Sensors and Materials, Vol. 35, No. 9 (2023) 3257–3268
MYU Tokyo

S & M 3389

Simulating Flash-over Point in Fire Alarm Metaverse: Evidence from University Lecture Room

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(Received November 25, 2022; accepted August 15, 2023)

Keywords: metaverse, flash-over, smartphone, temperature sensor, Roblox, online game

Flash-over is a special phenomenon indicating the critical point in the growing process of indoor fires. When flash-over occurs, the life of a person on the same floor and a relevant room is in danger, and the fire can spread throughout the building through the stairs between floors. As alarms that indicate emergencies are frequently malfunctioning, it is common that students on college campuses do not leave immediately when they hear a fire alarm siren. The aim of this study was to simulate flash-over points in the fire alarm metaverse. A smartphone's temperature sensor showed sufficient detection capability to satisfy the accuracy of temperature survey equipment as required by the World Meteorological Organization (WMO) observation guidelines. The flash-over point metaverse built-in Roblox showed potential as an educational tool for fire disasters by enabling students to easily understand the mechanisms inherent in fire alarm sounds. This study can be an important reference as a fire disaster education instrument in an online game environment by presenting a metaverse's potential in visually implementing the flash-over principle.

1. Introduction

The early detection of a fire is an important factor in determining the scale of damage caused by a fire. Flash-over occurs when most of the exposed building materials indoors heat up to an ignition temperature and release flammable gases. The time to reach flash-over in case of fire is the criterion for determining the allowable time required for human evacuation. The phenomena arising from the fire can be used for fire detection only when they are clearly distinguished from these occurring in everyday life. The temperature at which the detector operates has the greatest effect on early fire detection.

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https://doi.org/10.18494/SAM4260

ISSN 0914-4935
https://myukk.org/

The detector does not operate when the flame reaches its peak and the temperature increases rapidly. Even in the slightest heat, when the temperature rises relatively slowly, an alarm is issued when the temperature achieves a certain rate of increase.[1] The differential detector installed in university classrooms uses the temperature difference between the inside and the outside to detect flash-over. Therefore, nonfire alarms become frequent in winter when the temperature difference between the inside and the outside is severe. When the wind from an air conditioner directly hits the detector in hot weather, an alarm may sound owing to a sudden temperature difference. Automatic fire detection equipment should provide reliability for all people who use building facilities. However, it is often recognized as a piece of troublesome equipment that causes inconvenience due to unexpected alarms in the case of nonfire.

Suppose students suffered from unnecessary pain due to a malfunctioning alarm. In that case, the university authorities must provide the students with a convincing explanation and make it easy for them to access the data on the alarm causing the malfunction. Regardless of how precise the equipment, there is a limit to the efficient use of the instrument if the user who operates it does not properly understand the operating principle of the fire alarm. Basic knowledge of the working principle of fire alarms should be given to students so that they can understand the provided data. Governments of each country emphasize evacuation-oriented education in the event of a fire disaster.[2] There are significant limitations for general students who do not major in fire and disaster prevention in accessing tools for understanding the principles of flash-over detection. This reality is far from the request of disaster-related agencies to strengthen the flash-over education of students by operating a virtual reality and three-dimensional homepage. In such a flash-over education system, disaster-related knowledge cannot be continuously passed on to students, making it difficult for them to recognize the importance of fire and encourage more active participation in fire prevention.

There have been three major waves of innovation in computer technology so far, i.e., the introduction of personal computers, the Internet, and mobile devices. The fourth wave of computing innovation is centered on spatial and immersive technologies such as virtual and augmented reality.[3–6] In particular, metaverse computing is a next-generation ubiquitous computing paradigm with the potential to innovate not only fields such as online education, business, and remote work but also specialized fields such as building management and disaster prevention.[5] In the metaverse, a significant portion of work based on computers is performed independently. In the beginning, the metaverse was considered to be limited to occupations directly related to the information industry. However, in recent years, the metaverse is expanding to almost all areas of human activity, such as economy, culture, and real estate, including education.[7]

The technology representing the fourth industrial revolution is cyber-physical systems (CPSs). In CPSs, cyber-to-physical bridging is a sensing process that uses sensors to acquire spatial information about physical phenomena.[8] The term metaverse or digital twin can be described as a digital copy of any physical system. In particular, linking information between sensors for the efficient management of buildings and cities is a concept related to smart cities, factories, and buildings. The metaverse is a system that expands reality into an Internet-based cyber world and allows all activities to be performed in a virtual space. A virtual laboratory means that any place can be an educational space as long as there is a smartphone and an

environment where the Internet is available. Numerous previous research studies have been conducted on how to increase the accuracy of fire detection.[9] However, it is very difficult to find a previous study where the concept of a virtual laboratory based on the metaverse is applied to teach the concept of flash-over. Suppose this virtual laboratory concept is introduced to educate students regarding the flash-over phenomenon. In that case, it is considered that the serious problem of no longer trusting smoke alarms can be addressed to some extent. Therefore, in this study, we started to develop an educational tool to visually experience flash-over and pre-flash-over situations through a temperature sensor installed in a smartphone.

2. Materials and Methods

The study area was the Kyungpook National University campus in Daegu Metropolitan City, South Korea. There are 102 buildings on the campus with an area of 782000 m^2. University buildings do not have full-time residents; especially during summer vacations, very few people are in the classrooms. It is possible to sense the temperature distribution of a lecture room in a natural state without external disturbances because there is no air conditioning. Therefore, it meets the conditions necessary to predict fire episodes by measuring changes in the trends of classroom temperature under controlled conditions.

Fire detection and alarm facilities using existing wired networks have fundamental limitations such as network failure as well as the misidentification of ignition locations.[10] IoT-based fire detection systems have long been expected to be an alternative because they can detect environmental information about fires and provide services through information processing in a short time.[11,12] However, applying these IoT technologies to individual buildings is difficult since they are expensive, especially if it is not a public facility or a government-backed project.[13]

Recently, the technological development of smartphones has opened the possibility of using them for detecting disasters, such as fires and earthquakes. Smartphones are powerful minicomputers equipped with various sensors, and above all, the majority of the population has one, making it easy to measure the temperature in various situations.[14] In addition, owing to their portability and broadband Internet access, smartphones can be used as tools for low-cost fire monitoring. Overeem *et al.* conducted research on the correlation between the temperature sensor data of a smartphone battery and the atmospheric temperature of a city center, and confirmed the possibility of measuring the temperature of the atmosphere with a smartphone.[15]

However, because the amount of fire detection information collected through a smartphone has to be processed simultaneously in real time, it is difficult to accurately judge a fire if the detection criteria are not clearly defined. Therefore, it is necessary to ensure reliability by comparing verified sensor-based temperature-measuring devices. To solve this problem, we attempted to confirm the reliability of the smartphone sensor by comparing it with that of hardware-type temperature-sensing devices.

In addition, by transmitting the measured temperature data to a server in real time and detecting any temperature changes in connection with the building model in the metaverse, a system that can detect the fire location in the event of a fire was implemented, as shown in Fig. 1.

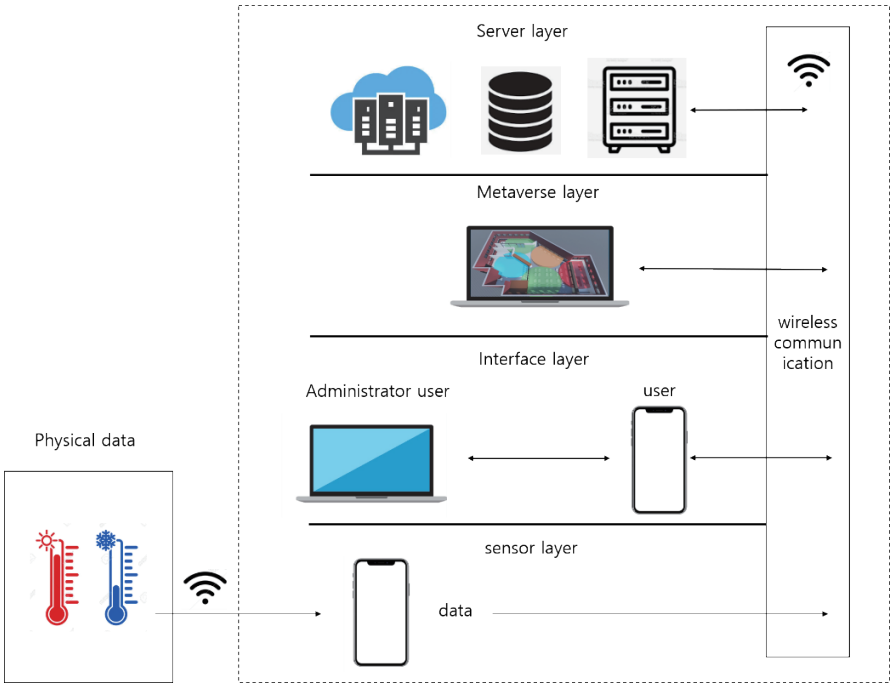


Fig. 1. (Color online) Flash-over alarm system in the metaverse.

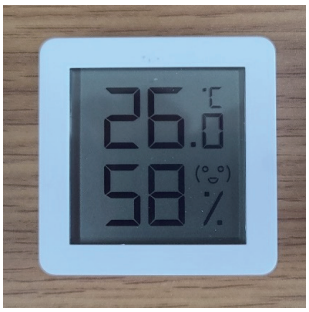
2.1 Temperature measurement

The clearest expression of a fire inside a building is a change in indoor temperature over time. Generally, a fire undergoes a process of attenuation after reaching a maximum temperature through a growth period from the ignition point. To minimize the damage caused by a fire, it is very important to detect the fire before the flash-over phenomenon occurs at the highest temperature. Therefore, the detection of fire factors and research on fire models are being continuously conducted.[16,17] In particular, the function of searching for a fire occurrence based on computer vision has been mainly developed for fire detection; however, color-based fire detection still has the problem of a high false alarm rate.[18,19] A phenomenon that is caused by a fire can be used for fire detection only when it can be clearly distinguished from daily phenomena, i.e., heat, gas, and light are common phenomena even when there is no fire; therefore, research is needed to increase the accuracy of fire detection.[20]

For the early detection of fires, it is essential to accurately measure the temperature. Most smartphones are not equipped with temperature sensors as individual accessory hardware to measure ambient air temperature. However, all smartphones are equipped with temperature sensors to detect battery overheating. Nevertheless, most smartphone manufacturers do not provide detailed specifications for the built-in temperature sensor to automatically detect battery overheating. The indoor temperature was measured between July and August using an empty classroom at the university, as shown in Fig. 2. The temperature was measured at 1 h intervals between 9 a.m. and 9 p.m. using a digital thermometer with an error range of ±0.1 °C and a smartphone (Table 1). The number of people entering the lecture room was minimized, and the

Fig. 2. (Color online) Typical scene of the lecture room used to verify the accuracy of temperature measurements.

Table 1
(Color online) Specifications of equipment used.

	Digital thermometer		Smart Phone	
hardware				
	XIAOMI MHO-C101		Samsung SM-G935	
	Temperature display unit	0.1 °C	Temperature display unit	0.1 °C
	Temperature accuracy	±0.1 °C	Temperature accuracy	—
Software	Server: Python (notebook PC) Client: Android Studio (smartphone) Roblox lua (desktop PC)			

environment was maintained in the same state throughout the measurement period. In addition, the external factors affecting the indoor temperature were minimized by stopping the air conditioning operation.

2.2 Building target facility in Roblox

The most important condition for the metaverse to spread to the public is that everyone must be able to easily and quickly create or participate in the platform. Roblox is a highly accessible metaverse platform with approximately 150 million monthly active users that can create and link

virtual worlds in real time. Roblox does not simply model buildings on the platform but uses the Lua language through a studio to support reality-based interaction models such as complex physical actions and behaviors, complex terrain designs, and various development environments such as audio and video.[21] It is suitable for the metaverse implementation of building environments because it provides a smooth link between external data such as sensor measurements and statistical databases and the platform in real time.[22]

In this study, Roblox Studio was used to model the building to be studied. The welfare center at Kyungpook National University was selected for this study. The welfare center is home to various facilities such as cooking rooms, restaurants, health centers, and cafeterias, and is the most used building by school members. In particular, cooking is performed every day in a high-temperature environment in the cooking room; therefore, changes in indoor temperature are high, and the risk of fire is heightened.

As shown in Figs. 3(a) and 3(b), the studied buildings were implemented in Roblox, a metaverse program. The model was built using drawings and measurement data of the building under study, and its characteristics were reflected and implemented so that the main facilities of the room could be identified with the naked eye. In addition, an environment for measuring smartphone temperature data was configured in the major facilities, and the temperature data were transmitted to the server in real time so that changes in the indoor temperature of the building could be immediately identified in Roblox.

3. Results

3.1 Comparison between smartphone versus digital thermometer

The data of the hottest period in the results of the indoor temperature measurement in the research space are organized as shown in Table 2 and then displayed as a graph of the changes over time, as shown in Figs. 4(a)–4(d). The comparison of the temperature measurement results shows that the difference in temperature between the two sensors is consistently small at approximately 0.2 °C on average. Therefore, this level satisfies the accuracy of the temperature

(a) (b)

Fig. 3. (Color online) Target building facility designed in Roblox: (a) exterior and (b) interior.

Table 2
Measurement data on room temperature.

Time	July 21			July 29			August 4			August 11		
	Smart Phone	Thermo-meter	Compar-ison	Smart Phone	Thermo-meter	Compar-ison	Smart Phone	Thermo-meter	Compar-ison	Smart Phone	Thermo-meter	Compar-ison
9:00	26.4	26.6	0.2	29.3	29.5	0.2	31.6	31.8	0.2	29.9	30.1	0.2
10:00	26.9	27.1	0.2	30.8	31	0.2	31.4	31.6	0.2	30	30.3	0.3
11:00	27.8	28	0.2	32.6	32.8	0.2	31.8	32	0.2	29.4	29.6	0.2
12:00	28.5	28.8	0.3	33.5	33.7	0.2	32.5	32.7	0.2	29.1	29.3	0.2
13:00	29.8	30.1	0.3	34.2	34.4	0.2	33.3	33.5	0.2	28.5	28.7	0.2
14:00	31.5	31.7	0.2	34.5	34.7	0.2	34.5	34.7	0.2	28.7	28.9	0.2
15:00	32.1	32.3	0.2	34.8	35.1	0.3	34.5	34.8	0.3	29.2	29.4	0.2
16:00	31.5	31.7	0.2	33.8	34	0.2	34.7	34.9	0.2	28.2	28.5	0.3
17:00	30.6	30.8	0.2	33.7	34	0.3	34.7	34.9	0.2	27.4	27.6	0.2
18:00	29.8	30	0.2	32.5	32.7	0.2	34.6	34.8	0.2	27.4	27.6	0.2
19:00	29.2	29.4	0.2	31.4	31.7	0.3	33.7	33.9	0.2	27.2	27.4	0.2
20:00	28.4	28.6	0.2	30.1	30.3	0.2	32.4	32.6	0.2	26.9	27.2	0.3
21:00	27.9	28.1	0.2	29.7	29.9	0.2	31.7	31.9	0.2	26.9	27.1	0.2

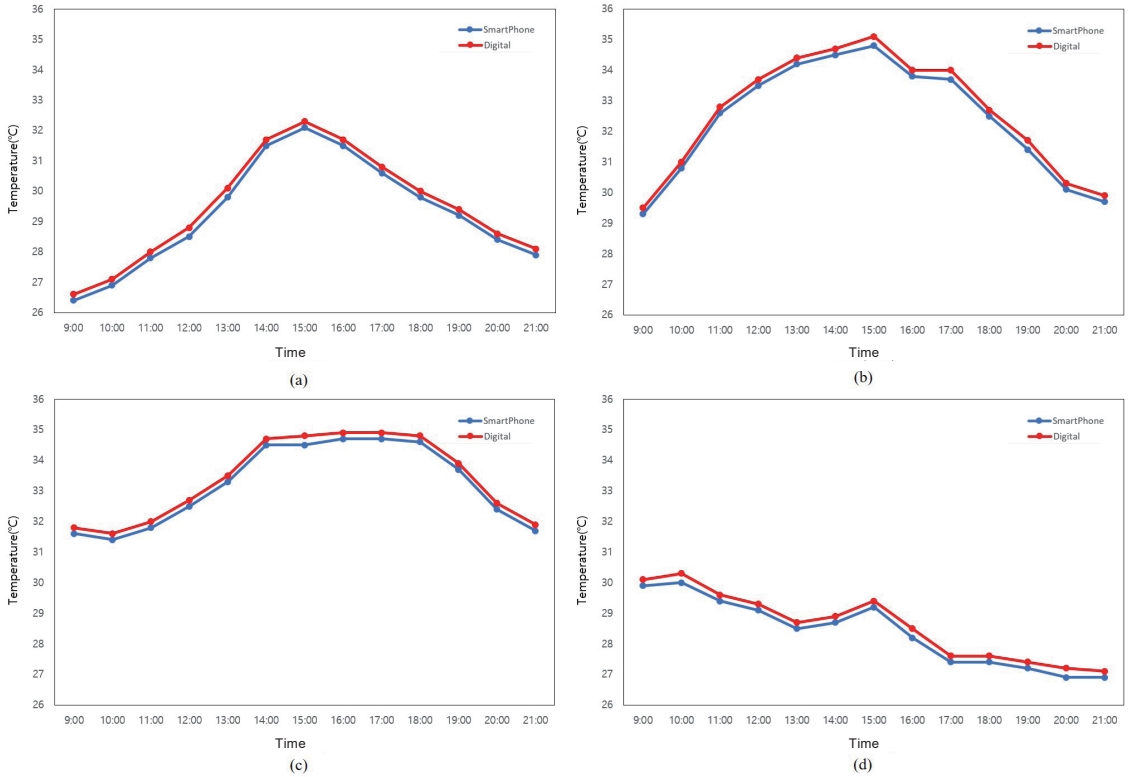


Fig. 4. (Color online) Changes in room temperature: (a) July 21, (b) July 29, (c) August 4, and (d) August 11.

observation equipment required by the WMO guidelines, and it can be determined that the reliability of the temperature measurement of a smartphone sensor is suitable for measuring the temperature of an indoor space.

3.2 Establishing a metaverse-based flash-over detection platform

In this study, a system was constructed, as shown in Fig. 5, by utilizing a commonly used smartphone and desktop environment for metaverse-based ignition location detection. The core function is to observe and report changes in a situation according to changes in temperature data in the virtual environment, that is, the metaverse, and to establish a digital twin platform in which the virtual environment matches reality. For metaverse expression, the virtual environment expressed the architectural elements of the research building using Roblox Studio.

For the virtual environment and real-world communication, an http-based web communication system was established to enable server–client communication, and the core server was built using Python on a desktop. The web framework used to build the web server uses a flask. Flasks can write code better than other web frameworks and can implement servers with only the necessary functions without creating unnecessary structures. In addition, the established web server was configured to enable two-way communication through the relay function of the Roblox Studio and Android applications, which were used as metaverse platforms.

Roblox implements http-based communication in Android studios based on the source code through the Lua language in applications. An Android studio based on Java implemented a stable client using okhttp, an open library created for http communication, and an Android application developed to measure temperature data. Temperature data are detected using hardware mounted on the smartphone itself. Okhttp is an open-source-based library for http and http/2 protocol communication provided by Square, and supports both synchronous and asynchronous methods for users to select and use. The advantage of using okhttp is that it is possible to omit complex preprocessing, such as exception processing, buffer I/O, and the HttpURLConnection connection.

In this manner, Roblox and Android applications can virtually express a real situation through two-way communication. The server is implemented for stable data communication between the metaverse and the applications, and supports two-way communication, serving as a

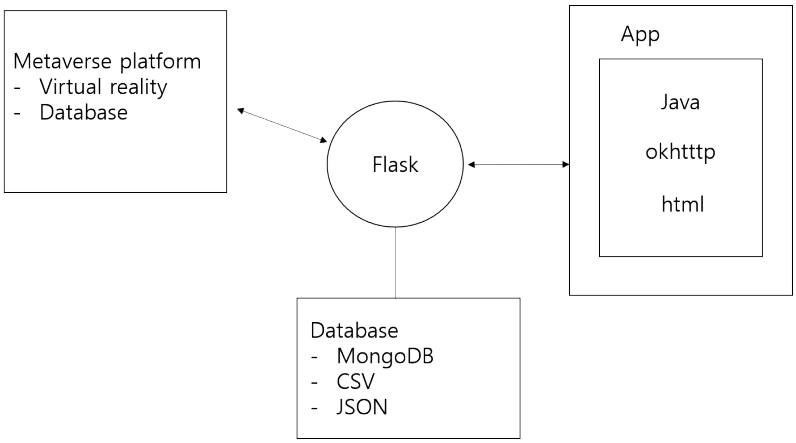


Fig. 5. Metaverse and server environment.

stepping stone for connecting the virtual and real worlds. In this study, a web server using the HTTP protocol was used and implemented using the Python code. Flask is a type of micro-web framework written in Python, which allows for creating a complete web server with a simple code and has strong scalability through various expansion modules. In implementing the metaverse and server environment, it was determined that using flasks with various expansion modules was a more efficient implementation, and flasks were selected and implemented.

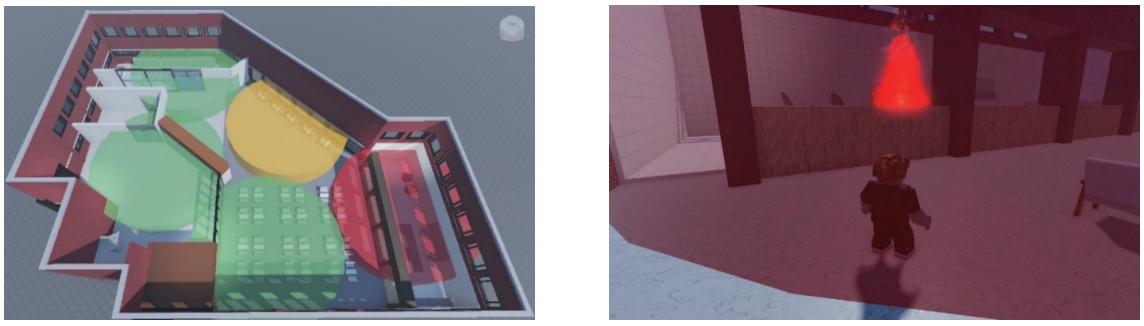
The implemented web server, metaverse platform, and application made it possible to express the state of reality in a virtual environment through interactions. Conversely, it is possible to track the state of reality in virtual environments. Managers and users can share their current status with a large number of people in real time using the Roblox platform, and practical evacuation or education can be provided depending on whether the situation is dangerous.

4. Discussion

The quantitative visualization function is one of the greatest strengths simulating flash-over points in the fire alarm metaverse. Since temperature data can be acquired from a smartphone, information about the normal state before proceeding to flash-over can be checked at any time. As a result, college students will be able to learn virtual reality information related to realistic flash-over points in classrooms where fire alarms often malfunction.

In this study, the temperature data for the experimental target acquired through a smartphone were delivered to a metaverse platform to enable real-time temperature monitoring. Inside the experimental target implemented in the metaverse, there are various spaces such as cooking rooms, restaurants, health centers, and cafeterias, and each space was assigned the temperature data of the real space using a smartphone. The temperature data measured in reality are expressed in real time on Roblox through a web server, and changes in temperature data in each space, in reality, can be monitored. As shown in Fig. 6(a), the current status of temperature detection inside the classroom can be expressed in real time.

Generally, the temperature does not change significantly, except in the cooking room when preparing food. Therefore, it can be seen that the temperature is distributed within the normal range. The system was implemented such that when the temperature significantly exceeded the



(a) (b)

Fig. 6. (Color online) Temperature and flash-over in the metaverse: (a) temperature representation in real time and (b) expression of flash-over.

normal range, the temperature expression area turned red and a fire alarm occurred, as shown in Fig. 6(b). It is divided into normal, careful, and serious stages according to the temperature. Evacuation guidance inside the building, safety management, and the confirmation of the relevant points are given for serious stages. Additionally, system users may report the current risk situation to the administrator.

The lithium-ion battery of a smartphone is equipped with a temperature sensor to prevent damage that can occur when the battery heats up excessively. The temperature sensor data of a smartphone battery can be affected by numerous factors (for instance, the user's body temperature when kept in a pocket) faced in the process of using a smartphone, not just the temperature of the *ambient* air. Chau[23] investigated how the temperature measurement function of a smartphone can be changed depending on the holding conditions, such as being in the user's pocket. It was confirmed that the ambient air temperature can be measured differently from an individually unique condition, even if the user is holding the smartphone inside clothing. Moreover, Redmayne[24] conducted a survey on smartphone use among women aged 15 to 40. It was confirmed that most of the day, the smartphone stays in a nonheating state that does not affect the operation of the battery. Thus, the result of this study validates that the smartphone remains capable of measuring the atmosphere's temperature. Previous studies have confirmed that the temperature approaching the flash-over situation of a fire does not generally appear under the condition (such as the user's pocket) that the individual user carries a smartphone.[24] This study was conducted on a specific smartphone produced by a well-known manufacturer. Follow-up research is required to generalize this study's results by using various smartphone models.

There is a previous study that tracked the flash-over of a fire in real time using deep learning.[25] However, previous studies have yet to attempt to track flash-over using the temperature sensor of a smartphone. Moreover, previous research has yet to attempt to visualize the signals derived from the smartphone's temperature sensor connected with the metaverse environment. In this study, we implemented a pilot system to simulate flash-over points in the fire alarm metaverse. Therefore, it was not possible to obtain measurement data at the temperature at which the actual flash-over was reached. Despite the limitations of this study, the constructed system is judged to serve as a visual instrument to some extent that allows students to understand the concept of flash-over points in a more familiar manner. Suppose such a fire alarm metaverse is introduced into university education. In that case, students will be able to diagnose the cause of the problem. In addition, they will make it an opportunity to approach flash-over from an academic viewpoint rather than ignoring it as a nuisance whenever the fire alarm sounds.

5. Conclusions

To the best of the authors' knowledge, this study is the first in the world to simulate flash-over points in the fire alarm metaverse of an online game environment. The temperature measured by a smartphone was consistently about 0.2 °C lower on average than that measured by a digital thermometer, with a temperature measurement error range of ±0.1 °C. The reliability

of the smartphone's temperature measurement is at a level that satisfies the accuracy of the temperature observation equipment suggested by the WMO. An interface capable of simulating flash-over points in the fire alarm metaverse was implemented in the Roblox environment. By introducing the virtual laboratory concept in an online game environment, any student with a smartphone can directly experience pre-flash-over and flash-over on the basis of the visual effects of the online game environment in real time. This is expected to contribute to determining a fire early and extinguishing the fire by expressing the point at which the temperature rises abnormally in stages and allowing managers to immediately grasp the fire situation through fire expression effects and warnings when a flash-over point is crossed. As a result of the pilot test, the fire alarm metaverse almost eliminated the existing controversial issues related to tools to learn the principle of the fire alarm to the extent that university students or interested users can have a fairly encouraging recognition of detection technology maturity on pre-flash-over and flash-over. Simulating pre-flash-over points based on the virtual laboratory concept bridges the real and virtual worlds. This study is expected to be an important reference using representative technologies of the fourth industry as a tool for educating the public regarding fire disaster response such as flash-over points.

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