A Seat Occupancy/Vacancy Detection Method Using Smartphone and High-Resolution Infrared Sensors in a Non-territorial Office

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Abstract—We have conducted research on the Intelligent Lighting System that realizes illuminance demanded by a worker at minimum power. In the system, workers are necessary to change the occupancy/vacancy status. However some workers didn’t change appropriately it. Thus there were lights that provided brightness more than required even though there were no workers and energy saving deterioration the Intelligent Lighting System. On the other hand, in a non-territorial office, however, as any individual’s seat is not fixed, it is not easy to manage information on which seat workers occupy. Then We propose the method to detect a status of seat occupancy/vacancy automatically using a smartphone and high-resolution infrared sensors.

Keywords: infrared sensor, intelligent lighting system, smartphone, position estimation

1. Introduction

It has been demanded in recent years to improve intellectual productivity and creativity of workers in an office environment. It has also been reported that improving office lighting environment enhances workers’ intellectual productivity[1]. In particular, there have been extensive studies on the impact of office lighting environment on workers’ comfort, and it has been clarified that providing each individual with the optimal brightness for their work leads to an improvement in their comfort[2].

Against such a backdrop, we have conducted research on the Intelligent Lighting System which realizes illuminance demanded by a worker at minimum power[4]. The intelligent lighting system realizes the target illuminance for each worker. The target illuminance refers to brightness desired by a worker and is set by the illuminance sensor button on the PC on his/her desktop or the physical button installed on an illuminance sensor. The effectiveness of the Intelligent Lighting System has been verified so far. As its effectiveness was acknowledged, demonstration tests have been conducted in real office environments.

If a seat is not occupied by a worker, the Intelligent Lighting System judges that it does not need brightness. By dimming or turning off lighting for an area around a seat unoccupied by a worker in such a manner as not to affect working space of other workers, the system realizes even higher energy saving. The results of demonstration tests at real offices, however, showed that workers did not appropriately change the occupied/vacant status of their seat. Those results confirmed that there were lighting fixtures which provided brightness more than required even though there was no worker.

We thus proposed a method to automatize the toggling of the occupied/vacant status of a worker’s seat in an office with fixed seats by using a high-resolution infrared sensor[7]. At present, the Intelligent Lighting System expanded the scope of its application and being introduced into non-territorial offices. A non-territorial office refers to a type of office designed by a method whereby individuals do not have their dedicated seat and equipment and fixture are shared by multiple people. As opportunities for interaction between workers in an office increase and each worker can work at a place he/she prefers in a non-territorial office, it is expected to improve intellectual productivity and comfort. Also partly because of its excellent space saving property, it has been introduced into many companies. In a non-territorial office, however, as any individual’s seat is not fixed, it is not easy to manage information on which seat workers occupy. This study thus examines a method for managing information on whether workers are seated or not in a non-territorial office in which the Intelligent Lighting System has been introduced by enabling the identification of a worker by using a smartphone each worker carries with him/her.

The proposed method determines whether each worker is seated or not and identifies the location of a seat the worker has taken. Whether each worker is seated or not is determined on the basis of his/her smartphone’s angle to the horizontal plane calculated by an accelerometer embedded in the smartphone. The location of the seat in which each worker is seated is identified by using the accelerometer and geomagnetic sensor embedded in a smartphone in combination with a high-resolution infrared sensor. Combining a smartphone and a high-resolution infrared sensor enables the automatic management of information on whether workers are seated or not under the Intelligent Lighting System introduced in a non-territorial office. If the target illuminance for each worker is registered with a database, the worker does not have to set his target illuminance each time, and the Intelligent Lighting System will operate quickly to adjust illuminance to the worker’s preference. In addition, managing information on which worker is seated in which seat in
MEMS Thermal IR Sensor

1.6
5
3.6 m
90
0.15

Table 1: Specification of the infrared sensor with high resolution

<table>
<thead>
<tr>
<th>Measurement</th>
<th>MEMS Thermal IR Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element Type</td>
<td>16 × 16 pixels</td>
</tr>
<tr>
<td>Detection Range</td>
<td>3.6 m × 3.6 m</td>
</tr>
<tr>
<td>View Angle</td>
<td>90°</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>5 – 50 °C</td>
</tr>
<tr>
<td>Temperature Resolution</td>
<td>0.15 × 10⁻² °C</td>
</tr>
</tbody>
</table>

a non-territorial office is expected to increase opportunities for interactions.

2. High-Resolution Infrared Sensor

A high-resolution infrared sensor is a 16 × 16 noncontact MEMS temperature sensor that combines a wide range of visual field and high-precision area temperature detection. Table 1 gives the specifications of a high-resolution infrared sensor.

If a high-resolution infrared sensor is installed on the ceiling 3 m from the floor, assuming that the distance from the floor to the desktop is 1 m, the distance from the desktop to the ceiling is 2 m. The detection range will then be 3.6 m × 3.6 m. This detection range is divided into 256 sections for 16 elements × 16 elements, and the average temperature is output for each section. It is then possible to identify the number and position of thermal sources on the basis of the temperature distribution in the detection range of the high-resolution infrared sensor.

Difference between existing infrared sensors and high-resolution infrared sensors is that the latter can identify the approximate number of persons. Existing infrared sensors distinguished between the following two states: whether there are any human beings in its detection range or not. In contrast, using a high-resolution infrared sensor, which can grasp a certain number of heat sources, has enabled the simultaneous detection of multiple persons. As it detects heat sources in the detection range, however, it also detects heat emitted by PCs and OA devices. Therefore, if a high-resolution infrared sensor is actually introduced, as there are many heat sources such as PCs and OA devices, it is conceivable that such heat sources are mistakenly detected as human beings. It is thus necessary to distinguish human beings from PCs and OA devices based on temperature data obtained.

Temporal difference in temperature is used to distinguish human beings from other heat sources. By comparing the current temperature data with those before a certain period of time, human beings and other heat sources are distinguished from each other.

Since, however, a high-resolution infrared sensor is a temperature sensor, it cannot determine which worker was seated in a particular seat in a non-territorial office. Therefore, in this study, a smartphone carried by each worker is used to identify an individual.

3. Detection method of a seat occupancy/vacancy using a smartphone and high-resolution infrared sensors

3.1 Outline of the proposed method

This study proposes a method using a smartphone-embedded accelerometer to determine whether each worker is seated or not and smartphone-embedded accelerometer and geomagnetic sensor, together with a high-resolution infrared sensor, to identify the seat, if any, in which a worker is seated. If a worker takes a seat, the point of time at which his/her seated/unseated status changes and the point of time at which a high-resolution infrared sensor detects a human being are compared to determine which seat the worker is seated in. If a worker leaves a seat, it is detected by the smartphone’s determination of whether the worker is seated or not.

In addition, if multiple workers take their seat at the same time, the position of the seat which a worker is seated cannot be identified by a smartphone’s determination of whether the worker carrying the smartphone is seated or not together with the identification of seat locations by a high-resolution infrared sensor. Therefore, the position of the seat in which a worker is seated is identified by estimating which worker is located in an office by using an accelerometer and a geomagnetic sensor embedded in a smartphone to estimate the location of a worker who carries it.

3.2 Judging method of a seat occupancy/vacancy status

A method is thus proposed for detecting whether a worker is seated or not by using a smartphone. For the method in this study for detecting whether a worker is seated or not, it is assumed that a smartphone is put in a trousers pocket, where it is most frequently put.

Under the proposed method, the smartphone terminal’s angle to the horizontal plane is measured to determine whether a worker is seated or not. The smartphone terminal’s angle to the horizontal plane used to determine whether a worker is seated or not is calculated by using data measured by a 3-axis accelerometer embedded in the smartphone. Formula (1) gives the calculation formula.

\[
\theta = \arctan(Accy, Accz) \tag{1}
\]

\[
Accy : \text{Acceleration of the smartphone terminal to the longitudinal direction of horizontal plane }
\]

\[
Accz : \text{Acceleration of the smartphone terminal to the vertical direction} \tag{2}
\]
The angle is calculated by averaging 25 immediate and consecutive points. If a worker is not seated, he/she is judged to be walking or standing and therefore his/her smartphone terminal’s angle to the horizontal plane is close to 90 degrees. On the other hand, if he/she is seated, his/her smartphone terminal’s angle to the horizontal plane is close to 0 degrees. A threshold is thus established, and the angle greater than the threshold is defined to correspond to a worker not seated, and the angle less than the threshold is defined to correspond to 0 degree, to determine whether a worker is seated or not.

3.3 Detection method of the position of a seat occupancy

PDR (pedestrian dead reckoning) is used to estimate the position of a worker in an office. In this study, the position of a worker is estimated by calculating three kinds of data — the number of steps, the direction a worker is headed to, and step length — through feature value calculation using data measured by an accelerometer and a geomagnetic sensor embedded in a smartphone. The distance moved is calculated by simply multiplying the number of steps detected and step length. Using data for the moving direction, the direction and distance of movement from the immediately preceding position are estimated.

In this paper, step length is calculated by the height of a worker. Formula (3) calculates step length. Step length calculated by this formula is said to be the average human step length.

\[
\text{Stride}[\text{m}] = \text{Height}[\text{m}] - 1
\]  \hspace{1cm} (3)

A method proposed by Muramatsu et al. is used to obtain data for the number of steps. The square root of the sum of the squares of the acceleration for each axis measured by the accelerometer is calculated to obtain a composite acceleration, the maximal value of whose waveform is detected as a single step. In this paper, the composite acceleration is calculated by taking the square root of the sum of the squares of the acceleration for each axis of 3-axis acceleration measured by a smartphone. The 25-point moving average of the composite acceleration is calculated, and the maximum value of the moving average waveform is detected as a single step. Formula (4) gives the calculation formula.

\[
\text{Acc} = \sqrt{\text{Acc}_x^2 + \text{Acc}_y^2 + \text{Acc}_z^2}
\]  \hspace{1cm} (4)

\text{Acc} : \text{Triaxial synthetic acceleration}  
\text{Acc}_x : \text{Acceleration of the smartphone terminal to the lateral direction of horizontal plane}

PDR, however, entails an error between an actual position after movement and an estimated position. The position of the seat in which a worker is seated is thus identified by combining PDR with person detection by a high-resolution infrared sensor. Figure 1 shows an example of detecting a worker seated by temperature change.

The detection of the position of the seat in which a worker is seated by a high-resolution infrared sensor uses comparison of temperature over time. A high-resolution infrared sensor cannot distinguish between a human being and a PC. Therefore, temperature change is used to distinguish between them by taking a human being as a moving heat source and a PC as a non-moving heat source.

If the status of a worker changes from "not seated" to "seated" in the decision of whether the worker is seated or not by a smartphone, the position of the seat in which a worker is seated is identified by comparing the temperature data at the time measurement by the high-resolution infrared sensor is taken and the temperature data before a worker is seated.

4. Verification experiment

4.1 Experimental outline

This section verifies the effectiveness of the proposed method with regard to the following three points.
• Precision in determining whether a worker is seated or not by using a smartphone-embedded accelerometer
• Precision in estimating the position of a worker in office by using smartphone-embedded accelerometer and magnetic sensor
• Precision in identifying the position of the seat in which a worker is seated by using temporal difference in temperature

The verification experiment was conducted in a non-territorial office simulating environment in the Room KC104 in Kochikan, Doshisa University. The plan for the experimental environment is shown in Figure 2.

In this experiment, a high-resolution infrared sensor was installed in the center of the ceiling in the experimental environment, with a camera installed beside it. There were four seats for work at the desk directly under the detection range of the high-resolution infrared sensor.

A subject with a smartphone in his/her trousers pocket enters Kochikan, walks into Room KC104, and takes a target seat in the room. The Wi-Fi radio field intensity is measured by the smartphone. The trajectory of the movement of the subject is calculated by PDR with the smartphone from the time the Wi-Fi access point in Room KC104 was detected to estimate the subject’s position. Position estimation ends at the time the subject is seated. The method for calculating the trajectory of movement is as previously described.

Since it takes several seconds to get connected to Wi-Fi, a large error in the starting point is considered to result. The trajectory of movement is thus compensated by comparing the trajectory calculated and map information including information on the passage and the desk in the experimental environment. A two-dimensional coordinate is superposed on the experimental environment, and the point where the moving direction changed is calculated for compensation on the basis of changes in x and y coordinates for each position where the number of steps is detected.

The subject works at a PC for an arbitrary time after taking the target seat and then leaves the seat. The experimented was conducted with four subjects, with 100 trials performed in total.

4.2 Precision in determining whether a worker is seated or not using a smartphone

A preliminary experiment was conducted to determine the threshold of a smartphone’s angle to the horizontal plane for determining whether a worker is seated or not. A smartphone’s angle to the horizontal plane was calculated by measuring 3-axis acceleration of the smartphone terminal when a person carrying it with him/her was walking and seated. Subjects were instructed to walk and take seat in their normal posture.

Figure 3 shows the result of measurement. Based on this result, the threshold for determining whether a worker is seated or not was set to 40.0 deg.

![Figure 3: Angle measurement of the smartphone terminal to the horizontal plane](image)

The status of the subject as to whether he/she was seated or not was compared with photos taken by the camera installed on the ceiling of the experimental environment. Whether the subject was seated or not was determined at an interval of 0.1 second. Figure 4 shows the result of the experiment from 0 to 3,600 seconds after the start of the experiment.

As a result of comparison, it was confirmed that whether the subject is seated or not was determined correctly 100% when a smartphone was put in his/her trousers pocket. There was a delay of about 1 second from the time a subject actually takes a seat to the time the smartphone determines that the subject is seated. This is considered to be attributed to the fact that the smartphone’s angle to the horizontal plane is calculated as the average for 25 consecutive points. A delay of 1 seconds does not matter from a power consumption saving perspective in managing information on whether workers are seated or not. Therefore, if a smartphone is in a trouser pocket of a subject, it can be determined precisely whether he/she is seated or not. Hence the proposed method for determining whether a worker is seated or not is effective.
4.3 Precision in estimating the position of a worker in office using a smartphone

The precision in estimating the position of a worker using a smartphone was verified, and an experiment was conducted to verify whether the seat taken by a worker can be identified or not. These are evaluated below. Figure 5 shows an example of estimating the position of a moving subject.

A seat taken by the subject is determined on the basis of the result of estimating the position of the subject. The nearest seat to the estimated position of the subject was determined to be taken by the subject in accordance with the proposed method. The distance between the seat which the subject actually took and the estimated position of the subject was evaluated as an error. The detectable range of the high-resolution infrared sensor was defined as the seatable area. Table 2 shows the result of determining the position of the subject’s seat.

Table 2: The result of determining the position of the subject’s seat

<table>
<thead>
<tr>
<th>error[m]</th>
<th>Specific rate[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>1.13</td>
</tr>
<tr>
<td>Min</td>
<td>0.06</td>
</tr>
<tr>
<td>Ave</td>
<td>0.46</td>
</tr>
</tbody>
</table>

The result of determining the position of a moving subject after correction

![Figure 5: Result of estimating the position of a moving subject after correction](image)

4.4 Precision in identifying the position of the seat using high-resolution infrared sensors

It is not easy to identify the seat which a worker takes by position estimation using a smartphone. Therefore, the seat position is identified by using a high-resolution infrared sensor installed in the identified seatable area. 256 sections of the detection range of the high-resolution infrared sensor were superposed on the positions of seats, and 4 sections were assigned in advance to one seat as seat sections. Temporal difference in temperature was used to identify the position of a seat in which a subject is seated. Temporal difference in temperature was obtained by measuring the detectable range every 1 second, and data measured were compared with those 5 seconds before. The section for which temperature difference was 0.6°C or greater was determined to be an occupied section. The method described above for determining whether a subject is seated or not using a smartphone embedded accelerometer was used to detect that a subject has left a seat. This is because, if the position of the seat in which a worker is seated has been identified, it is not required to identify the position by the high-resolution infrared sensor as a smartphone the worker carries with him/her is used. If 2 or more of seat sections assigned to one seat are determined as occupied, it is determined that the seat has been taken.

The experiment was shot by the camera installed beside the high-resolution infrared sensor and compared with positions detected as occupied by the high-resolution infrared sensor. Figure 6 shows the status of seat occupancy detection from 1,500 to 3,100 seconds after the start of the experiment.

![Figure 6: The status of seat occupancy detection using high-resolution infrared sensors](image)

The result of the experiment shows that the detection rate was 100 % although seat occupancy was detected several seconds earlier than the time the subject actually took a seat because the high-resolution infrared sensor detects heat before the subject is seated. This result confirmed that the seatable area cannot be identified at the rate of about 2 %. Since, however, the maximum error is 1.13 m, the estimated area is adjacent to the seat which the subject actually took. Therefore, it can be estimated on the basis of the time at which a smartphone determines that the subject has left the seat by synchronizing the smartphone with the high-resolution infrared sensor.
position of the seat in which a worker is seated can be identified by obtaining temporal difference in temperature using a high-resolution infrared sensor.

5. Conclusion

In the system, workers are necessary to change the occupancy/vacancy status. However some workers didn’t change appropriately it. Thus there were lights that provided brightness more than required even though there were no workers and energy saving deterioration the Intelligent Lighting System. On the other hand, in a non-territorial office, however, as any individual’s seat is not fixed, it is not easy to manage information on which seat workers occupy. Then We proposed the method to detect a status of seat occupancy/vacancy automatically using a smartphone and high-resolution infrared sensors.

If the target illuminance for each worker is registered with a database, the worker does not have to set his target illuminance each time, and the Intelligent Lighting System will operate quickly to adjust illuminance to the worker’s preference. Therefore the system detects the occupied/unoccupied status automatically and improve the energy saving performance in the Intelligent Lighting System. In addition, managing information on which worker is seated in which seat in a non-territorial office is expected to increase opportunities for interactions.

It is necessary, however, to expand the scope of application by estimating how a smartphone is held when it is held in hand or placed in a bag.

References