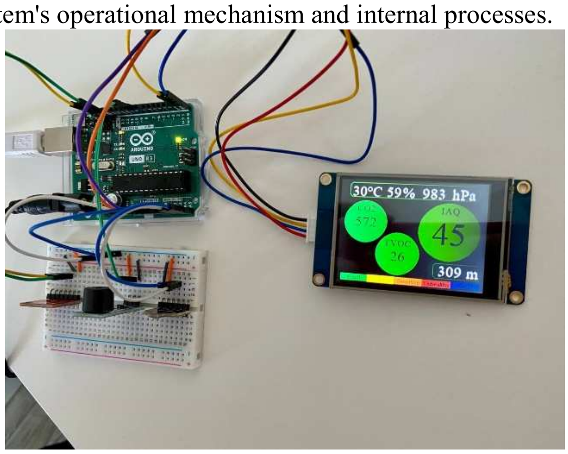

Fig. 1. The appearance of the system

The BME680 and CCS811 air sensors communicate with the Arduino microcontroller via the I2C serial bus. They capture air quality indicators and send the data to the ontroller for processing. The NX3224T028 display interfaces with the Arduino using the UART port (RXD and TXD modules) to present information to the user. The speaker is connected to the system for sound notifications upon detecting critical air quality indicators.

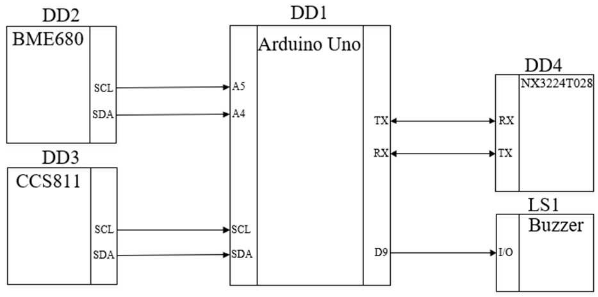

Fig. 2. Functional electrical diagram of the system

The system incorporates a color-coded display specifically designed to visualize the IAQ, carbon dioxide (CO_2), and VOC air quality indicators. The ranges those indicators of air quality are presented in Table I.

TABLE I. RANGES OF COLOR INDICATIONS OF AIR QUALITY PARAMETERS

Quality index (color)	**IAQ**	**CO_2**	**VOC**
Good (Green)	≤ 50	≤ 700	≤ 200
Moderate (Yellow)	51 - 175	701 - 1000	201 - 400
Unhealthy for sensitive groups (Orange)	176 - 200	1001 - 1500	401 - 600
Unhealthy (Red)	201 - 300	1501 - 2500	601 - 1000
Hazardous (Purple)	> 300	> 2500	> 1000

Table II shows the measurement errors of all air indicators in the system, based on the values provided by the sensor manufacturers.

TABLE II. TABLE OF AIR QUALITY MEASUREMENT

Air indicator	**Maximal Permissible Error**	**Measurement ranges**
Atmospheric pressure	± 1 hPa	300 — 1100 hPa
Carbon dioxide	± 3%	400 — 8192 a. u.
Humidity	± 3%	0 — 100 %
Temperature	± 1.0 °C	-40 — 85 °C
Volatile Organic Compounds	± 3%	0 — 11870 ppb

A. Analysis of variations in air quality indicators across different residential spaces

An experiment was conducted in three separate rooms - a bedroom, a kitchen, and a bathroom - to investigate air quality variations. Sensor data was collected over 10 days with daily recordings at 1:00 PM, preceded by a 30-minute warm-up period to ensure precision. This approach aimed to comprehensively understand the indoor air quality differences among the rooms. The results for IAQ, humidity, carbon dioxide, and VOC data for the three rooms are presented in Fig. 3, 4, 5, and 6, respectively.

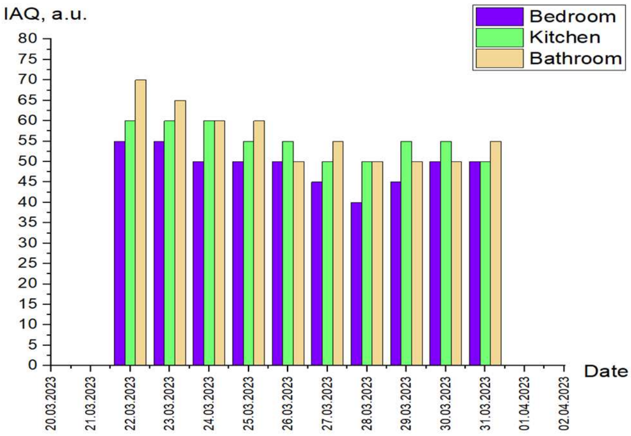

Fig. 3. Data collection for different rooms in the house. IAQ values

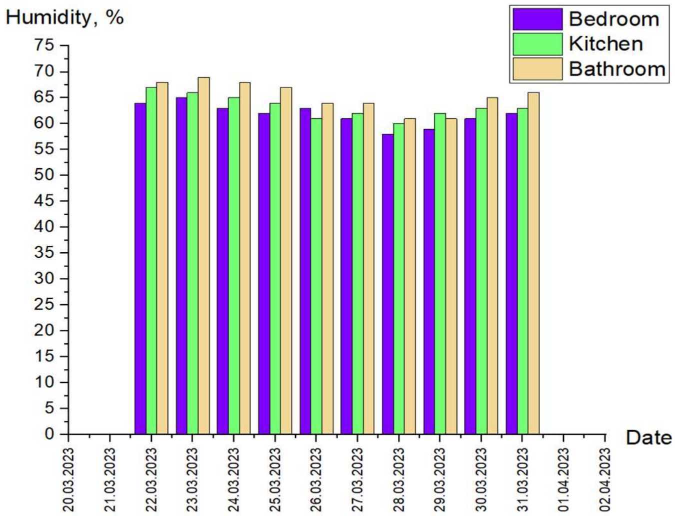

Fig. 4. Data collection for different rooms in the house. Humidity values

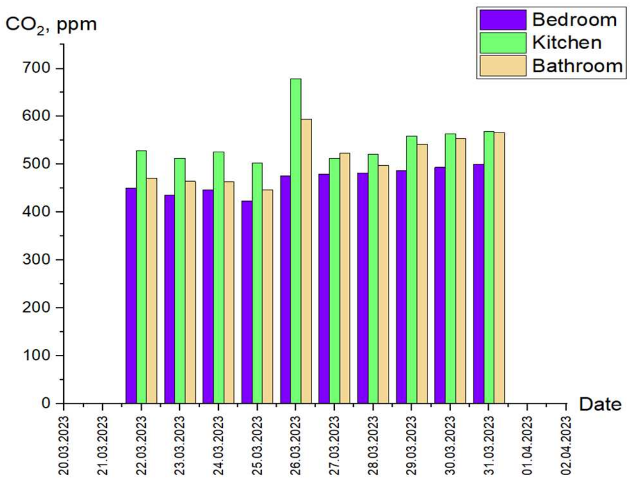

Fig. 5. Data collection for different rooms in the house. CO_2 values

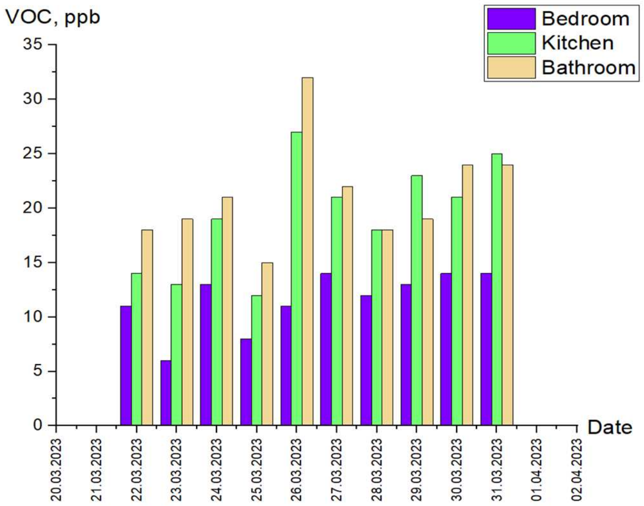

Fig. 6. Data collection for different rooms in the house. VOCs values

Figure 3 illustrates the discrepancy in indoor air quality among rooms. The kitchen and bathroom show poorer air quality compared to the bedroom, influenced by household chemicals, cleaning agents, air fresheners, and higher humidity levels.

Figure 4 highlights higher humidity levels in the bathroom and kitchen due to continuous water usage and inadequate ventilation. Activities like cooking and water evaporation also contribute to increased humidity.

Figure 5 reveals the kitchen has the highest CO_2 levels due to poor ventilation, gas stove use, and household chemicals. The bathroom's CO_2 levels are lower but still exceed the bedroom due to better ventilation offset by cleaning agents and air fresheners.

Figure 6 demonstrates that the bathroom has the highest abundance of VOCs from sources like air fresheners, cleaning agents, disinfectants, cosmetics, and personal care products. VOCs are also present in the kitchen from cooking and air heaters. The bedroom lacks these VOC sources, resulting in lower levels.

Moreover, this study established a significant linear correlation between gas resistance and humidity levels. The findings indicate that as humidity increases, there is a corresponding change in gas resistance. This correlation provides valuable insights into the relationship between humidity and the gas resistance parameter, contributing to a deeper understanding of the underlying mechanisms influencing air quality in indoor environments.

B. The Impact of Fragrance Products on Air Quality

Indoor air quality is affected by volatile organic compounds from cleaning agents and chemical reactions in residential settings. To analyze this, an experiment assessed air quality indicators when using common household products like aromatic diffusers, perfumes, and aerosols.

Figure 7 presents the IAQ values, Figure 8 showcases the CO_2 levels, and Figure 9 depicts the VOC measurements for the mentioned household products.

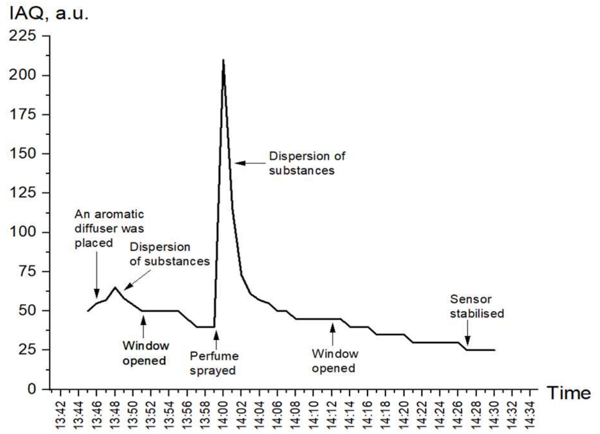

Fig. 7. Controlled experiment: effect of aromatic diffuser and perfume. IAQ values

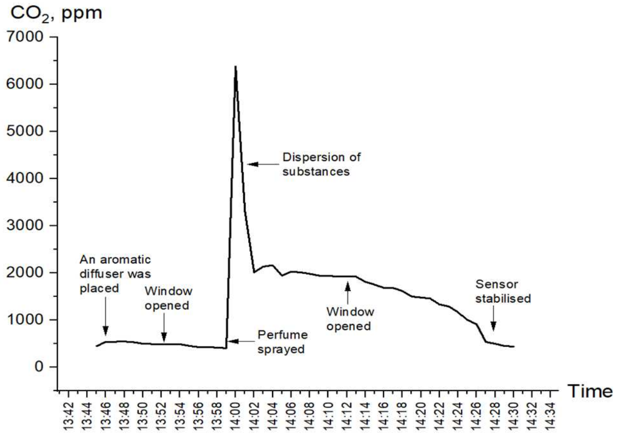

Fig. 8. Controlled experiment: effect of aromatic diffuser and perfume. CO_2 values

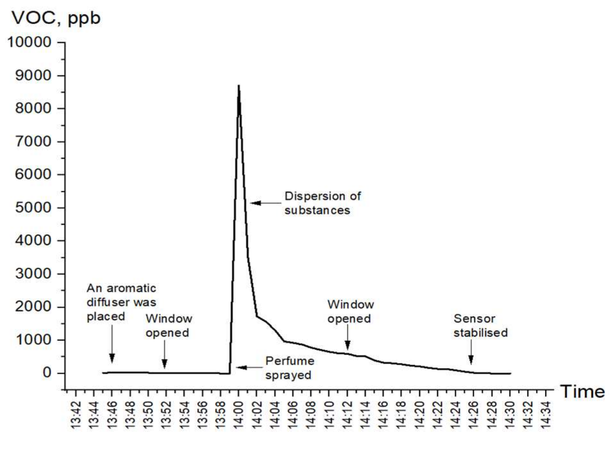

Fig. 9. Controlled experiment: effect of aromatic diffuser and perfume. VOC values

At 15:00, spraying 17% perfume from a distance of five meters significantly deteriorated air quality, evident from critical readings. VOC presence persisted for about ten minutes before gradually dissipating. By 14:12, readings stabilized, and opening the window further improved air quality. At 14:26, the sensors fully stabilized, ensuring reliable measurements.

This study compares the influence of household products on indoor air quality, offering valuable insights. Addressing indoor air pollution is vital for human well-being, and intelligent air quality monitoring systems help identify and mitigate health risks, reducing the occurrence of diseases and related conditions.

V. Conclusion

This study presents the implementation, testing, and research conducted on an intelligent indoor air quality monitoring system utilizing the Arduino Uno platform. The primary objective of this system is to enhance air quality in indoor spaces by mitigating the transmission of airborne viruses and pollutants that contribute to respiratory illnesses. By providing near real-time data, this developed system aims to serve as a reliable solution for air quality monitoring.

The obtained results from two experiments unequivocally reveal the adverse effects of household chemicals and perfumed products on indoor air quality and, consequently, on the well-being of occupants. This underscores the significance and relevance of the present research in deepening our understanding of the potential health risks associated with such household products.

Moreover, the collected dataset contributes to the broader field of IAQ research by providing a comprehensive ten-day dataset encompassing three distinct locations within a single building.

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