Verification of Applicability Positioning Systems with Thermopile Human Sensor in Office

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Abstract. The purpose of this study is a discussion on the multifaceted utilization of indoor positioning systems such as building facility control, use situation grasping, and operational analysis in offices. Thermopile human sensors have been come into practical use by MEMS (Micro Electro Mechanical Systems) technology and are becoming widespread. In this report, the accuracy of presence / absence and human count detection for a thermopile human sensor was verified and discussed possibility of use according to the purpose in the office.

1 Introduction

The purpose of this study is to verify the possibility of using indoor positioning systems for various purposes such as equipment control and determining the status in an office.

There is currently a need to pursue a rational approach to building operations, for which new technologies are being pursued. In particular, the need to focus on human behaviour is increasing. In recent years, indoor positioning systems have become widely diffused as a technology for capturing human behaviour and bringing about a paradigm shift to conventional building operations, such as advanced equipment control, positional information visualization, traffic line analysis, and an evaluation of the space utilization rate. The research on indoor positioning methods in Japan started with RFID and PHS around 2000, and later diversified into various methods using Bluetooth, wireless LAN, geomagnetism, ultrasonic waves, infrared rays, and visible light. Yamamoto, Ono, and Otsuka et al.[1)] reported on a premises PHS network, Kurosaki and Saito et al.[2)] on a wireless LAN, and Morishima et al.[3)] on a location information system using Bluetooth. Since then, the research aimed at technological evolution and sophistication[4,5)], applied research such as measurement, monitoring, and analysis of flow lines and behaviour using indoor positioning[6,7,8,9)] and the research aimed at application to worker productivity analysis[10,11)] have progressed. At the same time, it is also spreading in the construction field as a method for controlling lighting and air conditioning and grasping position information.

A human sensor with a thermopile array is a thermopile that used to be a single pixel but has been miniaturized and made into multiple arrays through micro-electro mechanical systems technology. Indoor positioning systems are becoming more wide-spread, and commercial products such as sensors, lighting, and automatic control are available on the market. They are also being applied to lighting and air conditioning control. Aoyama et al.[12)] have also developed a system that integrates thermal images from multiple sensors into a single image and detects people.

The accuracy required for indoor positioning systems differ depending on the intended use. Such systems are being used for many purposes without verification and there have been no quantitative comparisons of the accuracy required for each intended use. In this study, an overview of indoor positioning systems and an outline of such a system using a thermopile human sensor will be described. Furthermore, the accuracy of the system in an actual environment are verified.

2 Overview of Thermopile Human Sensor

There are various indoor positioning methods, which can be roughly divided into two methods. There is a method in which the target is passively detected by heat, light, radio waves, etc., and a method in which the target is actively detected using signals transmitted from smartphones, BLE (Bluetooth Low Energy) tags, RFID tags, etc. held by the target. Furthermore, there are two methods for the latter active detection method. There is a method in which the positioning system captures the radio waves of the device held by the target, and a method in which information such as BLE beacons installed in space is read by a smartphone, transmitted to the positioning system, and compared with the map.

The principle and system configuration of the thermopile human sensor are described below, it's used

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in the indoor positioning system for accuracy verification in this research. First, a thermopile is an element that uses the Seebeck effect and measure radiation temperature to obtains an electromotive force proportional to the amount of incident energy of infrared rays.

This commercially available sensor[13] has 16 x 16 thermopile elements, 256 thermopile elements in total. The distribution is measurable. It's possible to measure the temperature distribution in the detection area of 1,000mm in height and 3,600*3,600mm in horizontal plane when the installation height is 3,000mm (Figure 1). Furthermore, the sensor detects people based on this temperature distribution, and can distinguish people from objects with temperatures close to those of humans based on the below three features. (1) Human body temperature is higher than room temperature (human body temperature is 4°C or higher than background temperature), (2) Hot objects such as heaters do not move (human body speed is within 0.3-1.0 m/s), (3) Human position is continuous. The spatial resolution of this sensor is 900*900mm for presence/ absence detection and 3,600*3,600mm for people detection. In this verification, the data acquisition interval (time resolution) is set to 1 second.

3 Overview of Accuracy Verification

3.1 Object of Office

Accuracy verification was performed on one floor of an office building completed in 2003 in central Tokyo (14 floors above ground, 1 floor below ground, 1 penthouse, total floor area of 20,000m2). Figure 2 shows the plan.

- Target area: 925m2 (work area only)
- Number of registered people: 110
- Number of seats: 255

3.2 Installation Status of Sensors

A total of 80 thermopile motion sensors are arranged in 5 rows and 16 columns so that they can cover the entire target floor (Figure 3). In addition, a cloud-connected network system (Figure 4) has been constructed to synchronize and efficiently manage data from 80 sensors installed throughout the floor. By incorporating a BLE beacon into a thermopile-type human sensor, sensor data is transmitted and stored in a data server on the Internet via a BLE gateway.

3.3 Metric Definition

For accuracy verification, the indicators are defined as follows.

$$Space\ utilization = \frac{N_{Count}}{N_{All}} \times 100\ (\%) \quad (1)$$

$$Presence/Absence: Incorrect\ answer\ rate = \frac{N_{Error}}{N_{All}} \times 100\ (\%) \quad (2)$$

$$Numbers\ of\ people: Relative\ error = \frac{(\sum H_{Sen} - \sum H_{Obs})}{\sum H_{Obs}} \times 100(\%) \quad (3)$$

Table 1. Specification of Thermopile Human Sensor.

Item	Specification
Pres/Abs detection output	Presence - Absence (4 or 16 areas)
Human count detection output	0 -16 people
Undetected areas	16 areas can be set
Temperature output	5 - 50 ℃ (16 areas)
Ambient temperature	16 - 29 ℃
Temperature difference	Over 4 ℃ (People > Ambient)
Moving velocity	0.3 – 1.0 m/s

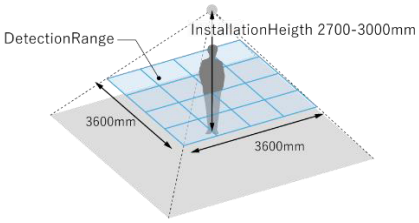


Fig. 1. Measurement Area of Thermopile Human Sensor.

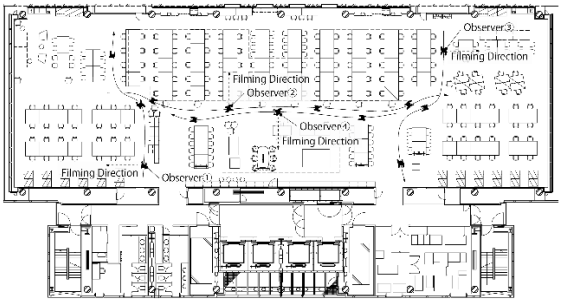


Fig. 2. Plan of Observation Floor.

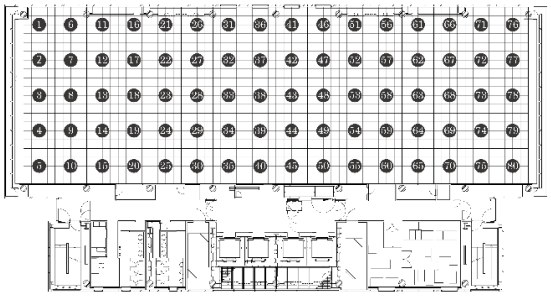


Fig. 3. Plan with Thermopile Human Sensor.

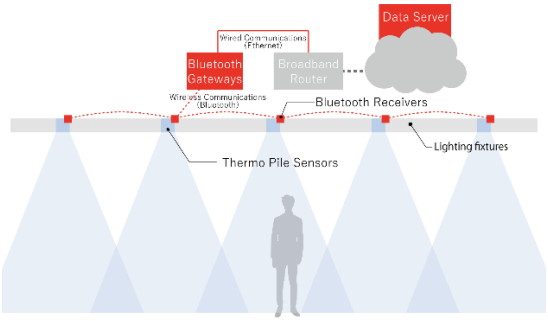


Fig. 4. Network System with Thermopile Human Sensor.

N_{All} is the total number of presence/absence detection grids of thermopile motion sensors (4×4 grids per thermopile motion sensor, 5 rows and 16 columns for the entire floor, 1280 in total). N_{Count} is the number of grids in which the presence of a person is confirmed or detected. N_{Error} is the number of grids in which the actual measurement and the presence/absence result of the thermopile type human sensor do not match.

3.4 Actual Measurement by Visual Inspection

The visual observation was performed from 8:00 to 20:00 on February 13 and 14, 2020. People move from time to time for work, and position information changes dynamically in a real environment office. The thermopile human sensor can measure the positional information of the entire floor at any given time.
On the other hand, in actual measurement by visual observation, it takes time for the observer to record the position information of the entire floor, so the actual measurement result may include dynamic changes in the position information. We divided it into the following two tasks in order to minimize the dynamic change of position information in the actual measurement.

- Video shooting (using a tablet device)
- Transcription from video to plan view

It can be shortened to several seconds to several tens of seconds by video shooting but it took a few minutes to record the position information of the entire floor on the plan view one by one. Furthermore, we tried to shorten the time taken by dividing the video shooting by four observers in this research.

The positional information was transcribed on a plan view showing a grid similar to the measurement grid of the thermopile motion sensor while viewing the recorded video. Presence/absence judgment is counted as one square if it is within the grid, and as multiple squares if it spans multiple grids (Figure 5).

Figure 6 shows the temporal variation of the space utilization rate measured visually, and Figure 7 shows the temporal variation of the number of people visually measured. The space utilization rate fluctuated around 10% after 10:00, dropped to around 7% between 12:00 and 1:00 p.m., and fluctuated around 10% again after 1:00 p.m. It reproduces the movements of people in the office, such as those who come to work in the morning, those who leave for their lunch breaks, and those who leave in the evening.

The number of people fluctuated around 100 after 10:00, fell to about 75 between 12:00 and 1:00, and fluctuated around 100 again after 13:00. From the above, it can be seen that the office is used at 0.1 person/m2. It is thought that the movement of people in the office is reproduced well, as well as the presence and absence.

4 Result of Accuracy Verification

4.1 Verification of Presence/Absence Detection Accuracy

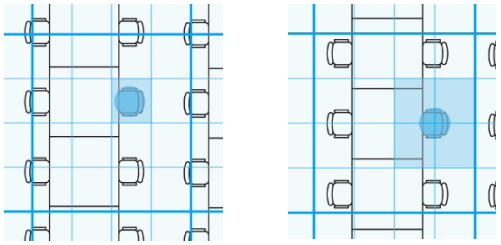


Fig. 5. Calculation of Space Utilization Rate.

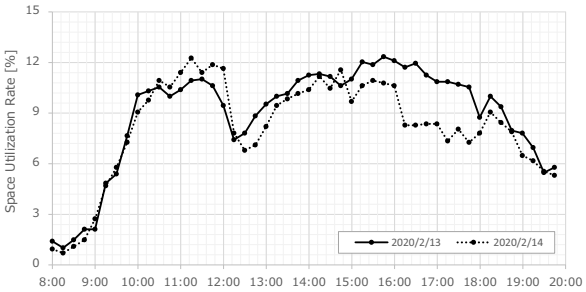


Fig. 6. Time Series of Space Utilization Rate.

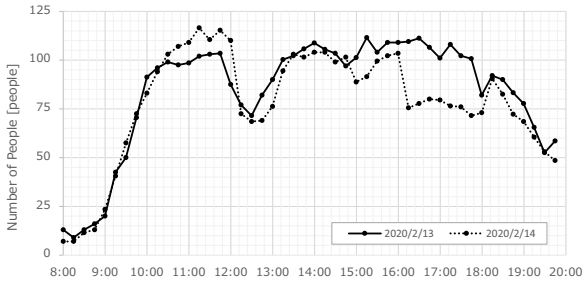


Fig. 7. Time Series of Number of People.

Figure 8 shows the space utilization rate and incorrect answer rate based on the thermopile motion sensor and actual measurements. Figure 9 shows the time series of the space utilization rate and incorrect answer rate measured by the thermopile motion sensor and actual measurements.

Looking at each thermopile type human sensor, the wrong answer rate is high for a specific sensor. In particular, sensor IDs with an incorrect answer rate of over 30% can be organized as having the following locational characteristics.

- Passage space: 3, 8, 15, 23, 63, 77
- Private desk or meeting table: 14, 22, 29, 31, 37, 42, 47, 52, 54, 57, 64, 79
- Around the heating element: 26, 51, 76

In addition, the time series of the space utilization rate by the thermopile human sensor changes around 20% after 10:00, and the space utilization rate of the thermopile human sensor is about twice that of the actual measurement. On the other hand, the incorrect answer rate fluctuated around 20% because it is evaluated based on whether the presence or absence is accurately judged.

Incorrect answers were classified into the following two, and the breakdown was calculated. As an example, Figure 10 shows the time series of the incorrect answer rate on February 13th.

“a” Thermopile type human sensor: absence, actual measurement: presence

"b" Thermopile type human sensor: presence, actual measurement: absence

It can be seen that the time series of the incorrect answer rate for "a" fluctuated around 5%, while the time series for the incorrect answer rate for "b" fluctuated around 15%. It turned out that b accounted for most of the incorrect answers.

The following three points can be considered as factors for "a".

(1) Blind spot of sensor detection area

(2) Human-to-human integration on thermal images

(3) Decrease in surface temperature due to clothing

(1) Plants, cabinets, and fixtures are obstacles, and part of the detection area may be a blind spot for the thermopile-type human sensor.

(2) Multiple people appear to be integrated as one thermal mass in the thermal image and are counted as one person when people are actually close to each other or appear to be close to each other in terms of elevation angle.

(3) There is a possibility that people will not be detected because clothing does not cause a difference of 4°C or more from the ambient temperature. The ambient temperature difference is less likely to occur because only the lower half of the body with less exposed surface can be seen from the sensor at the edge of the sensor's detection area when a person stands up. Also, even if it is directly under the sensor, the ambient temperature difference is less likely to occur due to clothing, hair, masks, etc. in winter.

The following five factors can be considered as factors for "b".

(4) Overlap of sensor detection area at low height

(5) A part of the body that is far from the trunk, such as the arm

(6) Non-human heating elements such as refrigerators, multifunction machines, and PCs

(7) Floor temperature rise due to direct solar radiation

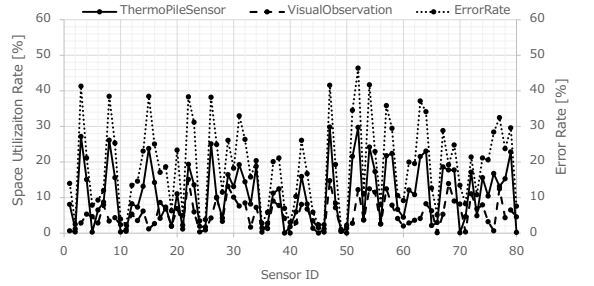
(8) Afterimage

(4) The sensor detection area overlaps below the assumed human detection height (700-800mm) because the thermopile human sensor has an elevation angle. This may lead to double counting in overlapping regions.

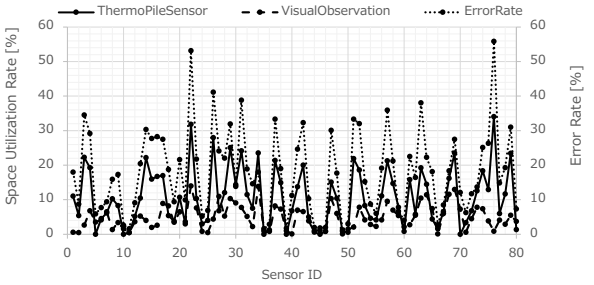
(5) A person is modelled as a circle in actual measurements, but the thermopile-type human sensor also judges parts of the body, such as the arms, that are distant from the trunk as being "present."

(6) It also detects heating elements other than people, such as refrigerators, multifunction devices, and PCs, as "presence". because the thermopile human sensor detects "presence" based on temperature. The position of the thermopile type motion sensor, which has a large error, matches the installation position of the refrigerator and multifunction device when compared with the position on the floor plan.

(7) "Presence" is detected due to the difference in temperature between the floor that is exposed to direct sunlight and the floor that is not. It was confirmed that even though there was no person in the area exposed to direct sunlight, it was detected as "presence" when the direct sunlight hits the perimeter.

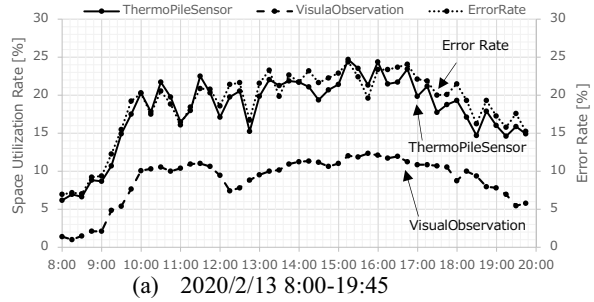


(a) 2020/2/13 8:00-19:45



(b) 2020/2/14 8:00-19:45

Fig. 8. Each Sensor of Space Utilization rate and Error Rate.



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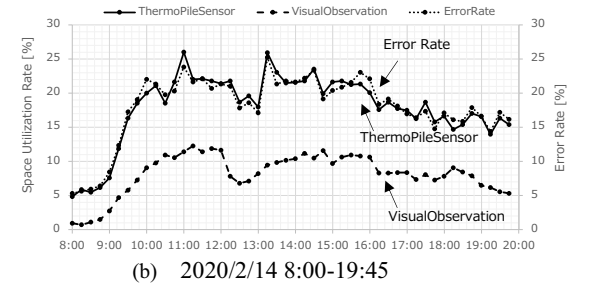


(b) 2020/2/14 8:00-19:45

Fig. 9. Time Series of Space Utilization Rate and Error Rate.

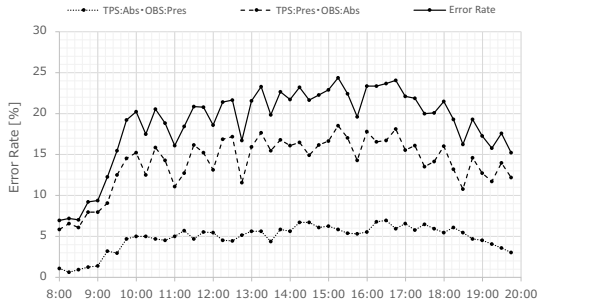


Fig. 10. Time Series of Error Rate and the Breakdown (2020/2/13).

(8) The surface temperature of the chair rises, When a person sits on the chair. The surface of the chair with a high temperature is recognized as a person even if a person leaves the seat.

4.2 Verification of Number of People Detection Accuracy

Figure 11 shows the number of people and the relative error from each thermopile human sensor and actual measurement, and Figure 12 shows the time series of the number of people and the relative error from the thermopile human sensor and actual measurement.

It can be seen that the error is large in a specific sensor, as with presence/absence detection looking at each thermopile human sensor. In particular, the error exceeds 200% for sensor IDs 15, 66, 71, and 76 on February 13, and for sensor IDs 1, 40, 66, and 76 on February 14. It is thought that there are errors due to factors 4 to 8 above regarding the number of people.

On the other hand, there are many places where the relative error shows a negative value, that is, the number of people detected by the thermopile human sensor is smaller than the number of people measured by actual measurement. This is also thought to be due to the errors caused by the aforementioned factors (1) to (3).

The time series of the number of people using the thermopile type motion sensor has been around 100 people since 10:00. It was found that the trends generally match but the number of people using the thermopile type human sensor is always about 20 more than the number of people actually measured.

It is considered that the error is relatively large in the morning because the number of people detected by the thermopile human sensor is raised mainly by the above-mentioned error factor (6) while the number of people in the room is small. The effects of possibility on (5) and (8) is low because there are few people in the morning. In addition, the effect of possibility on (7) is also low because direct solar radiation does not enter the perimeter due to the automatic control of the blinds.

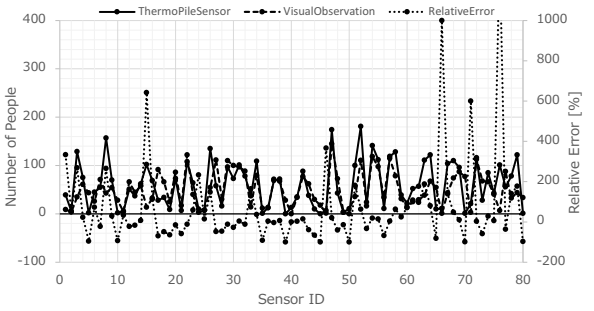
5 Verification of Applicability in Office

5.1 Lighting Control

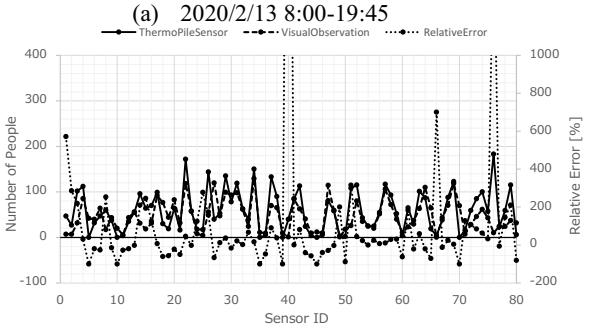
Presence detection needs to be 100% accuracy because it is unacceptable to have the lights not turn on when a seat is occupied. An off-delay (about several minutes) is set in general lighting control so that the lights are not turned off even if the sensor makes an erroneous detection. Therefore, 100% detection accuracy is not necessarily required for absence. There are few false detections such as lights not turning on despite the presence of people as shown in Figure 10. For these reasons, there are still issues regarding detection accuracy for application to lighting control.

5.2 Air Conditioning Control

Temperature control is often performed on a schedule due to the spatial equilibrium properties and slow response on air. Therefore, it is considered that temperature adjustment does not depend on accuracy of presence/absence or the number of people. Outside air introduction is generally set at 800ppm with a margin

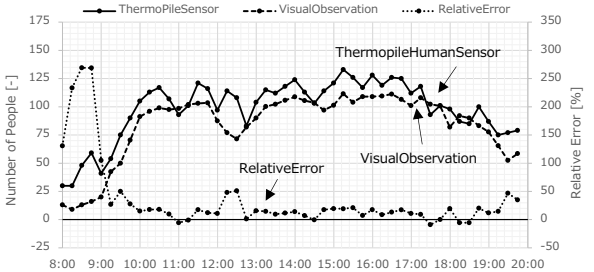


(a) 2020/2/13 8:00-19:45

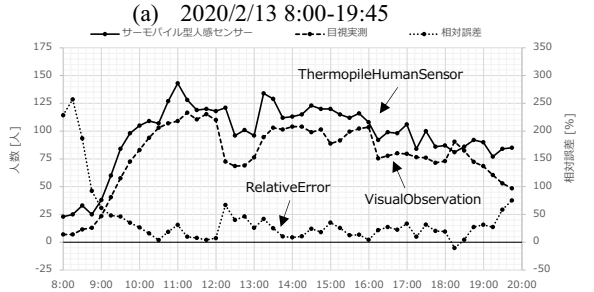


(b) 2020/2/14 8:00-19:45

Fig.10. Each Sensor of Number of People and Relative Error.



(a) 2020/2/13 8:00-19:45



(b) 2020/2/14 8:00-19:45

Fig. 11. Time Series of Number of People and Relative Error.

for the standard value of 1,000ppm of the building environmental hygiene management standard stipulated by "Act on Maintenance of Sanitation in Buildings". Assuming that the CO2 concentration in the outside air is 400ppm, the CO2 concentration does not exceed the standard value even if there is a 50% error in the number of people who are the source of the CO2. This set value varies depending on the engineer. If the set value of CO2 concentration is 1,000ppm, the accuracy of the number of people is required to be 100%.

The relative error in the number of people has been around 10% as shown in Figure 10. For these reasons, it is possible to use it for air conditioning control by setting it according to the target scale and design concept.

5.3 Positioning Information

The required detection accuracy can be specified based on the assumed occupancy rate of seats on the premise that it is sufficient to sit in any seat. The attendance rate will not exceed 100% even if the number of people includes an error of 40% if the attendance rate is assumed to be 60%. Therefore, the required accuracy can be defined as 60% for the generally assumed attendance rate of 60%[14].

It can be said that it can be used for location information by setting according to the target scale and design concept as with air conditioning control.

Positioning information also requires information about who is where. It is necessary to use an active sensor that can grasp attribute information by having a unique ID such as BLE. The thermopile-type human sensor cannot be used for location information because it is impossible to identify an individual although it meets the requirements for accuracy.

6 Conclusion

Accuracy of the indoor positioning system using a commercially available thermopile human sensor was verified in a real environment. In addition, the possibility of utilization was verified for lighting control, air conditioning control, and position information, which are expected to utilize indoor positioning system in current equipment control. It was confirmed that the accuracy is sufficient for grasping the trend of the presence/absence and the number of people in the entire space.

Some ingenuity is required to use the thermopile type human sensor because the relative error and its variation depending on the environment of the sensor installation position are large due to many possible factors such as below (1) – (8).

(1) Blind spots in the sensor detection area
(2) Human-to-human integration on thermal images
(3) Drop in surface temperature due to clothing
(4) Overlapping sensor detection areas at low heights
(5) Parts of the body distant from the trunk, such as arms
(6) Machines, PCs, and other heating elements
(7) Floor temperature rise due to direct solar radiation
(8) Afterimages

It is possible to detect people after consolidating thermal images from multiple sensors into one because this sensor can also acquire thermal images that are the basis for detecting people. However, it is thought that only 4 can be solved by it.

It can be expected to be used as an even more accurate indoor positioning method if software capable of more advanced post-processing such as maintaining the continuity of presence/absence and number of people information is developed.

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