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A DEVELOPMENT OF MEASUREMENT METHOD OF ROOM AIR POLLUTION IN ENCLOSED SPACE USING ODOR SENSORS

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Abstract. *Recent COVID-19 measures in Japan have focused on managing enclosed spaces to avoid "Three-Cs". High CO_2 concentrations increase the risk of virus infection. Thus, monitoring devices using CO_2 sensors have been installed in stores, but it is difficult to notice problems without checking the devices. In addition, pet-keeping has increased with telecommuting, creating odor problems in airtight housing. These factors have increased demands for monitoring air pollution in specific spaces. However, the measurement of CO_2 and odor requires dedicated sensors, and it takes time to measure them depending on the volume of the space, airflow, and distance, which can cause delays in alerts. In order to solve this problem, it is necessary to design a system that considers the space's characteristics and the sensor's location. In this paper, we developed a device that combines an odor sensor and an embedded control system to detect changes in odor and alert the user via the Internet. Furthermore, we examined a method for detecting odors by generating odors in a closed space and checking the changes in values detected by the sensor. In future research, we plan to simulate odor diffusion and airflow to determine quick alerting methods. Therefore, it is first necessary to design the device housing and adjust the measurement parameters based on the room volume and air flow.*

Keywords: Arduino, Embedded control system, Odor sensor, Ethanol, Pet, Dog, COVID-19

1. **Introduction.** In recent years, measures for COVID-19 have been implemented in Japan to avoid three enclosed environments (closed spaces, crowded places, and close-contact settings) called "Three-Cs". Especially in enclosed spaces, it is required to properly control the indoor airflow, ventilation conditions, and concentration of the gas (CO_2) [1, 2, 3]. Since it is suggested that high CO_2 concentration in space increases the possibility of viral infection [4], monitoring devices using simple CO_2 sensors have been installed in stores to visualize the CO_2 density. However, those devices display a density value and notify the change by text color or LEDs. Therefore, it is hard to notice a problem until directly looking at the device.

In addition, working styles have changed, with more workers teleworking and more time at home, which has increased the opportunity to have pets [5, 6] because many pet owners are worried about odor problems caused by having pets in modern houses, which are highly airtight [7]. These points indicate that the demand for monitoring air pollution (CO_2 and odor) in a specific space continues to increase.

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It is necessary to have dedicated CO_2 and odor measurement sensors, but they do not stay in place because they are gases. Therefore, it takes time to measure the exact density according to the volume of the space, the airflow, and the distance from the gas origin, resulting in a delay in the measurement and the alert. To solve this problem, we need to design a system that takes account of the volume of the space, the airtightness of the space, the position of the ventilation fan, the position of the circulator, the position of the object to be measured, and the position of the sensor.

A recent paper has conducted research on "environmental odor sensing used at various living or manufacturing spaces to use five semiconductor gas sensors and a smartphone" [8]. In their research, the sensor module communicates with the Internet by establishing a connection with a smartphone. In our research, the sensor module itself is capable of directly connecting to the Internet and transmitting the measurement results. Therefore, in environments where a Wi-Fi network is available in the target space, we can install sensor modules inexpensively and simultaneously measure multiple locations. We consider that the utilization of multiple location measurements is beneficial for assessing spatial biases in odor (specific gravity and airflow) and determining the distance from the odor source.

In this paper, focusing on odors, we report on developing a device that detects changes in odors by combining an odor sensor and an embedded control system and alerts users via the Internet. In addition, we check what changes occur in the sensor values when the device is installed in a closed space of any volume and odor is emitted and study the method of detecting the emission of odor from the changes in the sensor values. Then, the measurement results confirmed that under no airflow and spontaneous evaporation and diffusion in the experimental apparatus, the time until detection increases with distance. Additionally, it was confirmed that the fan mixed the ethanol vapor, and the detection time was significantly shortened.

This paper first describes the design of the device (microcontroller, power supply, and sensors). Section 4 describes the standard specifications of the sensor, and Section 5 describes the experimental environment to measure the detection time. Finally, Section 6 presents the conclusion of this paper.

2. Selection of Sensors and Schematic Design.

This paper focuses on pet odors, especially those after urination and defecation. The odor components of urine and stools include a variety of substances [9], but we have decided to selectively detect sulfur compound gases (such as H_2S) and ammonia. Because these gases are typical odor components, humans feel uncomfortable with just 0.1 to a few [ppm] in the air [10]. We decided to use the TGS2450 sensor manufactured by Figaro Engineering Inc. to satisfy these conditions [11]. This sensor has a high sensitivity to sulfur compound gases such as CH_3SH or H_2S and is also sensitive to ammonia and ethanol, thus fitting the purpose of this paper. Based on the sensor specifications, the schematic shown in Figure 1 was designed and implemented as shown in Figure 2. The outer dimension of the board is 20 [mm] × 22 [mm].

The TGS2450 has a heater voltage (point A in Figure 1) of 1.6 [V], a heater resistance of 8.5 [Ω] to 10.5 [Ω], and a current of 138 [mA]. The available power supply voltage is 3.3 [V] because of using 3.3 [V] embedded control systems. Therefore, considering the V_{ce} of the transistor, R4 should be around 10 [Ω]. In this case, we used a 10 [Ω] resistor rating of 1 [W]. In addition, this sensor has a period of 250 [ms] for operation, and a sequence of measurements must be made in this period. The first 237 [ms] of this 250 [ms] must be idle, the next 5 [ms] must be reading the sensor signal with a pull-up, and the remaining 8 [ms] must be heating the heater. We must be cautious not to overheat the heater excessively, as this can damage the sensor. These controls are implemented using an embedded control system.

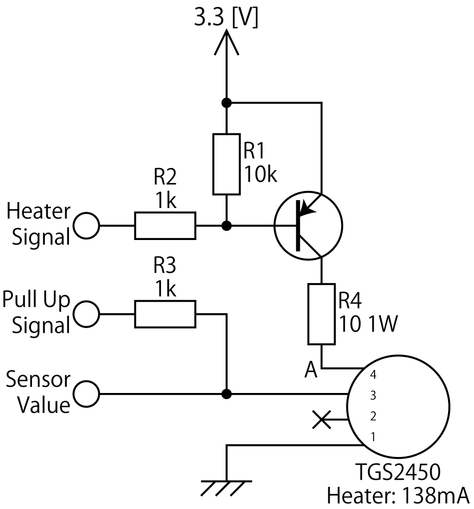

Figure 1. Typical TGS2450 schematic at 3.3 [V]

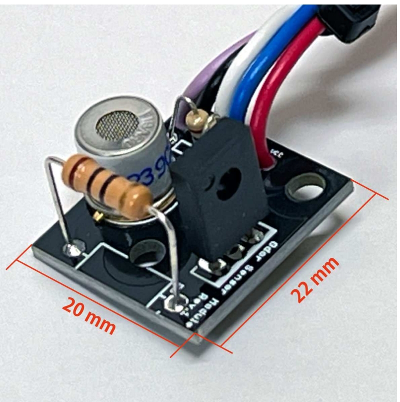

Figure 2. Mounted odor sensor module board

3. **Design and Function of Embedded Control Systems.** We use the ESP32 module, a modularized ESP32-D0WDQ6 [12] manufactured by Espressif Systems, as the microcontroller used in the embedded control system. This module is compatible with Arduino and can be developed using Arduino IDE (Integrated Development Environment) [13]. Additionally, this microcontroller has the functions of the wireless LAN (IEEE 802.11 b/g/n/e/i) required for an Internet connection, so it can easily communicate with the Internet by only writing the settings for the access point.

Next, we need an ADC (Analog Digital Converter) to measure the values from the odor sensor. When using the internal ADC of the ESP32 module, caution must be used. The internal ADC of the ESP32 can accept only 1.1 [V], so the attenuator is set at -11 [dB] by default. It is not easy to accurately calculate the voltage from the measured value because the characteristics of this attenuator are not linear. Therefore, in this paper, we do not use the ADC in ESP32 but use the MCP3002 [14] manufactured by Microchip Technology Inc. It communicates to the ESP32 module via SPI (Serial Peripheral Interface).

Also, we use a temperature/air pressure sensor LPS25HB [15] manufactured by ST Microelectronics to measure the room temperature and air pressure at the same time. We designed the ESP32 module and various modules, as shown in the schematic of Figure 3, and implemented them as shown in Figure 4. The outer dimension of the board is 50 [mm] × 50 [mm].

The overall view of the ESP32 and the odor sensor module board is shown in Figure 5. The yellow and black wires are connected to the power supply.

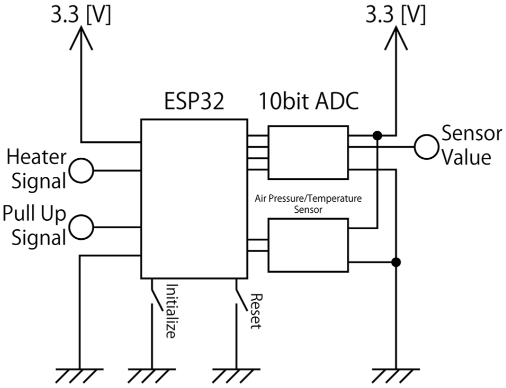

Figure 3. Schematic with ESP32 module

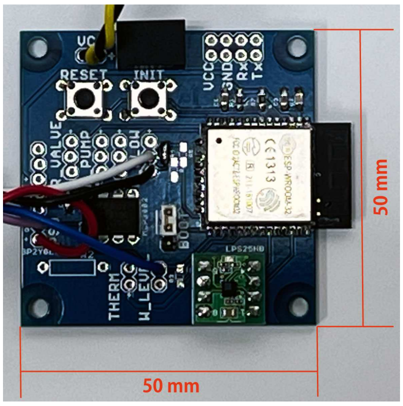

Figure 4. Mounted ESP32 module board

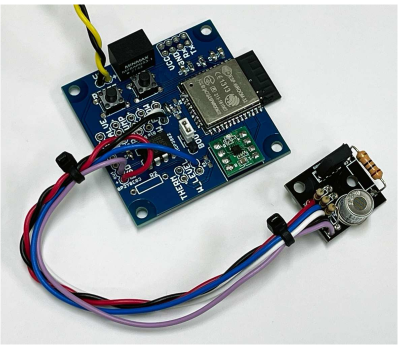

Figure 5. (color online) Overall view of board

4. **Measurement and Detection of Odors.** Based on the sensor specifications, odor sensor measurements must be taken every 250 [ms] cycles. The values measured from the sensor have small fluctuations frequently. Therefore, we averaged the values 20 times (5 [s]) and kept 5 [s] moving averages.

Figure 6 shows a flowchart of this process.

These operations are implemented in an embedded control system, and the calculated values are shown in a graph in Figure 7. In Figure 7, an ethanol-soaked cotton ball was placed near the sensor at around 02:50. Soon after, at around 02:55, the sensor value decreased, indicating that it responded to ethanol. Then, we can confirm that the values return to normal when the cotton ball is removed from the sensor.

When a human checks the graph, it is easy to determine where the change occurs. However, it is necessary to calculate the time series data using the statistical method

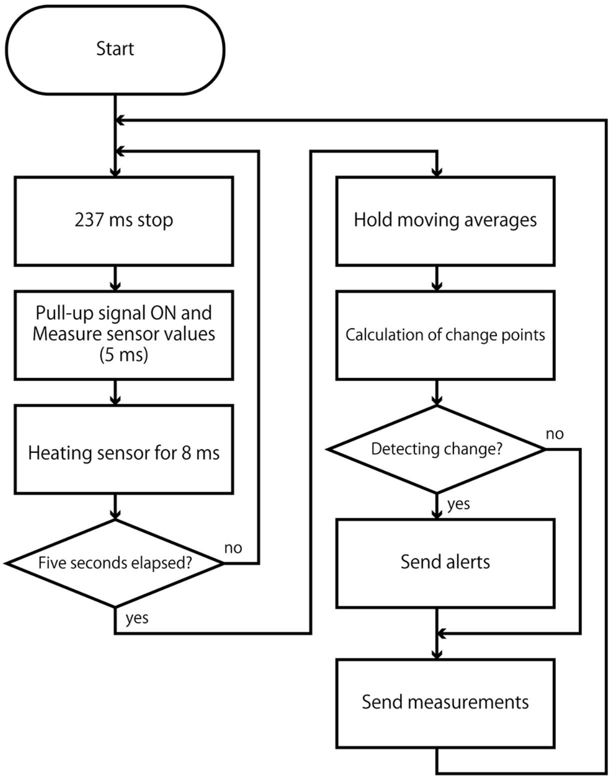

Figure 6. Flowchart on odor measurement and detection

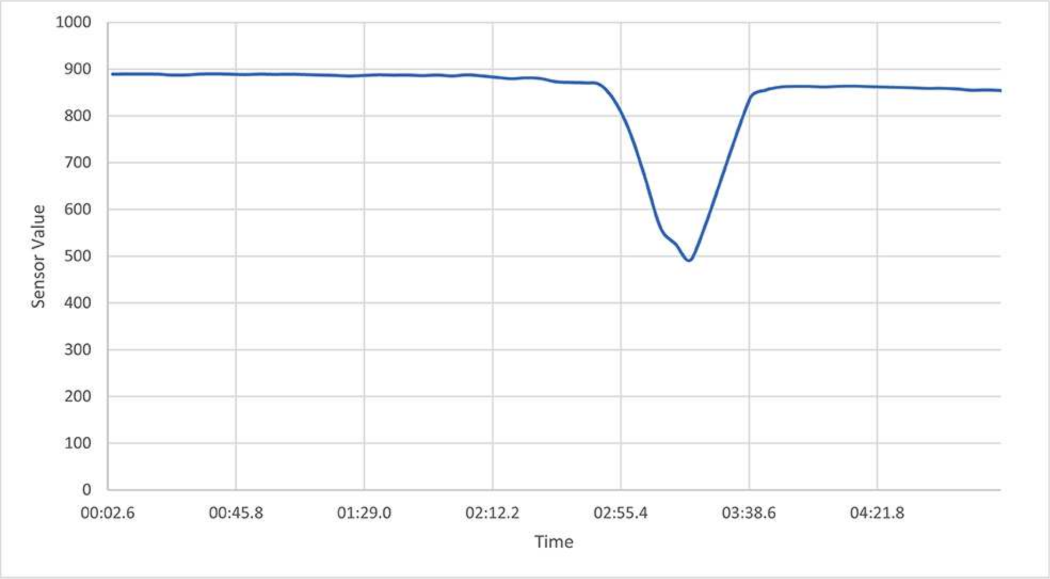

Figure 7. Movement of sensor values when an odor is detected

[16, 17] for detecting the point of change on the computer, for example, calculating a change from the steady state and determining it using a threshold or accumulating the error from an expected value and determining it when an accumulated error exceeds a threshold. Therefore, the threshold cannot be estimated in some environments and requires tuning each time. In this paper, we do not determine by simple change, but we determine the variance from the difference between moving averages. In other words, we determine the deviation from a normal change value.

When a change is detected, it sends a notification to an external server via the Internet. This implementation uses LINE Notify [18] to send notifications via LINE.

5. **Experiments on Odor Measurement in an Enclosed Space.** In the previous section, we implemented an embedded control system using the odor sensor. We confirmed that it could detect the value change and the change point when approaching the ethanol. Next, we will consider the actual use of a real application.

We assume that the room in which the sensor is installed is a typical six-mat room in Japan. A typical six-mat room has a floor surface size of 3,640 [mm] times 2,730 [mm] and a height to the ceiling of 2,500 [mm]. Thus, the volume of the room is 24.843 [m^3]. Also, air conditioners and fans circulate air, so this should also be considered.

However, we created a scaled-down version of an experimental apparatus because running an experiment in an actual room is difficult. Figure 8 is an overall view of an experimental apparatus. In Figure 8, a cover is opened. When measuring, a cover can be closed and sealed. It has a volume of 5,700 [cm^3] and can be powered from the outside to the inside, even when the cover is closed. Compared to the volume of a typical 6-mat room, it is 1/4358, and the fan is designed to be turned on and off, assuming an air conditioner or an electric fan.

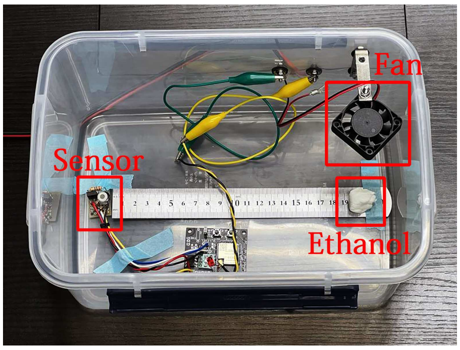

Figure 8. Odor measurement using an enclosed space

We placed the sensor and an ethanol-soaked cotton ball, the odor source, in the experiment apparatus and recorded the time required to detect the odor.

In the experiment, the following patterns were measured.

- Set up a cotton ball 200 [mm] from the sensor
  - Without a fan
- Set up a cotton ball 200 [mm] from the sensor
  - With a fan
- Set up a cotton ball 100 [mm] from the sensor
  - Without a fan
- Set up a cotton ball 100 [mm] from the sensor
  - With a fan

Table 1 shows the measurement results. At the time of measurement, the room temperature is 26 [°C], and the relative humidity is 52 [%].

Comparing the two results without a fan, the detection time is shorter when the distance is nearer. It corresponds to the time required for the experimental apparatus's ethanol density to increase as it volatilizes gradually and for the density around the sensor to reach a detectable value. Therefore, if the volatilization rate is constant, the detection time is proportional to the distance.

Next, compare two results with a fan. The ethanol vapor was detected at around 8 [s] in both cases. This result is due to ethanol volatilized by the fan quickly diffusing into the experimental apparatus and reaching a detectable density around the sensor. However, the difference in the average value is only about 0.2 [s], even if the distance is different.

There may be two reasons for these results. First, the measurement values are averaged at 5 [s]. In the previous section, we used the average value of 5 [s] for the sensor value,

Table 1. Time from ethanol placement to detection

	Between sensor and ethanol 200 mm		Between sensor and ethanol 100 mm	
	without a fan [s]	with a fan [s]	without a fan [s]	with a fan [s]
1	41.75	7.60	33.36	8.25
2	39.05	8.01	33.43	8.28
3	40.23	7.78	32.90	7.93
4	39.50	8.28	33.07	8.41
5	39.07	7.81	32.98	8.20
6	38.90	7.80	33.16	8.06
7	40.21	8.30	33.60	8.00
8	38.95	8.05	33.50	7.96
9	41.28	8.04	33.58	7.88
10	39.88	7.60	32.29	8.23
Average	39.88	7.93	33.19	8.12

which means that at least 5 [s] are needed for the detection. Therefore, even if the detection time is less than 5 [s], it is not reflected in the detection time.

Second, it is the relationship between the fan's flow rate and the experimental apparatus's volume. In the experiment, we used a fan operating at 5 [V] with a size of 40 [mm] square. A typical 5 [V] 40 [mm]-square fan has a flow rate of approximately 0.11 to 0.20 [m^3/min]. Thus, the fan can replace all the air in the experimental apparatus at 1.71 to 3.11 [s].

For these two reasons, the experimental apparatus is thoroughly mixed before the detection timing of 5 [s] immediately after start-up. Therefore, it is possible that the detection density is reached within 5 [s], and the effect of the distance is neglected. On this point, we should consider adjusting the power of the fans of the experimental apparatus based on the relationship between the airflow of an actual air conditioner or an electric fan and the volume of the room in future studies.

Comparing the results with and without fans, it is known that the evaporation rate of ethanol increases when the airflow is more significant than when there is no airflow [19], so there are no severe problems in the measurement results.

6. Conclusions.

In this paper, we focus on odors and create a system combining an odor sensor and an embedded control system to detect changes in odors and alert the user via the Internet. We measured the time to detection in four different conditions, changing the distance between the sensor and an ethanol-soaked cotton ball, and with and without a fan, in an experimental apparatus using a sealed container. The measurement results confirmed that under no airflow and spontaneous evaporation and diffusion in the experimental apparatus, the time until detection increases with distance. Additionally, it was confirmed that the fan mixed the ethanol vapor, and the detection time was significantly shortened.

According to these results, the detection time of urine and stool excreted by pets is possibly affected by the room size, the distance between the odor target and the sensor, and the room with/without ventilation.

The current problem is that we use moving averages for detection, which causes a time lag of at least 5 [s]. It is necessary to examine the change point detection method in the future to solve this problem.

In future research, we plan to develop a more precise method to simulate odor diffusion and airflow. Then, we consider a method of detecting odors more accurately and sending out notifications more quickly as possible. Therefore, the detection accuracy can be improved by using the parameters such as the room volume, the position of the air conditioner, and with/without the air circulator. In addition, the design of the odor sensor casing must be considered. Because it is more advantageous to have airflow for detection, we consider adding an air intake fan in the case to improve the detection performance.

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