

A Study on Intelligent Space Sterilization System Using UV

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Abstract: There is a need for a system that can block the spread of contaminants in the air flow path of multi-use facilities, where it is difficult to wear masks continuously frequent contact with humans or food consumption, etc. and to prevent disease at all times. In order to measure the pollution level of an enclosed indoor space, we intend to develop an intelligent system that monitors the environmental data obtained in real time using sensing information. Furthermore, it is intended to develop an intelligent system that intensively sterilizes places where contamination is expected to occur frequently according to the flow of people and the form of crowding. This can be applied to all theme facilities such as public transportation facilities (SRT) and medical facilities. As a modular product, it has the function of purifying fine dust/various harmful substances in the indoor space and sterilizing harmful bacteria, viruses, harmful microorganisms, mold, etc. It has the function of sterilizing harmful bacteria, viruses, harmful microorganisms, mold, etc. As an AI-based space sterilization system, the structure consists of surface sterilization lighting and air sterilizer. Surface sterilization lighting consists of a double-edged 405nm LED module that is harmless to the human body in addition to general surface lighting. And the air sterilizer is composed of a photocatalyst-coated spiral structure air load pan, HEPA filter, UVC LED module, complex sensor, wireless communication device and SMPS. AI technology was applied to analyze the distribution type and movement route of people in space, and air purification and sterilization power were controlled through air pollution measurement and contamination location analysis through complex sensor data. Mechanism design and UI/UX were designed. Surface sterilization lighting and air sterilizer mechanism design and UI/UX design were designed, and it can be used in an eco-friendly manner in various multi-use spaces.

Keywords: Surface Lighting, UV-LEDs, Complex Sensors, Intelligent, Space Sterilization

1. Introduction

Due to the corona pandemic, constant disinfection of buildings where an unspecified number of people live has become important. As a result of research showing that microbial damage such as bacteria and mold occurs in indoor buildings, the need for disinfection inside buildings is being raised [1]. In offices without air conditioning, most airborne bacteria fall off over time and cling to surfaces such as floors. When the air conditioner is running, a large amount of outdoor air must be introduced and the air must be sterilized, so energy costs rise rapidly [2]. It takes a lot of labor to permanently fire the entire building with a spray-type chemical product. As a physical disinfection method without direct stimulation, the disinfection method by ultraviolet and

visible rays is effective. UV sterilization is known to have an excellent sterilization effect by inhibiting virus growth [3], and is harmful to the human body, limiting exposure to the skin and eyes to 30 J/m² [4]. Yun and his colleagues [5] found that most air purifiers for improving indoor air quality are removed by filters. In fact, since ultraviolet rays can only be sterilized in a limited area, a photocatalytic filter that works not only in ultraviolet rays but also in visible rays to remove indoor air quality and airborne bacteria.

As a result, an air sterilization and purification device with a convergence structure was developed. Murdoch and colleagues [6] asserted operational advantages associated with the use of visible (non-ultraviolet (UV)) light sources. Additionally, they claim that the inactivation achieved with yeast cells and fungal spores is due to the efficiency of 405

nm light in fungal decontamination applications.

Kim and his colleagues [7] conducted field experiments and analyzed the results to determine the sterilization performance of 405 nm LEDs in the visible ray region when they were actually used in the field. When the same intensity, wavelength, and irradiation distance were maintained, it was found that the sterilization effect increased as the irradiation time increased. The product standard for electric sterilizers in the 275nm region is limited to a structure that does not directly leak ultraviolet rays, so it can be used only when the disinfection target is placed in an enclosed space [8]. Therefore, UVGI (Ultraviolet Germicidal Irradiation) sterilization is possible even in a limited space without contact with the human body, such as inside an air conditioner. As a result of simulating airborne bacteria in individual office spaces using a simulation program, it was suggested that data using the ratio of falling bacteria and attached bacteria and CFD applied to ventilation analysis should be accumulated [9]. Jo and his colleagues [10] revealed that sterilizing power can be secured with low-speed flow in the sterilization section and the sterilized air can be discharged at high speed in any direction by narrowing the flow path at the end of the sterilization section.

Joo and his colleagues [11] argued that there are various sources of indoor air quality pollution, but fine dust is the main pollutant to be removed. Because in the case of fine dust, fine heavy metals and ionic substances are sources of indoor air quality pollution, are chemically and electrically attached to the surface.

However, indoor air quality purification technology using filters has the advantage of low energy consumption and high removal rate compared to other methods, but problems such as additional pressure loss occur during continuous filter management and purification through filters. Therefore,

improvement or development of alternative technologies is required. There is a need for a system that can block the spread of contaminants in the airflow of multi-use facilities where it is difficult to wear masks continuously, and can sterilize the space at all times.

For indoor object movement detection, research related to positioning in an indoor environment requires the use of computer information. Active research is being conducted as an important issue in the society [12, 13]. Recently [14], data was collected using a UWB radar sensor from behind an obstacle and machine learning was applied to research on people counting and location measurement. The use of object location recognition is proposed. In addition, Dabove et al. used UWB to provide occupants in indoor spaces. For accurate positioning of the two-way time-of-flight (TWTF: Indoor location commercial using two-way time of flight. The system was proposed and verified [15]. Since research on algorithms for counting the number of people in an indoor space using WB is in progress, in this study, it is approached with the use of verified vision-based object location recognition to perform intelligent space purification and sterilization according to indoor air pollution. Moreover people density, followed by WB Application research is also planned.

2. Concept of System

2.1. Concept of Space Purification System

The AI-based spatial sterilization system, an alternative to daily quarantine, is a modular product that can be applied to each theme facility, such as public transportation facilities (SRT) or medical facilities.

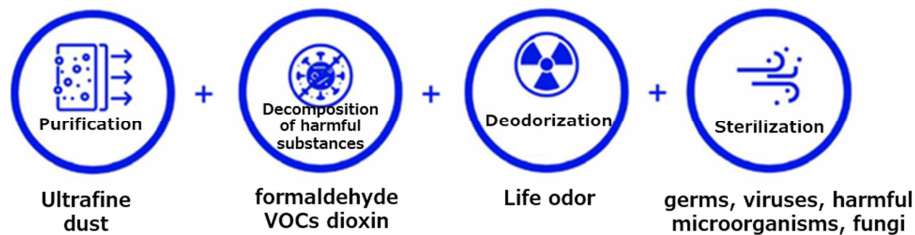


Figure 1. Function of space purification system.

Its function is to purify fine dust, decompose harmful substances, remove bad odors, and sterilize bacteria, viruses, harmful microorganisms, and fungi. This is an intelligent sterilization system using IoT sensing and AI technology according to the person's movement route and the distribution of people in the space.

2.2. Design of Space Purification System

The space sterilization system consists of surface sterilization lighting and air sterilizer. The surface sterilization lighting consists of double edge 405nm LED modules that are harmless to the human body in addition to general surface lighting. It consists of a UVE LED module,

complex sensor, wireless communication device and SMPS.

2.2.1. Surface Sterilization

The surface sterilization lighting consists of UVA (405nm) visible light LED modules with double edges to sterilize at all times, and manufactured its own special heat sink to eliminate heat.

Surface sterilization light irradiates bacterial cells with 405nm and reacts with porphyrin in bacteria to generate active oxygen to destroy bacteria.

2.2.2. Air Purification and Sterilization

The air sterilizer filters the polluted air taken in through the fan with a HEPA filter and sterilizes germs and viruses by

irradiating UVC to the spiral structured air load coated with a photocatalyst. Sterilized air passes through a deodorization filter to adsorb and remove remaining odorous and harmful substances, and the purified air is exhausted. By adopting a HEPA filter of H11 grade or higher on the supply and exhaust side, it purifies the air by filtering fine dust below PM2.5.

The air load is designed in a spiral structure to increase the

filter and UVC irradiation time by adjusting the air speed. The strong sterilizing power of UVC LED destroys and inactivates the DNA structure of bacteria and viruses in the air. The photocatalyst TiO_2 can obtain air purification, sterilization, and odor removal effects through strong oxidation when UVC is irradiated. It can be used semi-permanently by applying a coating agent to the utensils.

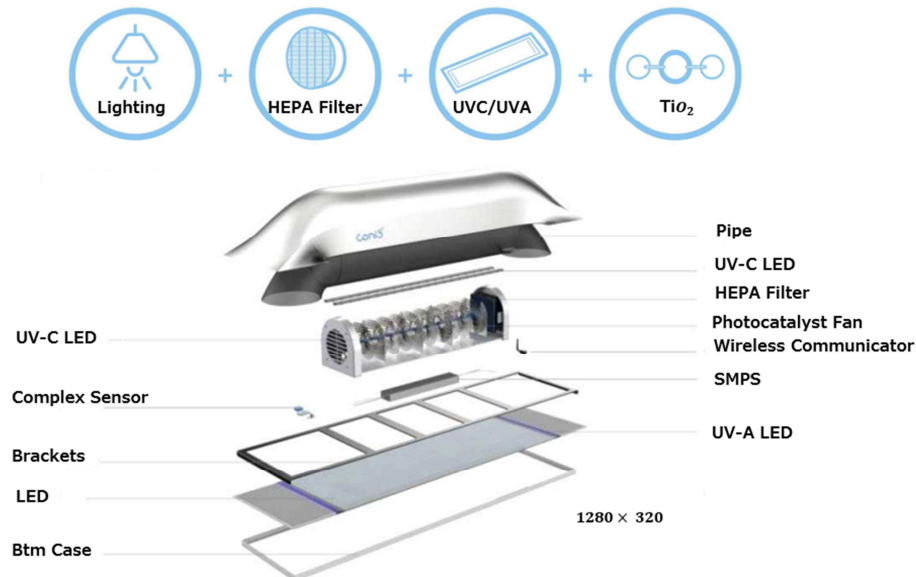


Figure 2. Structure of space sterilization system.

3. Method

3.1. Simulation for Design

3.1.1. UV-LED Placement Design

Sterilization device selection and characteristics were investigated. The 275nm UVC LED element is OSLO UV3636, and the light output is 100mA, 4.68mW. The sterilization rate is 99% (2,000sec) and 99.999% (5,400sec)

based on 24ea.

The 405nm visible light LED device is the UV3528 series, 210mW, 3.3V, and the sterilization rate is 99.9% (18 hours) based on S. Aureus. 72 LEDs were used to manufacture the sterilization module PCB, and 12EA in series and 3EA in parallel were produced for low power consumption. The amount of UV irradiation for 99.9% sterilization was simulated. The irradiation angle is modeling for 120 degree viewing.

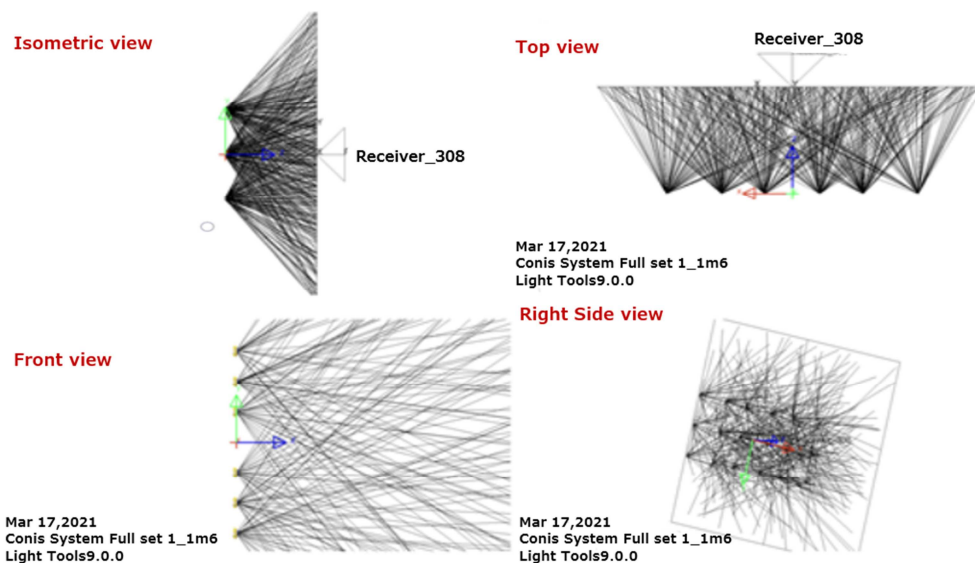


Figure 3. Radiation of space sterilization system.

3.1.2. Sterilization Simulation

The simulation results through the Pu-Kyong National University Marine ICT Convergence Technology Center are as follows. The minimum Does amount for sterilization was simulated under conditions of maximum center illumination and various heights.

Figure 4 shows the exposure time of 3.4min. for the maximum illumination intensity of the center of 367mW/m^2 and the minimum does of sterilization of 3.72mJ/m^2 under the condition of 1m height.

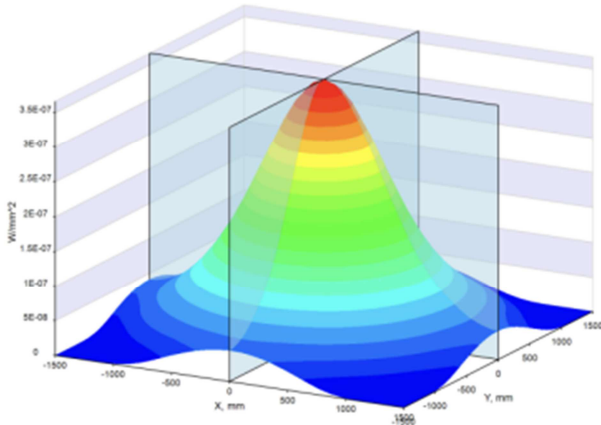


Figure 4. 367mW/m^2 center maximum at 1m height.

In Figure 5, the exposure time is 5.6 sec for the maximum illumination intensity at the center of $13,302\text{mW/m}^2$ and the minimum does of sterilization of 3.72mJ/m^2 under the condition of 1m height.

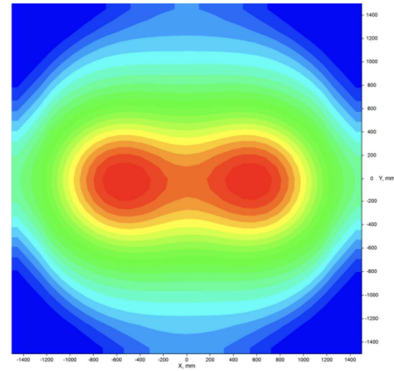


Figure 5. Maximum $13,302\text{mW/m}^2$ center at 1m height.

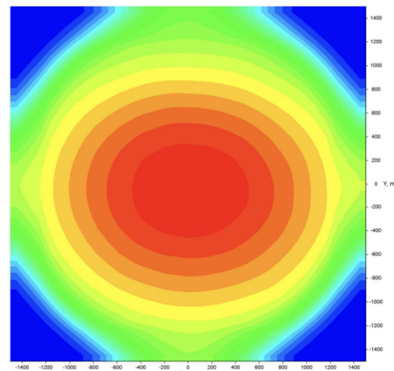


Figure 6. Maximum 3635mW/m^2 center at 2.6 m height.

In Figure 6, the exposure time is 20.5 sec for the maximum illumination intensity at the center of $3,635\text{mW/m}^2$ and the minimum does of sterilization of 3.72mJ/m^2 at the height of 2.6m.

3.2. Design of the Control Board

The design circuit diagram for manufacturing the 275nm control board and the actual product are shown in Figures 7 and 8 below.

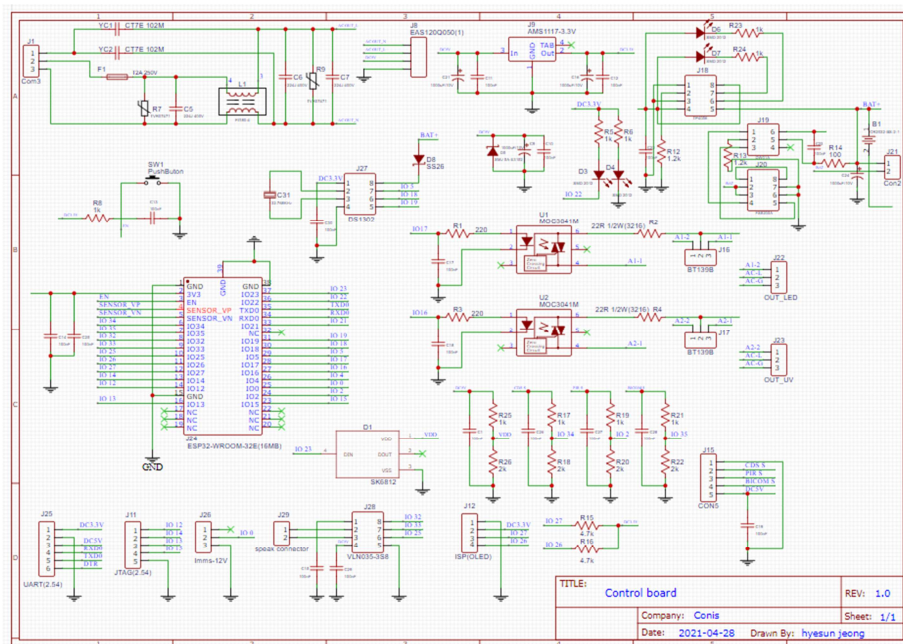


Figure 7. Control board circuit diagram.

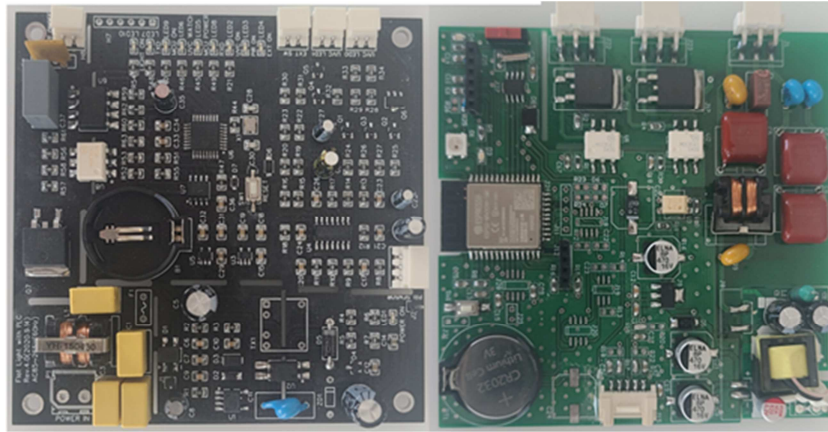


Figure 8. PCB fabrication board.

3.3. Object Movement Identification Technology

It controls intelligent space sterilization by analyzing the distribution form and movement path of people in the space. Advance IR sensing and direction coefficient collection technology for moving objects in space.

While PIR sensor is not suitable for detecting the density of a large number of people, IR-UWB radar sensor can extract people signals from precise distance resolution, and estimate the number of people. So, we use the IR-UWB radar

sensor to calculate the crowding coefficient in the quarantine space and estimate the people count.

A multi-target tracking algorithm using a plurality of IR-UWB radar sensors is applied. By using the detection information (location, attribute) obtained from two or more sensors, it detects a spatial area that is frequently used by users by associating target information with the previous route. Thus, the spatial sterilization ability for areas with high contamination frequency, such as the enhanced sterilization time allocation, is strengthened.

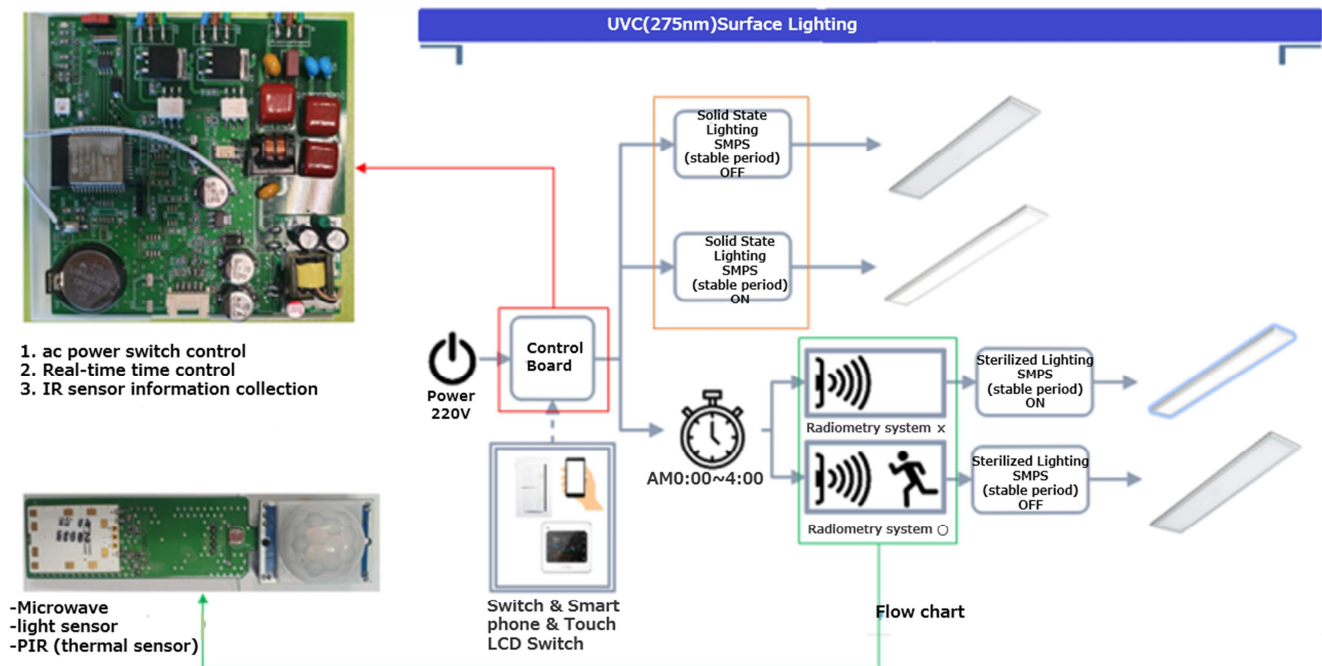


Figure 9. Sterilization lighting switching control system.

3.4. Edge X Platform Service

Apply an efficient edge AI framework to the space sterilization system by the edge environment, such as managing buildings, large complex spaces, and remote public facilities.

As a distributed storage system that reduces the load on the

central integrated control system server, the entire learning data is distributed and stored to multiple clients, and global models are learned through federated learning.

In order to apply to frequency of use prediction service using Edge X platform, Edge AI service was expanded by upgrading human body detection system by existing PIR sensor.

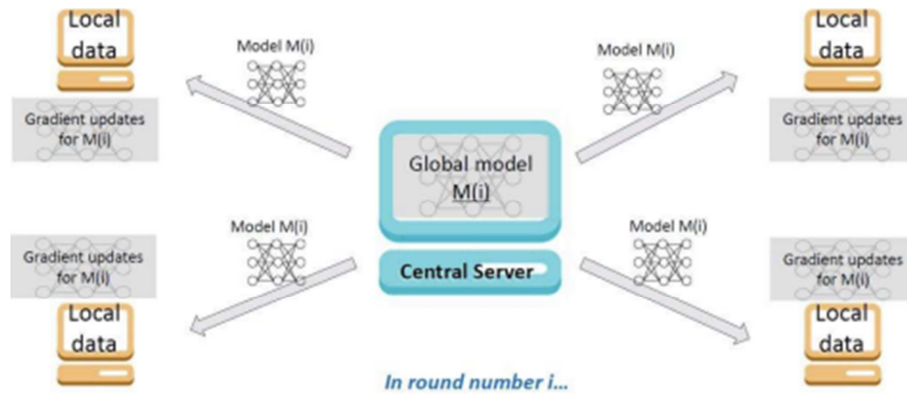


Figure 10. Edge Network & Edge Framework.

4. Results

4.1. Frequency of Use Prediction System

A control board was produced by expanding the Edge AI service by upgrading the user confirmation board by the PIR sensor developed with UVC sterilization lighting.

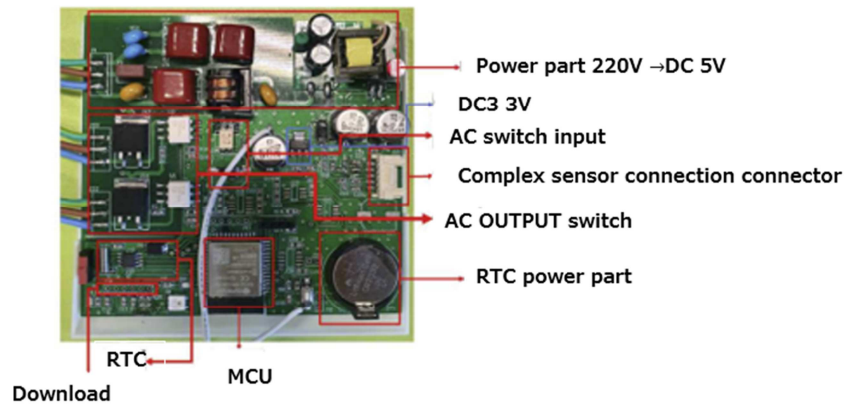


Figure 11. Control board of surface sterilization lighting.

Configure two or more Edge X clients in multiple LED light modules in the space and deliver local sensor information and 405nm UV sterilization information collected from each LED module to Edge X's device-MQTT service.

Use Edge X to receive sensor values from multiple

'intelligent space disinfection systems', process the values in the Edge X client, and allocate intelligent space disinfection execution information as a command message to the 'space disinfection systems' in the group.

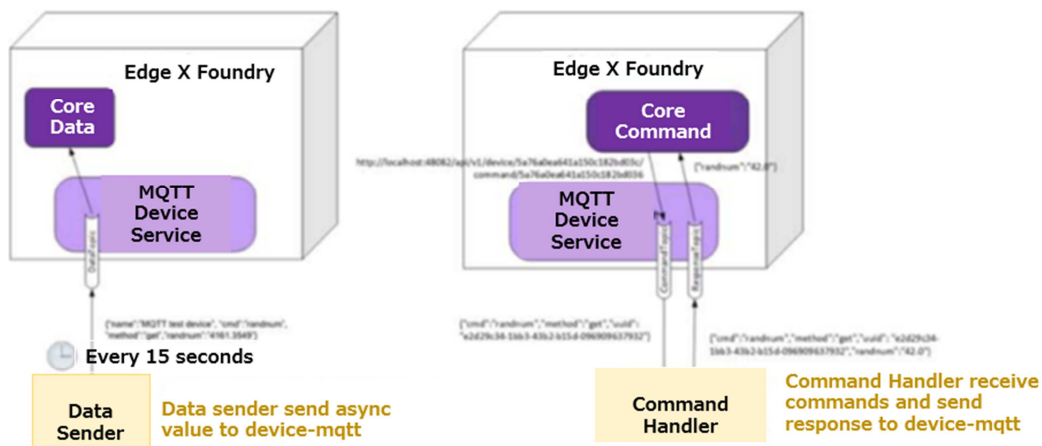


Figure 12. Send message from Edge X client.

4.2. Air Pollution Measurement and Location Analysis

Average the values measured by complex sensors (fine dust, carbon dioxide, temperature and humidity sensors, VOCs sensors) for 4 minutes and save the data in the DB.

Air quality level (good, normal, bad) of composite sensor data is performed based on the standard value of indoor air quality presented by the Ministry of Environment.

By arranging the DATA values in the leveled standard, the frequency of air pollution by ID is digitized, and an algorithm that can analyze the location of air pollution is established by establishing a correlation between each sensor DATA of each complex sensor.

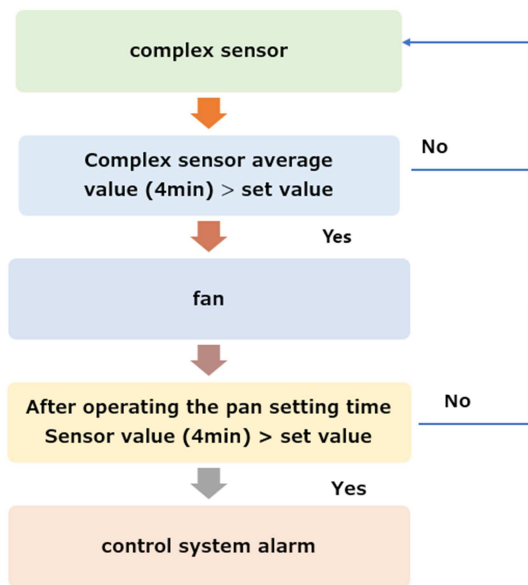


Figure 13. Air quality control by complex sensor.

4.3. Space Sterilization Integrated Control and Utilization

4.3.1. Sterilization Lighting Space Control System

Establish a control system such as interlocking switches and setting schedules for integrated control services in buildings and spaces. As a control system, design a control board for lighting on/off, Dali dimming, and wireless system

integrated operation.

Group control, smart touch for integrated control, mobile, tablet, and remote PC control and monitoring are possible.

Multi-level control is performed by sensors for motion detection, illuminance, and occupancy sensors, and schedules can be set for each time zone, and interlocking control is performed with other systems.

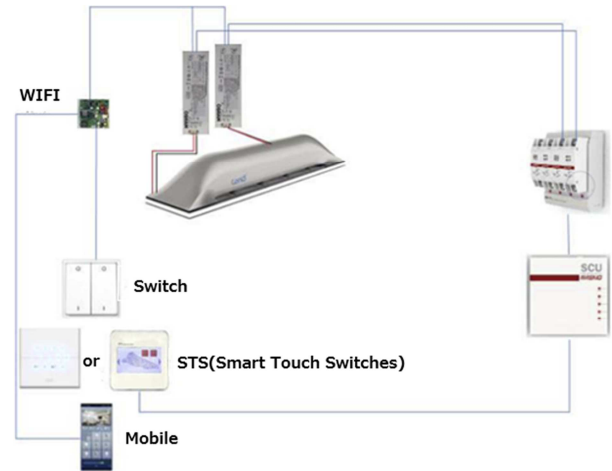


Figure 14. Sterilization lighting space control system diagram.

4.3.2. Development of Human Interface Module

To develop an integrated control system, design a control board for on/off, dimming, and integrated operation of wireless systems. Individual control, group control, smart touch capable of integrated control, mobile, tablet, PC control and monitoring are possible. It works with other systems and allows you to adjust the schedule by time zone.

The UVC driver, MCU control unit, and Bluetooth communication are possible, and the communication unit is wired so that general lighting, sterilization lighting, and FAN can operate. It drives the UVC sterilization module from the complex sensor and transmits data to the Edge X framework and interlocks wireless communication and human interface. The switch design is shown in Figure 15.



Figure 15. Various sterilization mode type touch design.

4.4. Demonstration of Disinfection Lighting for Railway Carriages

In order to establish a clean zone in public transportation, which has a high risk factor for the spread of infectious diseases, special quarantine is being carried out with disinfectants in special sections. And it has been applied as an intelligent space sterilization system with multi-purpose functions.

4.5. Antivirus Elevator Application

It is an intelligent elevator system that enables powerful sterilization by UVC to be performed safely and quickly with an operation control structure in which the UVC sterilization mode is activated only under unmanned conditions.

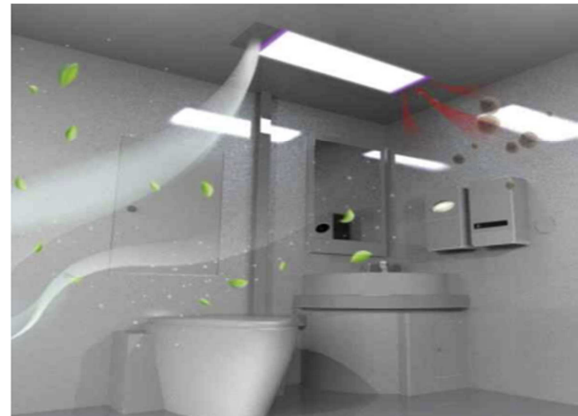


Figure 16. Application to toilets in passenger cars.

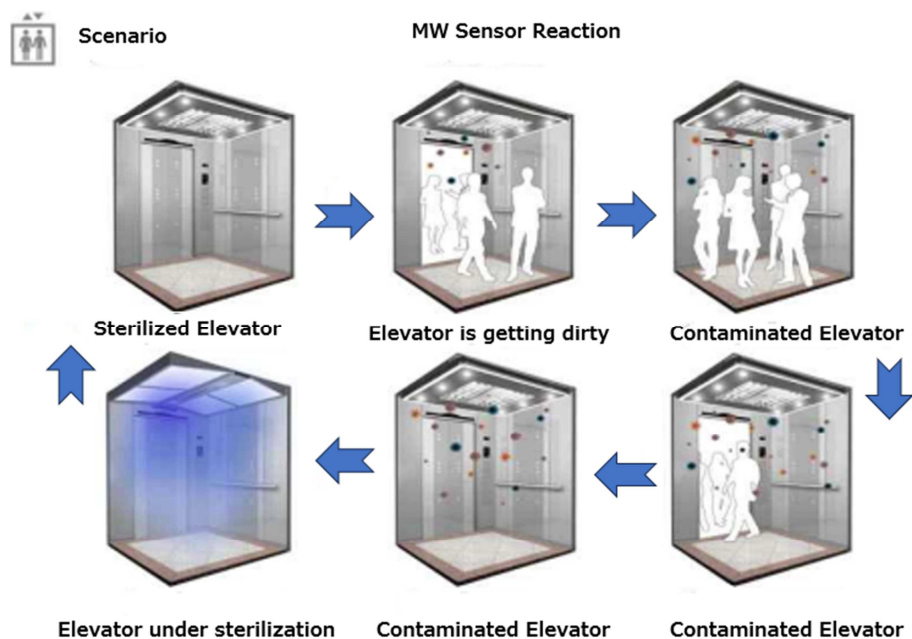


Figure 17. Application to toilets in passenger cars.

5. Conclusion

We developed a system that intelligently performs air purification and sterilization functions through real-time monitoring by measuring the pollution level of the indoor space through various IoT complex sensors (fine dust, VOCs, CO₂) and applying an algorithm that can predict the location of contamination. ToF (Time of Flight) sensor cameras and multi-target tracking algorithms were applied to areas with high frequency of use by people in the space, and the sterilization ability was strengthened accordingly.

The composition of the sterilization system is surface lighting for surface sterilization and sterilization air movement for space sterilization. For the sterilization lamp, a double-edged 405nm LED module surface light that is harmless to the human body was used. And for space sterilization, a UVC-Led module that is harmful to the human

body was designed to sterilize air in a closed type and slow down the air speed as much as possible.

For the air purification function, a photocatalyst-coated spiral structured air load fan and a HEPA filter were used together with a UVC LED module for air sterilization. Simulations were performed to predict the sterilization ability of various spaces according to the movement and density of people. The purifier can be attached with lighting in various spaces such as public transportation facilities, theme facilities, and elevators, and it detects the human body when entering and exiting and activates lighting and sterilization.

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