Feedback control of ozone concentration in a room using an ozone generator and the Internet of Things with built-in sensor

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Recently, coronavirus has spread worldwide and is becoming a major challenge. Under such circumstances, coronavirus inactivation using ozone has been reported. We have also installed a Sigfox antenna at Hiroshima Institute of Technology and have been developing Internet of Things (IoT) devices through the Internet using the Sigfox network. In this study, an ozone generator and an IoT device, which is an ozone concentration measuring device with a Sigfox communication function, were used to show the ozone concentration on a computer. Additionally, using feedback control, we obtained a CT value of 60, which can inactivate coronavirus from 1/10 to 1/100, after operating for 24 h at an acceptable ozone concentration (less than 0.1 ppm).

Keywords – Internet of Things, Matlab/Simulink, Ozone, Sigfox, ThingSpeak

Introduction

With the evolution of Internet technology and different sensors and technologies, the Internet of Things (IoT) era has arrived, in which many things around the world, such as home appliances, automobiles, buildings, and factories, are connected to the Internet in addition to conventional Internet connection terminals such as personal computers and smartphones [1].

Recently, coronavirus has spread worldwide and is becoming a big challenge. Under such circumstances, ozone-based coronavirus inactivation [2] and health hazards [3] have been reported. In Japan, in 1985, the Japan Society for Occupational Health's Allowable Concentration Committee set 0.1 ppm as the allowable concentration in the working environment [4].

Furthermore, we have installed a Sigfox antenna at the Hiroshima Institute of Technology and have been developing IoT devices via the Internet using the Sigfox network. In this study, an ozone concentration measuring device that aids in coronavirus inactivation is installed in an IoT device, ozone concentration data is shown on a computer using Sigfox, and the allowable ozone concentration is used by feedback control. It was operated for 24 h at (less than 0.1 ppm) and attempted to obtain a CT value of 60, which may inactivate coronavirus from 1/10 to 1/100.

Conditions for inactivation and inactivation of the new coronavirus by ozone [5]

For the first time in the world, Professor Toshikazu Yano, Director of Infectious Disease Center, Takashi Kasahara, Nara Medical University, and the research group of the MBT Consortium, member companies of Infectious Diseases Subcommittee: Quall Holdings Co. Ltd., Sanyu Shoji Co. Ltd., Tamura Teco Co. Ltd., and Marusan Pharmaceutical Biotech Co. Ltd., confirmed the new coronavirus inactivation by exposure to ozone gas. Additionally, the practicality was shown academically by clarifying the conditions of inactivation experimentally.

- At a CT value of 330 (exposure for 55 min, at an ozone concentration of 6 ppm), it is inactivated from 1/1,000 to 1 / 10,000.
- At a CT value of 60 (exposure for 60 min, at an ozone concentration of 1 ppm), it is inactivated from 1/10 to 1/100.

It was established that ozone inactivates up to 1/10,000.

Fig.1. Experimental device for inactivating a new coronavirus using ozone [5].

Various characteristics of an ozone sensor [6]

Fig. 2, Fig. 3, Table 1, Fig. 4, and Fig. 5 show the ozone sensor (MQ131) photograph, test circuit, technical parameters, typical sensitivity curve, and typical temperature/humidity sensitivity curve, respectively.

Fig.2. Photograph of ozone sensor (MQ131).

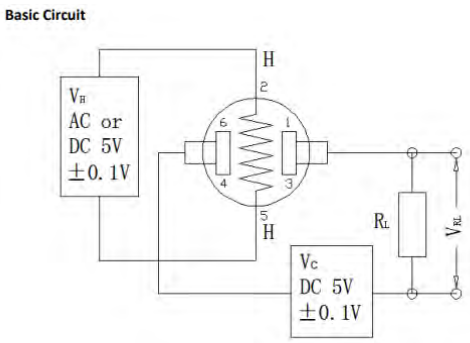


Fig.3. Ozone sensor (MQ131) test circuit.

Table 1

Technical parameters of the ozone sensor (MQ131)

Model			MQ131
Sensor Type			Semiconductor
Standard Encapsulation			Plastic cap
Target Gas			Ozone
Detection range			10～1000ppb Ozone
Standard Circuit Conditions	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.1V AC or DC
	Load Resistance	R_L	Adjustable
Sensor character under standard test conditions	Heater Resistance	R_H	34Ω±3Ω (room tem.)
	Heater consumption	P_H	≤900mW
	Sensitivity	S	Rs(in 200ppb O_3)/Rs(in air)≥2
	Output Voltage	ΔVs	≥1.0V(in 200ppb O_3)
	Concentration Slope	α	≤0.6(R_{500ppb}/R_{100ppb} O_3)
Standard test conditions	Tem. Humidity		20℃±2℃; 55%±5%RH
	Standard test circuit		Vc:5.0V±0.1V; V_H: 5.0V±0.1V
	Preheat time		Over 48 hours

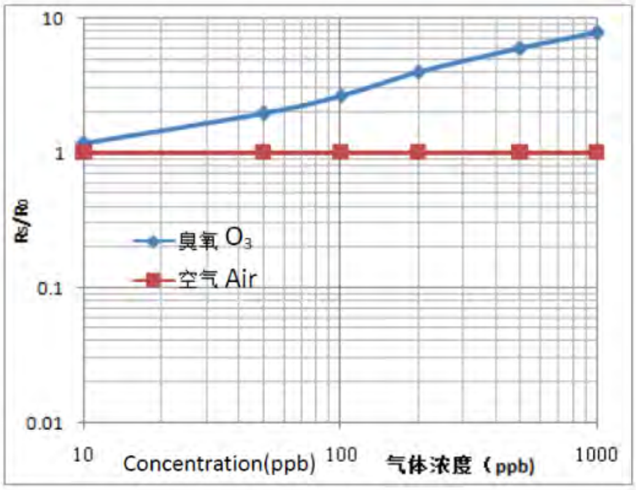


Fig.4. Typical sensitivity curve of ozone sensor (MQ131).

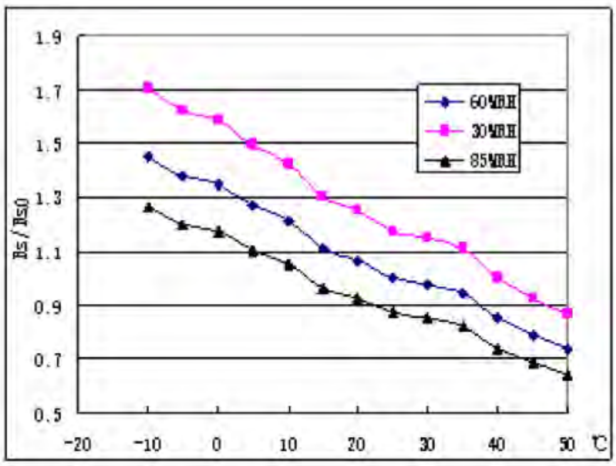
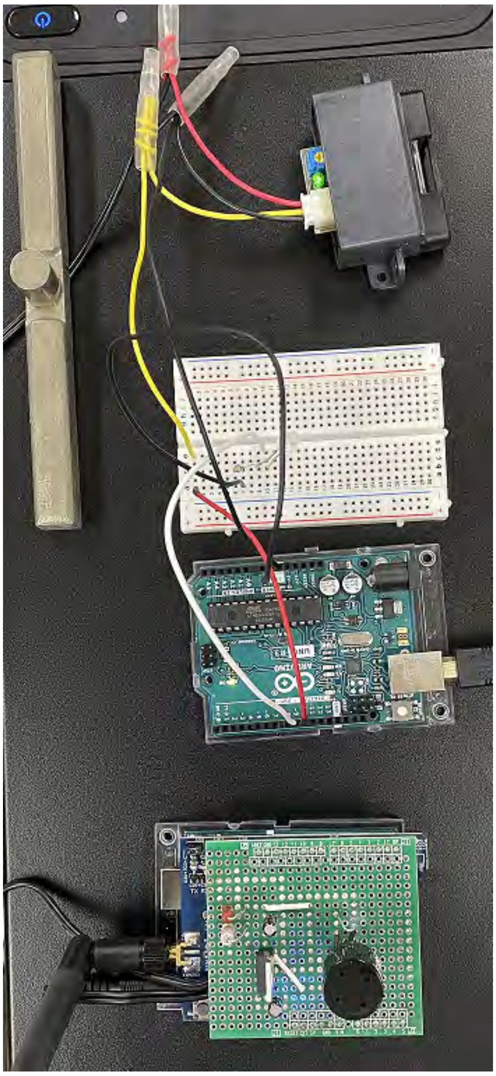


Fig.5. Sensitivity curve to typical temperature/humidity of the ozone sensor (MQ131).

Manufacture of ozone generator and IoT devices equipped with ozone sensors

The ozone generator consists of ozone generation module (Fig. 6 (a)), breadboard for wiring (Fig.6 (b)), and Arduino UNO for controlling ozone generation module (Fig. 6 (c)).

The Sigfox Shield for Arduino V2S was plugged into the Arduino UNO Rev3 to turn it into an IoT device, and the ozone sensor was also plugged into the Sigfox Shield to complete it. (see Fig. 6 (d)) [7]



(a)

(b)

(c)

(d)

Fig. 6. Arrangement photograph of the ozone generator and measuring device when measuring the ozone concentration. (a) ozone generation module, (b) breadboard for wiring, (c) Arduino UNO for controlling ozone generation module, and (d) ozone concentration measuring instrument.

In the IoT device, a temperature/humidity/barometric pressure sensor (BOSCH BME-280) was used as the sensor. The sensor specifications [8] are

- Operating temperature range: −40°C to +85°C (rated)
- Humidity: 0%–100% (relative humidity)
- Atmospheric pressure: 300–1100 hPa
- Temperature accuracy: ± 1°C (0°C to 65°C)
- Humidity accuracy: ± 3% RH (25°C, absolute accuracy tolerance)
- Barometric pressure accuracy: ± 1.0 hPa (0°C to 65°C, absolute accuracy)

A sketch (see Fig. 7) is developed for the Arduino UNO Rev3 in IoT device using the Arduino IDE and is used to control the ozone concentration mesuring instrument.

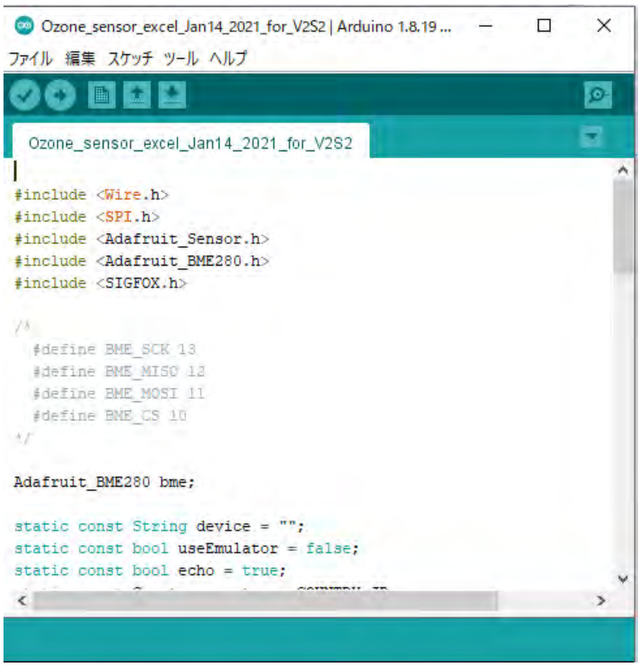


Fig.7. Example of the Arduino sketch employed in this study.

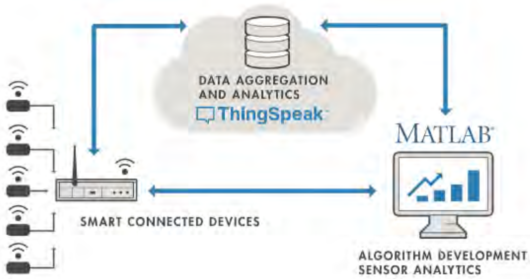


Fig. 8. Overview of IoT devices, ThingSpeak, and Matlab/Simulink [9].

The overview of IoT devices ThingSpeak, and Matlab/Simulink is shown in Fig. 8. ThingSpeak data processing is Analytics, and consists of Actions.

Analytics include Matlab analysis, Matlab visualizations, and Plugins. Actions include ThingTweet, TimeControl, React, TalkBack, and ThingHTTP.

Here, an ozone concentration measuring instrument is as smart connected devices in Fig. 8.

Fig. 9 shows example of Sigfox shield for Arduino V2S callback. Data of temperature, humidity, atmospheric pressure are send to ThingSpeak from smart connected device using callback shown in Fig. 9.

Fig. 9. Example of Sigfox shield for Arduino V2S CallBack.

Fig. 10 shows the ThingSpeak channel setting example. The graphs of various data such as temperature, humidity, etc. are drawn based on chanell setting.

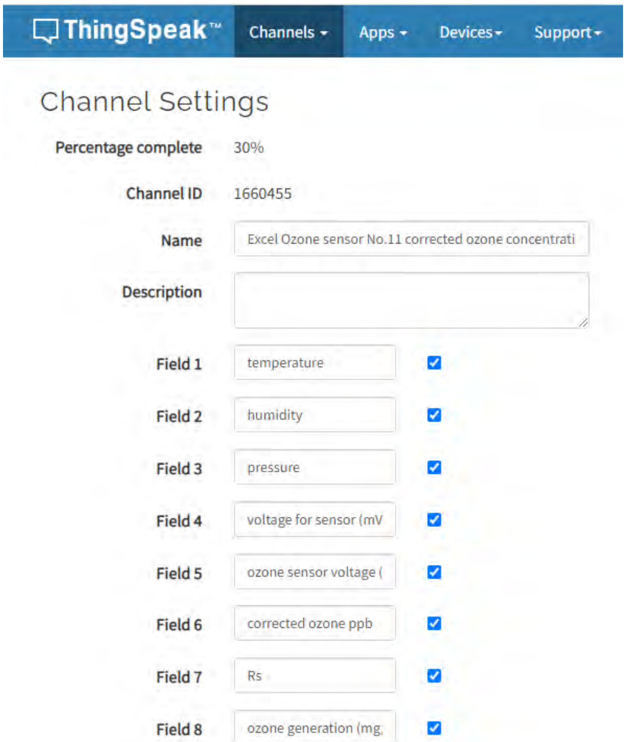


Fig.10. ThingSpeak channel setting example.

Actual measurement example

Ozone measurement method

Ornit developed the ozone generation module that was used. The amount of ozone produced ranges from 1 mg/h to 10 mg/h.

The arrangement of the ozone generator and measuring device when measuring the ozone concentration is shown in Fig. 6.

Fig. 11 – Fig. 15 show the measurement results' temperature, humidity, atmospheric pressure, ozone sensor applied voltage, and ozone sensor output voltage.

The ozone concentrarion and sensor registance calculated from data of temperature (Fig. 11), humidity (Fig.12), sensor applied voltage (Fig. 14), and ozone sensor voltage (Fig. 15) using Matlab analysis in Thingspeak is shown in Fig. 16 and Fig. 17, respectively.

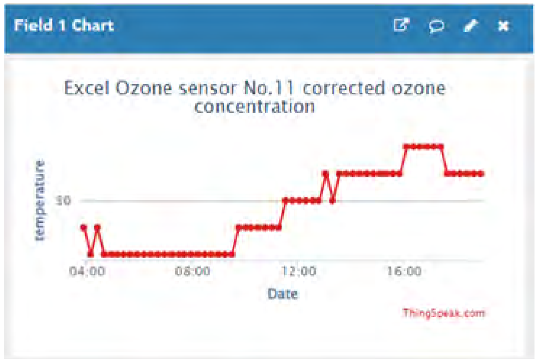


Fig. 11. Temperature measured using an IoT equipped with an ozone sensor.

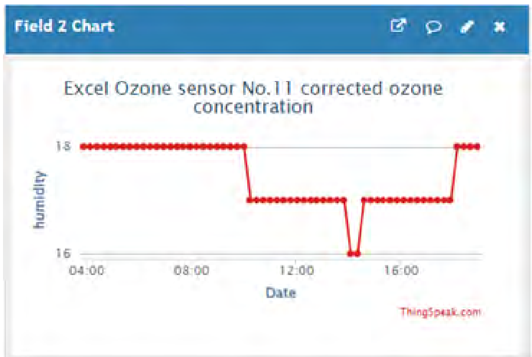


Fig.12. Humidity measured using an IoT equipped with an ozone sensor.

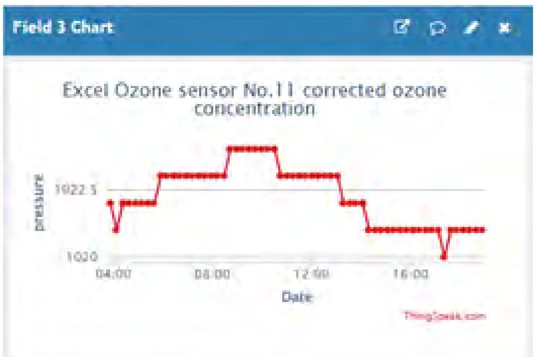


Fig.13. Atmospheric pressure measured using IoT equipped with ozone sensor.

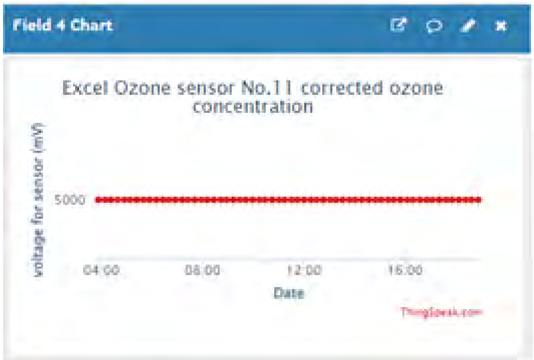


Fig.14. Ozone sensor applied voltage measured using IoT equipped with ozone sensor.

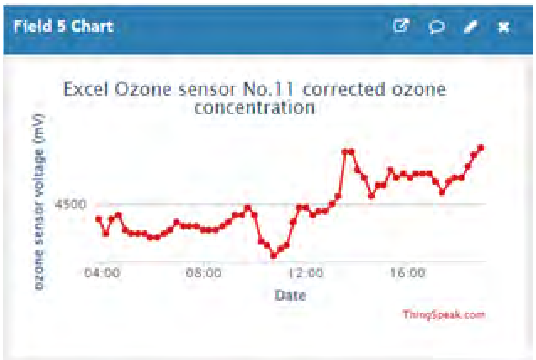


Fig.15. Measured ozone sensor output voltage using an IoT equipped with an ozone sensor.

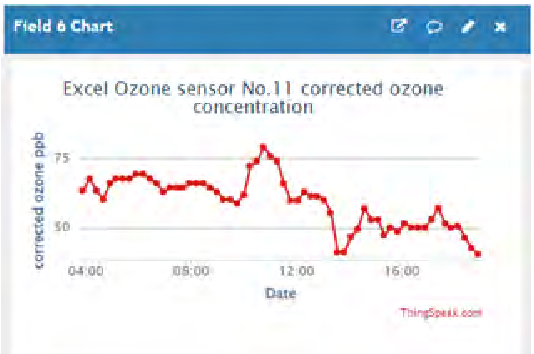


Fig.16. Ozone concentration calculated from temperature, humidity, sensor applied voltage, and ozone sensor voltage.

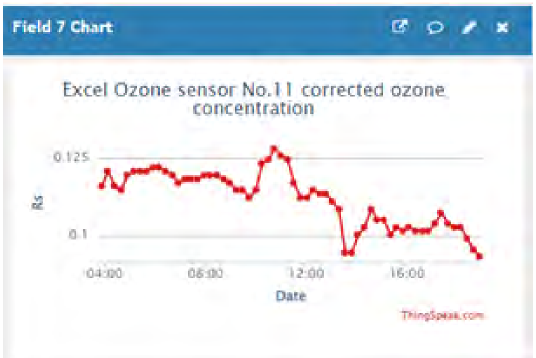


Fig.17. Sensor resistance, Rs calculated from temperature, humidity, sensor applied voltage, and ozone sensor voltage.

To achieve a CT value of 60, which can be operating 24 h a day with an acceptable ozone concentration (42 ppb less than 0.1 ppm) and inactivate coronavirus to 1/10 to 1/100, ozone concentration feedback control was used. The feedback control device is composed of an ozone generation module (Fig. 6 (a)), breadboard for wiring (Fig. 6 (b)), Arduino UNO for controlling ozone generation module (Fig. 6 (c)), and an ozone concentration measuring instrument (Fig. 6 (d)).

The outline of feedback control is to take the ozone concentration in the room into Matlab/Simulink (see Fig. 8), calculate it, and send the result to the feedback control device to generate ozone.

That is, as shown in Fig. 18, in the feedback control, when the ozone concentration is high, the ozone generation amount is low, and when the ozone concentration is low, the ozone generation amount is high, and as a result, the ozone concentration is stabilized.

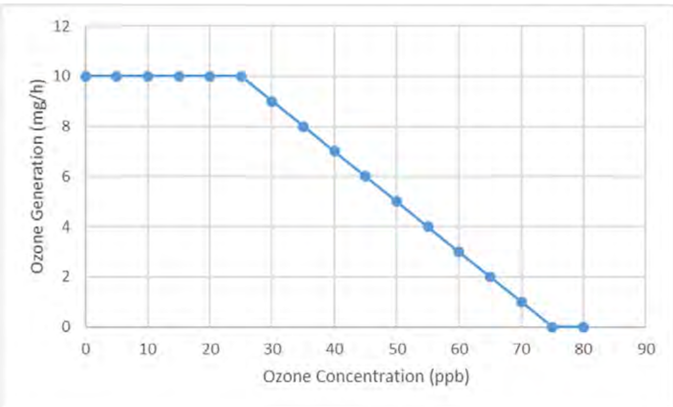


Fig.18. Ozone concentration dependence of ozone generation for feedback control.

The time dependence of the amount of ozone generated is shown in Fig. 19.

The amount of ozone generated varied between 1 and 10 mg/h, indicating that rudimentary feedback control was achieved.

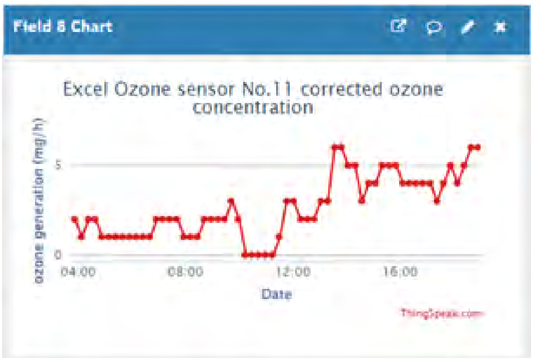


Fig.19. Ozone generator amount (mg/h).

On March 29, 2022, the average feedback-controlled ozone concentration was 53 ppb, with a maximum of 79 ppb and a minimum of 4 ppb. These values were higher than the average ozone concentration of 42 ppb, resulting in a CT value of 60 in 24-h operation, but lower than the permissible value of 100 ppb.

We achieved a CT value of 60, which can inactivate coronavirus from 1/10 to 1/100 by operating for 24 h at an appropriate ozone concentration (less than 0.1 ppm) using feedback control.

Conclusions

It was demonstrated that an ozone concentration measuring device that aids in the inactivation of coronavirus is installed in an IoT device, and the data can be presented on a computer using Sigfox. Furthermore, various characteristics of the ozone sensor (MQ131) were collected, and an ozone concentration measuring device was developed using a test circuit provided by the manufacturer to measure the ozone concentration. An ozone sensor built with the Arduino-MQ131 driver was manufactured, and the ozone concentration was computed. Additionally, after operating for 24 h at an acceptable ozone concentration (less than 0.1 ppm) and employing feedback control, we achieved a CT value of 60, which can inactivate coronavirus from 1/10 to 1/100.

We will apply it to actual hospitals and accommodation facilities in the future, consider it in detail and comprehensively, and explain its concerns, to achieve cooperation and mutual usage with the systems we have developed so far, and further cooperation with the local community.

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