Mobile Robot for Air Quality Monitoring Based on Condensate Water Analysis

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Abstract: *The Mobile Air Quality Analysis Machine is an innovative device designed for monitoring air pollutants in various indoor and outdoor environments. Poor air quality likely led to lung diseases like asthma, COPD, and lung cancer. However, indoor air quality is currently expensive to evaluate, and at least 440,000 workers were suffering from poor health conditions due to dangerous levels of air pollution in their workplaces. Therefore, creating an economical, efficient, and effective device that could evaluate indoor and outdoor air quality is crucial. At the same time, its real-time monitoring capabilities can help protect workers and prevent health problems. Equipped with several sensors to detect air pollutants and collect samples of condensate water from the air, the machine provides a more accurate measurement of air quality. Its mobility derives from four motors, allowing for more comprehensive data collection and analysis, as the machine can cover a wider area. After collecting data from 4 typical environments, a relation of the pH value of the condensate water and air's polluted gas concentration was generalized. Furthermore, the device provides real-time data analysis and visualization through 0.96 OLED, allowing for immediate detection of air pollution and facilitating effective and timely responses. The device can be implemented in indoor environments such as factories and warehouses, alerting workers to hazardous pollution indoors. The machine is a promising solution to the challenges of air pollution monitoring, and its potential applications are vast. This paper discusses the design, development, and testing of the machine.*

Keywords: *air quality, condensate water, mobile robot, indirect contamination detection*

1. Introduction

Recently, environmental issues are quickly entering the world's spotlight; the wide spread of social media has aroused people's concern about air quality, which is closely related to human health. Poor air quality likely brings healthy human lung diseases like asthma, COPD, and lung cancer.

Although local broadcasts are reporting air quality on a large scale, in specific places, the report could not accurately show the remarkable air quality of the ambient environment, such as indoors. According to a new whitepaper published by Global Action Plan and Zehnder Clean Air Solutions, approximately 440,000 workers were suffering from poor health conditions due to dangerous levels of air pollution in the workplace. Therefore, having a machine that accurately reflects the air quality in indoor workplaces emphasizes the issue, so the workers could be aware of their devastating potential health risks and make a change.

Current known indoor air pollution comes from both external factors and internal factors. On the external aspect, the indoor lousy air quality is derived from the room's location. As the surrounding environment retains a lousy air quality, indoor air quality would also be influenced. Moreover, the surrounding pollution could be attributed to mobile sources, including cars and trains; stationary sources, including power plants, oil refineries, industrial facilities, and factories; area sources, including agricultural areas, cities, and wood-burning fireplaces; and natural sources, including wind-blown dust, wildfires, and volcanoes. However, based on Thad Godish's research in his book "Indoor Air Pollution Control," environmental factors did not play a substantial role in indoor air quality.

On the other hand, the internal factors contributing to bad indoor air quality are less broad. Factors such as fuel burning, cooking, human activities, the use of the substandard building and decorative materials, and the airtight structure of houses are the major components of poor air quality, often worse than outdoor pollution[1].

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2. Current Research

During the spring of 2013, for investigating the atmospheric environment, 52 samples of “artificial-harvesting dew water”, which was the dew artificially condensed from vapor, were collected at the Shipai campus of South China Normal University in Guangzhou. The measurement of pH values and ion concentrations of the samples shows that: 1) they were not of severe acid rain status; Base on the characteristics of such pH values and ion concentrations could gain the information of the degree of cleaning. The pollution sources were mainly anthropogenic ones, such as the airborne dust of building, combustion of coal and oil, etc.

The article has attempted to target areas of significance to health care practitioners as well as educated professionals. During this process, it emphasized the relationship between indoor air quality and health as it pertains to exposure to the many different agents described in this review. “There are many different hazardous agents that can potentially affect persons from secondhand smoke and cleaning agents to the family pet, many individuals remain unaware of the potential detriment effects associated with these exposures. Lung health is important to both young and old alike and so it becomes crucial to target environmental exposures that may increase the risk for health problems, including asthma, allergic reactions, lung cancer and in a small but significant fraction. Accidental death. The federal government through various agencies continues to monitor and provide guidelines, reports, and recommended testing for many of these agents.”

The purpose of our research project is to develop a mobile robot for air pollutant monitoring based on condensate water quality analysis. The project aims to address the challenge of monitoring air pollution in a more efficient and accurate manner. The mobile robot will be equipped with sensors to detect air pollutants and collect samples of condensate water from the air. The quality of the collected water samples will be analyzed to determine the concentration of air pollutants, providing a more accurate measurement of the air quality. The project will contribute to the development of innovative solutions for air pollution monitoring and provide valuable insights for environmental policy-making.

Admittedly, there is various high-tech air purifier, but most, which include the ability to detect the concentration of PM2.5, are not sufficiently valuable, and the more functional and accurate air analysis devices are far from economical.

Therefore, by equipping all the sensors on a mobile car, the air quality can be monitored conveniently and efficiently in various indoor and outdoor environments. This mobility allows for more comprehensive data collection and analysis, as the mobile robot can cover a wider area and reach places that might be difficult or impossible to access for stationary monitoring devices.

Moreover, the use of a mobile robot for air pollutant monitoring also provides real-time data analysis and visualization, allowing for immediate detection of air pollution hotspots and facilitating effective and timely responses. This can be especially useful in emergency situations where immediate action is required to protect public health[2-3].

3. Method

3.1. Theoretical design

There are 4 sensors in total to receive information in the air. The PMS5003(G5) particulate matter concentration sensor module, dht11 temperature and humidity sensor module and MQ135 air quality sensor module directly detect and analyze the ambient air, and directly display the values of temperature, humidity, pm2.5 and pm10 on the display screen, so as to facilitate direct observation by users. Use a semiconductor refrigerator to condense water vapor from the air and store it in a container. The device uses a pH meter to detect and analyze the collected condensate water and obtains its pH value. After a function calculation, the content of sulfur oxide and nitrogen oxide in the ambient air is calculated. During the normal operation of the device, if the ambient air is proved harmless to human body by comparison with the standard after detection, the RGB LED light on the device will flash green. If the calculated content of sulfur oxide and nitrogen oxide in the ambient air exceeds the standard, the LED light flashes red. As is shown in Fig.1.

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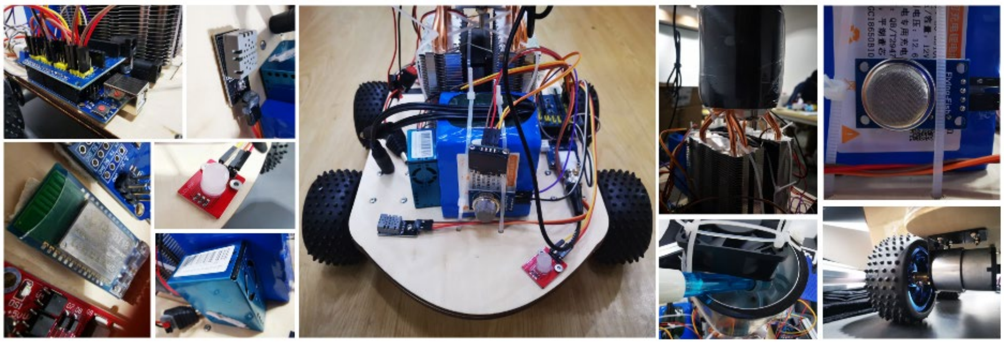

Figure 1: Overview of all sensors

3.2. Motion mode / software control / programming.

Arduino code

The device utilized two independent Arduino codes. For clarifying different Arduino boards, the motor control Arduino board was identified as Arduino UNO 1, and the sensor control Arduino board was identified as Arduino UNO 2.

Motor control

The overall concept of the Arduino code is based on differential steering, and the meaning of using PWM is for adapting the actuator, as the actuator could provide current so that the motor has the power to spin.

This part of the Arduino code is for enabling the car to be controlled by a human. Firstly, the motors should be connected to the actuator, which provides the motor current. Then, the actuator should be associated with the Arduino UNO board so that it can be controlled by the input signals coming from the Arduino board. Secondly, connect the Bluetooth module on the Arduino UNO 1, and after defining and implementing all code into the Arduino, the car can be controlled by the Bluetooth rocker. The algorithm used for the motor control is differential steering.

Differential steering.

The car's total weight is 2.7kg. The car's heaviness requires substantial power that could make it move at a fast speed. Therefore, the car is implemented with four-wheel drive, with four motors for four wheels. Each motor controls one wheel so that the car's power can increase relative to two-motor cars. The issue with four-wheel drive is the hardness of changing direction compared to two-wheel drive cars. The reason for the two-wheel drive car's ease is that its two front wheels are free to change direction, or front-wheel steering, as they are not connected to any motor that restricts their movement. However, the existence of the two different motors on the four-wheel drive car prevents it from having easy turns. As a result, the use of differential steering arises.

The Arduino code shows the idea of the car's wheel when receiving the signals fr om the blue tooth rocker. The input was on a scale of 0 to 255, and when the input was 128, the rocker was at the center. Therefore, the coordinate on the rocker when the rocker is still (128,128), the car will not move. Moreover, when the rocker swipes forward, the wheels gather speed on a scale of 1 to 128. When the car turns, for example, turns right, the left wheel would increase its speed, and the left wheel would decrease its speed for an identical numerical value. Therefore, there was a difference between the car's left-side and right-side wheels. The more the rocker swipes to the right, the more numerical speed would add to the left wheel, and the more numerical speed would be cut off from the right wheel, so the difference in the speed between wheels becomes larger. Under the difference in the spinning speed among the wheels, the car can reach the goal of turning directions[4].

Sensor control

Several sensors were integrated at the second sensor part of the Arduino code, and the output signals were collectively reflected on the OLED screen. The Arduino UNO 2 was implemented with a sensor shield, which enables more sensors to connect with the UNO board. Four modules connect on the Arduino UNO 2: Ph sensor, humidity and temperature sensor, dust sensor, gas sensor, OLED screen, and an RGB LED light. The four sensors' output was first analyzed by a function and then presented on the OLED screen. The information on current humidity, temperature, PM 2.5, PM 10, dust concentration,

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CO concentration, smoke, and the condensate water's pH was shown on the OLED screen on Fig.2.

3.3. Experiment principle

Condensate water

Condensed water form through condensation. During condensation, water vapors in the air change into a liquid. There are two primary ways of forming condensed water in nature: water vapor is so saturated that it can hold no more water, and the air is cooled to the dew point. Therefore, after weighing the difficulties between the two methods, artificially creating a low temperature below the dew point is more effective and economical.

Dew is liquid water formed when super-saturated water vapor near the surface condenses on the surface of the ground and objects with a surface temperature equal to or lower than the dew point temperature (Agam & Berliner, 2006; Beysens, 2006; Beysens, 1995; Jacobs et al., 2002; Jacobs et al., 1999; Monteith, 1957). When below the dew water, the cold air holds water vapor less easily than warm air, and this forces the water vapor in the air around the cold object to condense, and then the water condenses.

Semiconductor refrigeration

In order to reach the dew point temperature mentioned in 5.2.1.1, the machine was implemented with its core equipment, a semiconductor refrigerator. The semi-conductor refrigerator uses thermoelectric cooling in order to reach the aim of decreasing its temperature.

Thermoelectric coolers work on the Peltier effect. The Thermoelectric cooler has two sides, and when a DC flows through the device, it carries heat from one side to the other so that one side becomes cold and the other becomes hot.

The cooler side of the Thermoelectric cooler was connected to the aluminum container on top of the device, and the hotter side was connected to a four thick copper tube. The heat generated from the Thermoelectric cooler was transferred to the cooling fin through conduct by an intermediate of the copper. When the heat reaches the cooling fin on two sides, the electric fan blows the cooling fin in order to reduce its heat.

The container that receives the coolness form the Thermoelectric coolers soon reaches and surpasses the dew point temperature and then, starts to collect condensate water in the air.

4. Result

4.1. Materials

Arduino uno board, MQ135 ambient air detection module, PH Meter Sample detection module, condenser, etc.

4.2. Experimental environment:

A) Outdoor environment with relatively dry wind.

B) Dry indoor environment without wind.

Experiment time: around noon in the middle of the February

4.3. Experimental Procedures:

1) To measure the quality of the air in the cleaner outdoor environment and the pH value of the condensed water in the cleaner outdoor environment.

2) The quality of polluted outdoor ambient air and the pH value of condensed water in polluted outdoor ambient air shall be measured.

3) To measure the quality of cleaner indoor ambient air and the pH value of condensed water in cleaner indoor ambient air.

4) To measure the quality of polluted indoor ambient air and the pH value of condensed water in

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polluted indoor ambient air.

5) Analyze data and calculate.

4.4. Experiment execution

Data collection

Step 1: Measure the ambient air qua-lity reference value of the relatively clean ambient air with outdoor wind and the pH value of ambient air condensate. We have measured the value of outdoor ambient air in the case of outdoor wind. The figure below shows the content of harmful gases in the ambient air measured by the Arduino-based MQ135 module in the ordinary outdoor environment and recorded by the serial port monitor. It can be seen from the figure that the measured value of ambient air in the ordinary outdoor environment fluctuates around 60-67.

In addition, the pH value of the water condensed by the condenser is measured by the PH Meter Sample module based on Arduino, and the measured value is recorded by the serial port monitor. It can be seen from the figure that the pH value of the water condensed by the condenser in the ordinary outdoor environment fluctuates around 7.05-7.08

Step 2: Measure the air quality of polluted outdoor windy environment and the pH value of ambient air condensate. Record data through the serial port monitor.

Step 3: Measure the indoor ambient air quality and the pH value of indoor ambient air condensate:

Step 4: Measure the quality of polluted indoor ambient air and the pH of condensed water in polluted indoor ambient air

The harmful gas content value we measured in the polluted indoor environment fluctuates between 120 and 386, and the pH value of air condensate water in the polluted indoor environment is roughly 6.9 to maintain a balance, relative to the air quality of the polluted outdoor environment and air condensate water in the polluted outdoor environment has some small differences.

Data pattern

After calculation, we gained following data in Figure 2, 3, 4, 5, 6:

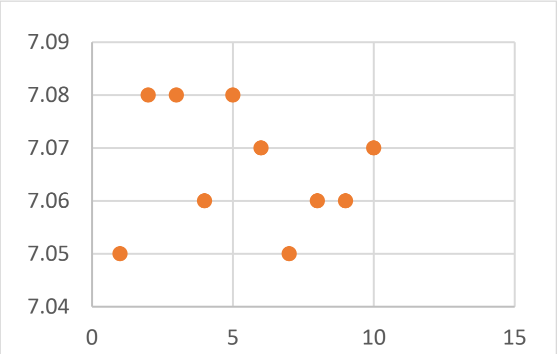

Figure 2: Plotted data from pH detection module and MQ135 module in outdoor clean environment.

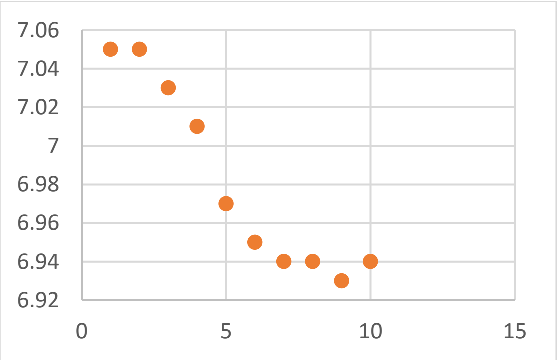

Figure 3: Plotted data from pH detection module and MQ135 module in outdoor clean environment.

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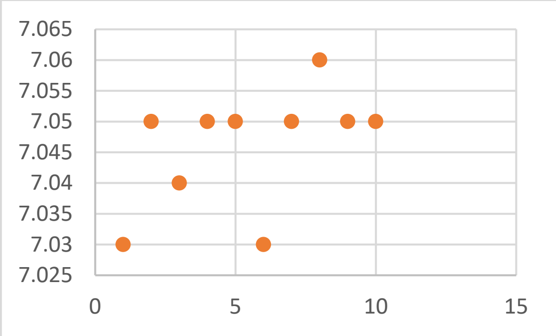

Figure 4: Plotted data from pH detection module and MQ13 module in outdoor polluted windy environment.

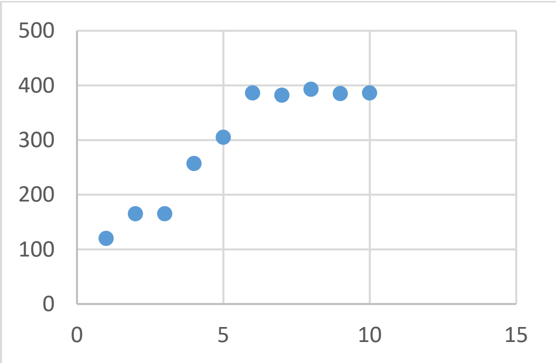

Figure 5: Plotted data from pH detection module and MQ135 module in indoor clean environment.

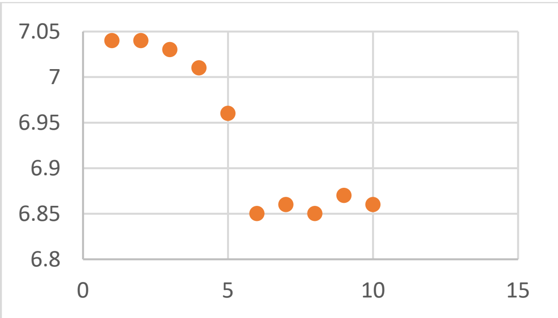

Figure 6: Polluted air concentration in polluted indoor air

Based on the data collected, the results gained from the deeply polluted environment are considerably higher than those collected from a cleaner environment. Moreover, the pH value of the condensate water collected from the polluted areas presents an acidity. It remains a slightly lower pH value than the condensate water collected from the cleaner areas. The data of the pH value of the water shows a positive correlation with the air's cleanness; this phenomenon indicates that the harmful acidic gas in the air dissolves in water and reduces the pH of water.

Also, the pH value of the condensate water collected outdoors is substantially lower than that of the condensate water collected indoors. This phenomenon could be generalized by the fact that the airflow in outdoor areas is faster due to the presence of the wind. The wind could prevent the acidic pollutant from dissolving in the water and contribute to the air's complexity, which could contain the gas whose aqueous solution is alkaline. Hence, the pH value of the condensate water presents slightly basic. The concentration of harmful gases in polluted ambient air measured in the room is lower than that measured outdoors, which may also be caused by the diffusion of gases caused by the outdoor wind.

Calculation:

According to the preliminary calculation results, the functional relationship between the independent variable (PH value of ambient air condensate condensed by the condenser) and the dependent variable (concentration of harmful gases in ambient air) is roughly as follows:

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PH Value of Ambient Air Condensed Water Corresponding value of harmful gas concentration in ambient air (before fitting)

The fitting results are as follows (linear function):

y = -1309.2x + 9417.3

As the difficulty of quantifying the concentration of sulfur oxides, nitrogen oxides, carbon dioxide and carbon monoxide in the ambient air under the above test, we have to set a critical pH value of ambient air condensate water to determine whether the concentration of sulfur oxides and nitrogen oxides in the ambient air is too high to harm the human body. Through observation and analysis, we set this figure as 6.95. As a result, based on the explanation in Pin Connection the specific value in which should be 6.95. As is shown in Fig.7.

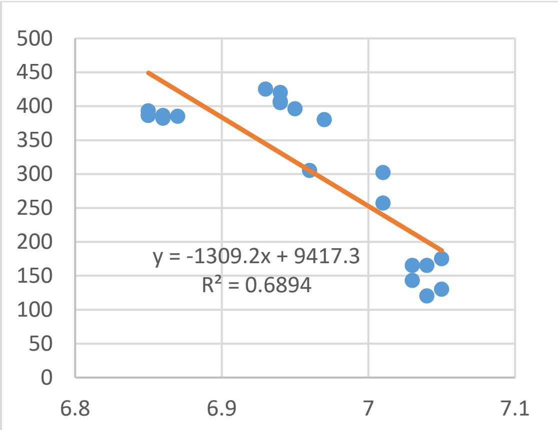

Figure 7: After linearization

5. Discussion

All the results from the experiment show a trait of stationary, without giant leaps from time to time.

For evaluating the accuracy of the data collected from the device in this project, MEF-500 from SENSOLOGY was used to serve as a comparator.

After comparing the result data from the device built into this project with the other air analysis cleaners in the market, the data shown from both machines present little deviations. Therefore, it proves the validity and accuracy of the device.

Through the repeating experiments, the data varied little, so it could be generalized that there are no uncontrolled events occurring during the experiment.

5.1. Existing issues

The basic prototype and basic functions of the device have been largely realized, but as an engineering product, some problems are still exposed in the process of testing and practical application, which are summarized as follows:

1) Considering the factors of cost and practicality, the power of this device is small, and the condensing speed is slow. Therefore, condensed water cannot be obtained at a large amount in a short time. However, the device works visibly faster when the ambient air is moist, but the time required much longer when the ambient air is dry.

2) In the experiment, due to equipment limitations, we could not obtain an accurate functional relationship between the pH value of ambient air condensate and the concentration of sulfur oxides and nitrogen oxides in the air. . However, since the feedback value of MQ135 gas sensor in polluted ambient air contains a variety of pollutants, besides sulfur oxide and dioxide, there are also high content of carbon dioxide and some carbon monoxide, and their specific content cannot be determined.

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5.2. Future research direction

The analysis's accuracy of the content in the ambient air was restrained by the data's singleness. Moreover, it is hard to apply to dry conditions, so making some improvements will address the relatively low practicability of some devices.

1) Increase the power of condenser without increasing too much volume, so that it can condense enough water to be analyzed by the device in a shorter time. Also, this could speed up the frequency of environmental air analysis by the device and reflect the quality of ambient air timelier and accurately. At the same time, it can also shorten the time for the device to obtain enough condensate water from the dry ambient air, and analyze the quality of the ambient air could become more efficient.

2) It is better to use and more sophisticated condensate detection modules, while the cost is low, to measure condensate more comprehensively and correlate with the content of specific harmful substances in the air. Moreover, multiple experiments and more accurate literature data could be combined to calculate more accurate functional relations, thus increasing the data quantity in the ambient air that the system can reflect.

3) Improve the container for collecting condensed water. Install an electric drain valve and water level sensor in the container and set a water level limit. As a result, when the water level reaches the set limit, the valve at the bottom of the container automatically opens to drain the excessive used condensate water. After the water is emptied, the valve closes automatically, and the device could begin the collection of ambient air condensate for the next round of inspection analysis. Having such improvement enables the device to have automatic continuous operation to enhance the practicality of the system.

6. Conclusion

As mentioned in the previous section of the essay, after comparing the mobile air quality analysis machine and MEF-500, the result shows little differences, so the result of the device shows accurate reflection of the ambient air quality.

The literature review and other work being done in the research area could be highlighted that the machine represents an innovative approach to air pollution monitoring. The ability to move the machine around different locations, both indoor and outdoor, provides a more comprehensive understanding of air quality.

In terms of the literature review, previous studies have focused on stationary monitoring devices, which are limited in their ability to cover large areas and respond to rapidly changing air pollution conditions. The Mobile Air Quality Analysis Machine fills this gap by providing a mobile and flexible solution for air pollution monitoring.

Furthermore, the machine's ability to collect and analyze condensate water samples for air pollutant concentration provides a novel approach to air quality monitoring. This approach has the potential to improve the accuracy of air quality measurements and provide valuable data for environmental policy makings.

The Mobile Air Quality Analysis Machine created in this project has a wide range of potential applications. One of the primary applications is in industrial settings such as factories and warehouses where workers may be exposed to hazardous air pollution. The device can be used to monitor the air quality in these environments in real-time, allowing for immediate action to be taken to protect the health of workers.

Another possible application is in outdoor environments, where the device can be used to monitor air quality in urban and rural areas. This can be especially useful for cities where air pollution is a significant problem, as the device can be used to detect pollution hotspots and facilitate effective and timely responses to protect public health.

Additionally, the Mobile Air Quality Analysis Machine can be used in research settings to collect data on air quality in different locations and under different conditions. This data can be used to better understand the sources and impacts of air pollution, and to inform policy and decision-making related to environmental protection and public health.

Overall, the Mobile Air Quality Analysis Machine has the potential to be a valuable tool for monitoring and improving air quality in a variety of settings, from industrial workplaces to urban and

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rural environments.

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