Respiro: A Personalized Asthma and Allergen Alert System—Advanced Spatial Sensing for Proactive Respiratory Health Monitoring

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Abstract

Asthma patients often face the risk of unexpected attacks in their daily lives. Respiro is a wearable device that provides real-time air quality monitoring, detecting volatile organic compounds (VOCs) and carbon monoxide. It delivers alerts through the Respiro app about potential asthma triggers before they become harmful, enhancing respiratory health management. By customizing notifications based on each user's health data and sensitivity to pollutants, Respiro is the first personalized air pollution monitor of its kind. Additionally, it tracks physiological changes like heart rate and pulse oxygen to detect asthma attacks, helping patients manage their condition more effectively and confidently.

Keywords: **Asthma management, wearable technology, real-time monitoring, personalized health alerts, respiratory health.**

Introduction

Statistics show that nearly 40% of the 9.8 million people from the U.S that have asthma, have had respiratory attacks (Centers for Disease Control and Prevention, 2023). The same is true for about 50% of the 16 million people that have COPD (Hurst et al., 2010). According to Allergy and Asthma Network's 2023 report on asthma statistics, 81.9 billion dollars are spent annually on healthcare costs and 72% of people that use inhalers, misuse them. Additionally 13.8 million school days are missed annually by the children that experience asthma, limiting their educational exposure (Allergy & Asthma Network, 2023). As discussed above, lung diseases such as asthma or COPD are very restrictive diseases that can interfere with the livelihood of individuals in substantial ways. It has also been proven that 85% of asthma patients have allergic rhinitis (Seasonal Allergies). Hence to find an effective solution to correlate and detect the pollutants in the surrounding environment becomes imperative.

Respiro comprises a glove, capable of detecting indoor and outdoor environmental pollutants that can cause asthma and other respiratory issues. The glove with pulse oximeters, to detect changes in oxygen content and heart rate, is attached to the dorsal aspect of the fingers. The portion of the glove that is worn on the wrist is capable of detecting levels of certain environmental pollutants that can cause respiratory distress such as asthma, COPD, or allergic flare ups. All of the collected information that is stored can be used to develop an allergen profile for the individual user that can be reported to the user via an app.

Method

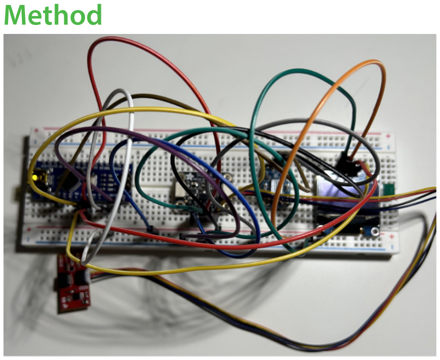


Fig. 1.

In crafting the hardware for this project, my goal was to engineer a foundational circuit for Respiro that combines an array of sensors for pollutant detection and heart rate monitoring. Firstly, I started by choosing sensors with proven accuracy in identifying volatile organic compounds (VOCs), carbon monoxide (CO), and in monitoring heart rate due to their precise sensitivity, swift response times, and compatibility with the Arduino microcontroller. In this case I used the Adafruit MiCS5524 CO, Alcohol and VOC Gas Sensor Breakout for measuring carbon monoxide, the Adafruit SGP40 Air Quality Sensor for monitoring VOCs, and the Arduino Nano V3.0 for the microcontroller. The Arduino microcontroller was deployed as the core processing unit, managing data processing, and overseeing communication with the sensors and the display interface. The initial assembly was conducted on a breadboard, allowing for the interaction between the sensors and the microcontroller as shown in figure 1. This allowed for the extraction of data from the sensors to begin the initial phases of testing. The introduction of an OLED LCD display allowed for the individuals to view the collected data in real time, making an effective way to preemptively warn them.

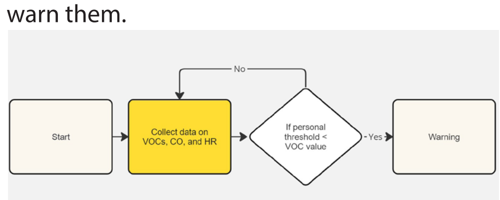
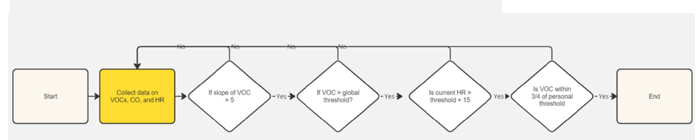


Fig. 2. (top)
Fig. 3. (bottom)



For the software component of the device, I chose to start with the Arduino Integrated Development Environment (IDE) for programming the Arduino microcontroller. Using IDE I wrote custom code for each sensor, enabling the microcontroller to collect data on VOC, CO levels, and heart rate, and print into the serial monitor. This involved initializing each sensor, setting the appropriate digital or analog input pins, and reading sensor outputs at regular intervals. I then used the aforementioned code and developed an algorithm that creates personalized air quality thresholds based on user sensitivity which is shown on figure 3. Starting with default VOC, CO, and heart rate (HR) thresholds from health guidelines, the app continuously collects and timestamps data. It calculates the rate of change for VOC and CO to detect spikes. If a rapid increase in VOC/CO levels exceeds initial thresholds and coincides with a rise in HR, this value is used to adjust the threshold for the individual as seen in figure 2.

Fig. 4.

In initial phases of testing, the prototype was wired directly to the computer and the inputs, analyzed by the Arduino IDE code was retrieved by a Visual Studio System which displayed information such as trends in pollution levels, warning systems, live tracking of vitals, and history of previous instances. This approach was ineffective due to its reliance on a wired system, which was impractical. Additionally, using a computer to notify individuals of sudden pollution changes was not ideal, as it's not always readily available in real-world scenarios. To address these issues, I introduced a BLE system and developed a mobile app using Xcode as shown in figure 4. With a peripheral simulator in Xcode, I was able to scan for nearby BLE devices and pair them with my prototype to receive input data. Since the Arduino Nano had already been programmed with the algorithm and processing code, the data could be easily retrieved and displayed through the Xcode UI. After designing a theme to present the key information originally shown in the Visual Studio app, I completed the Respiro mobile app.

Trials	Air Freshener Distance (feet)	Candle Light Distance (feet)	Carbon Monoxide Car (inches)
1	164.4 in	16.5 in	152 in
2	188.4 in	18.5 in	155 in
3	201.6 in	9 in	128 in
4	189.6 in	9.5 in	135 in
5	174.0 in	15.5 in	114 in
6	196.8 in	17 in	158 in
7	237.6 in	8 in	134 in
8	178.8 in	8.5 in	151 in
9	156.0 in	15.5 in	147 in
10	224.0 in	13 in	143 in
11	171.6 in	7.5 in	153 in
12	219.6 in	12.5 in	123 in
13	208.8 in	14.5 in	137 in
14	158.4 in	8 in	114 in
15	148.8 in	12 in	157 in
Average	187.92 in	12.4 in	140.07 in

Table 1

In testing the effectiveness of Respiro's hardware and software, I simulated increased VOC levels using air fresheners, candles, and vehicle emissions, then measured the device's detection range with the results shown in table 1. The control in this experiment was the baseline air quality readings prior to any increase in VOC levels. The independent variable was the type and source of the pollutant, while the dependent variable was the distance from which the device could detect these pollutants. Throughout the trials, variables such as temperature, humidity, and initial air quality were carefully controlled and kept consistent to ensure reliable results.

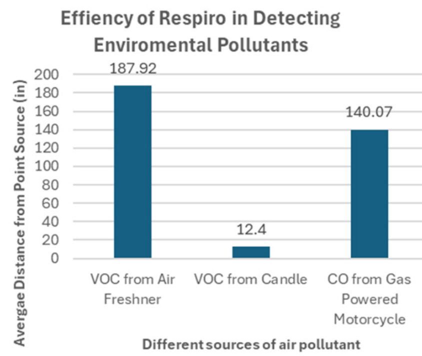


Fig. 5.

Results showed Respiro detected VOCs from air fresheners at an average distance of 187.92 inches (477.32 cm), from candles at 12.4 inches (31.50 cm), and CO emissions from vehicles at 140.07 inches (355.78 cm) as shown in figure 5. To verify whether the detected fluctuations in pollutant levels originated from the source, I gathered data before and after introducing the pollution. I also spaced out the collection periods to allow the VOCs sufficient

time to disperse. This approach helped me ensure the accuracy of my measurements by differentiating between background and source-related pollution levels. The gathered data suggests that the device's ability to detect pollutants is influenced by the emission rate and volume of the source. For example, the larger quantity and faster diffusion rates from air fresheners and vehicle emissions allowed for detection at greater distances compared to the more localized emissions from candles.

These tests confirm that Respiro can effectively warn users about environmental hazards, showcasing the practical distances at which individuals can avoid exposure to various pollutants. This ensures that Respiro can detect pollutants well before users are at risk of developing symptoms, providing timely alerts about environmental conditions.

Although these results demonstrate Respiro's effectiveness as a device and its accuracy at detecting pollutants, they do not confirm its effectiveness at preemptive asthma alert warning. This limitation arose due to the absence of a human testing component (measuring changes in heart rate, pulse oxygen, and breathing pattern analysis) of the device. The future experiments will concentrate on human testing to verify the accuracy of previous results and validate the data obtained during this study. In the meantime, Respiro proves to be an efficient asthma detection device for the future market.

Discussion

The engineering design criteria for my device closely aligned with the features of the current prototype, which was primarily focused on detecting VOCs and CO in the environment to preemptively alert users before these pollutants could trigger an asthma attack. The tests conducted demonstrated that the device not only effectively monitors these pollutants but also detects them at a safe distance before reaching the source, providing a reliable early warning system.

Additionally, the development of a mobile app was another important criteria, designed to display environmental pollutant data effectively. The app was used to display pollution data while testing, validating its functionality in real-time data monitoring and historical data analysis as shown in figure 5.

However, there were some limitations in our study that could affect the results. The controlled testing environment doesn't fully mimic the real-world scenarios where pollutant concentrations can vary greatly due to factors like weather conditions, traffic density, or geographical features. Furthermore, the pollutants released during previous trials can accumulate due to the indoor environment, affecting future trials' reading.

Overall, the device offers real-time detection of VOC and CO levels, preemptively alerting users of potential health risks from pollutant exposure, aligning with the aforementioned criteria.

Conclusion

Respiro represents a significant step forward in respiratory health monitoring, integrating advanced sensor technology with real-time data processing in a wearable format. The device has

demonstrated its capability to detect volatile organic compounds (VOCs) and carbon monoxide (CO) at safe distances, providing early alerts to users based on personalized thresholds derived from their specific health data. This proactive approach has the potential to significantly reduce the occurrence of asthma attacks and improve overall respiratory health management.

Despite these promising results, the study's limitations, including the controlled testing environment and the absence of human trials, show the need for further development. Future efforts should focus on validating Respiro's performance in real-world scenarios and through comprehensive human testing to ensure the device's accuracy, reliability, and practical applicability.

In summary, Respiro shows great potential to enhance the quality of life for individuals with asthma and other respiratory conditions by offering personalized, timely alerts based on environmental triggers. As the device undergoes further refinement and validation, it stands to become an essential tool in both personal and clinical respiratory health management.

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