A Study on Indoor Dimming Method Utilizing Outside Light for Power Saving

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***Abstract*— In the next generation power networks, more energy saving and energy-efficient network are required. One of the solutions is a location-aware energy distribution scheme, where persons' location is accurately estimated by a centimeter-order indoor localization scheme and the energy is preferentially allocated to the electric equipment near the persons. As one of its applications, there is an energy-saving indoor lighting control scheme exploiting person's location information and the estimated illumination intensity, and large energy saving effects are obtained. We have proposed an indoor diming scheme that considers an external light in previous studies. However, in the previous study, advanced intensity measurements at many reference points were required. Therefore, in this paper, we propose an energy-saving indoor lighting control method that uses an estimated external light to reduce the measurement points. Numerical results show the advanced performance of the proposed method.**

I. INTRODUCTION

Because of the development of information technologies and electronics technologies in recent years, the demand for electric power is increasing. In order to prevent power shortage caused by extremely large demands, an electric smart grid is considered to efficiently supply electricity to necessary places and not to wastefully send to unnecessary places. A smart grid is a next-generation electric power network, which is a power grid with overlapped communication and control functions of smart meters and home energy management system (HEMS) [1]. One of the technologies to realize it is a cooperation with people's location information. Obtaining person's location, we can distribute electricity to home appliances neighboring the person preferentially. In contrast, the priority of power distribution is decreased to where peoples are absent. As a result, efficient power usage and power saving are realized. Furthermore, by weighting the power with considering staying time and neighboring household appliances of the person, and including person's position prediction can realize more advanced smart grid. To enable these systems, an accurate indoor location estimation is required, and we have proposed a centimeter-order indoor location estimation technology [2]. Since global positioning system (GPS) cannot be used indoors, a triangulation, where a few sensor nodes whose location is known receive the radio wave from a target node whose location is unknown, and by more than three distance information of them, the target location is calculated, is used.

A sensor node whose position is known receives a received signal strength (RSS) and a signal time of arrival (TOA) from an object to be localized, the distance between the object and the sensor node is calculated, and the coordinate of the object is obtained by triangulation [3]. In our previous studies, it has been shown that high-performance location estimation in both line-of-sight (LOS) and non-line-of-sight (NLOS) environments is realized, and we have clarified that the effect of power saving from lighting control [4, 5] can be obtained by exploiting the position information. Furthermore, it has been clarified that further energy saving can be realized by considering natural light from outdoors. However, outside light changes by time and weather, and we had to keep measuring outside light at all reference points of a room. Therefore, in this paper, we utilize a regularity of external light at reference points and propose an indoor dimming method utilizing outside light with reduced reference measurements using small number of sensors.

In the following of this paper, we describe the position estimation method in Section II and explain the proposed dimming method in Section III. In Sections IV and V, we verify the effect of the proposed method by numerical simulations, and the conclusions are drawn in Section VI.

II. POSITION ESTIMATION TECHNIQUE USING SENSOR NETWORKS

A. Position estimation

GPS, which is one of the position estimation techniques, is mainly used outdoors, and position estimation cannot be accurately performed indoors. Therefore, to enable position estimation indoors, some techniques using communication networks are required. One of the popular schemes of indoor position estimation is the TOA estimation method which is a range-based position detection technology. Using three or more sensor nodes, each sensor measures the distance between the target and the sensor, and as shown in Fig. 1, each distance is represented by a circle. The estimated position of the target is obtained at the point where the circle intersects at one point. However, in actual environments, measurement errors are

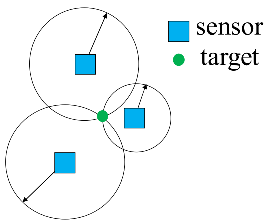

Fig. 1: Triangulation-based position estimation method.

included in the estimated distance due to noise and propagation model errors, and the three circles do not intersect at one point. Then, the average point is calculated by performing the multiple distance measurements instead of once. In this paper, we assume a two-dimensional estimation, and the target node whose position is unknown is (x, y) and N sensor nodes whose positions are known are located at (x_k, y_k) with $k = 1, \cdots, N$. Then, the distance between the kth sensor node and the target is obtained from measured TOA data multiplied by optical speed in the LOS and NLOS environments [6], respectively, by

$$d_{k_{LOS}} = \sqrt{(x - x_k)^2 + (y - y_k)^2} + n_k \quad (1)$$

$$d_{k_{NLOS}} = \sqrt{(x - x_k)^2 + (y - y_k)^2} + n_k + b_k \quad (2)$$

Here, n_k and b_k are the noise due to measurement error in the LOS environment and that in the NLOS environment, respectively. n_k is a Gaussian distribution according to the mean and variance of $(0, {\sigma^2}_k)$. b_k is a uniform distribution according to the mean and variance of $\mathrm{U}(0, \mathrm{B_{MAX}})$. Thus, even in the LOS environment, a measurement error is included. In the LOS environment, there is no obstacle between the sensor node and the target, and in the NLOS environment, it is assumed that there is obstacles between the sensor node and the target.

B. *Simulation result of position estimation*

Position estimation was performed when one target person was moving in the room randomly. The room layout and sensor arrangement in which the target moves are shown in Fig. 2. The

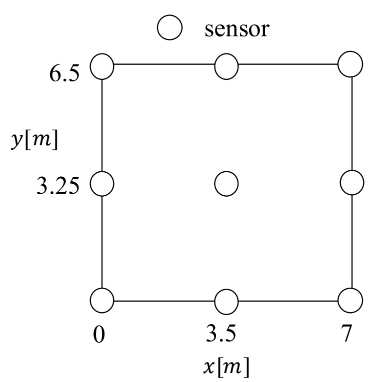

Fig. 2: Sensor field and position of sensor nodes.

Table 1: Simulation conditions 1.

Sensor field	6.5 [m] in length, 7 [m] in width, 2 [m] in height from the ceiling
Number of sensors	9
Number of moves	3600
Number of distance measurements used for estimation	30
Moving distance per second	0.1 [m]

objective of this simulation is to obtain how much error occurs in the position estimation in the LOS environment. As a result, the maximum error of the position estimation was 0.201 [m] in this sensor field, when the number of distance measurements was 30 for each sensor node in one estimation and the number of target movements was 3600. In this simulation, since the noise error is given by additive white Gaussian noise (AWGN), this error value is not proven as maximum. However, when a human is the target node, the width of human is more than 20 cm and it can be said that if 20 cm margin is configured for position estimation, the accurate estimation can be obtained for human target node. Thus, about 20 cm margin is used in the following consideration.

III. Power-Saving Dimming Control Method Considering External Light

A. *Proposed diming control scheme*

As shown in Fig. 3, it is assumed that there are six illuminations indoors, and that one closest light is illuminated when the target is located in the red area. Similarly, two and four closest lights are illuminated when the target is in green and blue areas. It is assumed that one light equips with three fluorescent lamps, and three times of luminous intensity is obtained with three times power consumption. In the conventional on-off dimming control [4], the lights are controlled as on or off. In the proposed dimming control, the

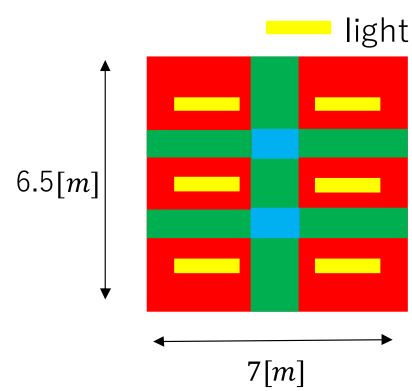

Fig. 3: Condition of lighting.

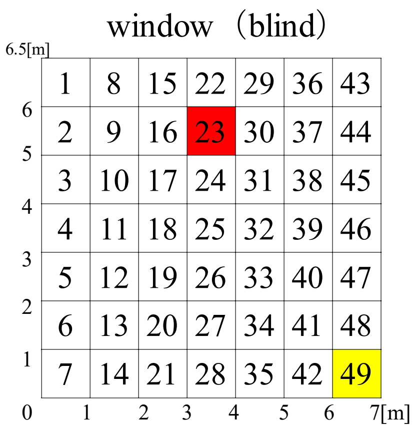

Fig. 4: Index of illuminance measurement areas in sensor field.

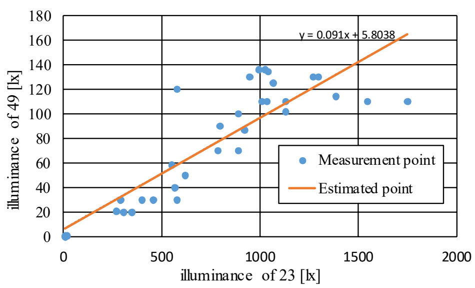

Fig. 5: External light estimation by using linear least squares method. 49th illuminance is estimated from 23rd measured illuminance.

illuminance of lights are controlled so as to obtain 500 [lx] at hand of human target, by using 10 %-step digital dimming. In addition, the external light is taken into account in the proposed scheme. The illuminance at hand is calculated from the distance from the lights, the angle, and the brightness of the illumination itself.

B. Illuminance estimation of external light

In the conventional scheme, the dimming control taking external light into account has been carried out using measurement results of external light at all reference points. However, it needs many and continuous measurements to follow the changes of time and weather. However, it is known when the outside light is blinded to the window, the direction of the light becomes constant by the diffusion. Therefore, the external light depends only on the magnitude of the brightness at the window, the angle of the sun becomes irrelevant, and the regularity appears in the room. We confirmed this regularity by the measurements of illuminance on every hour. The measurement field and the measurement points are shown in Fig. 4. The illuminance was measured at the center of each grid square and the height of measurements was 2 [m] from the ceiling of the room. The illuminance was measured by one luminometer. Based on the results measured at 49 places, the external light at other places is estimated by the linear least square method based on 23rd place. The example of external light estimation at 49th point by the measurement result of 23rd point is shown in Fig. 5. It is assumed that at 23rd point the external light is always measured and its result is used for the external light estimation at all other points. From the graph of Fig. 5, it is confirmed that the straight line is obtained by the least squares method, and 48 external lights other than 23rd point can be estimated by linear equations. However, in Fig. 5, there are some deviated measurement data because of the measurement errors. It is because we measured each of 49 places one-by-one and it takes times. Then, it seems that the magnitude of the brightness at the window has slightly changed.

IV. Numerical Results in Random Walking Scenario

A. Dimming control method

In this section, the daily power consumption of lighting in the proposed scheme is simulated and compared with the conventional scheme. Here, the conventional existing method is the dimming scheme where the external light in the room is measured at all reference points and the dimming is controlled. In addition, it is assumed that the one human target randomly moves. Note that in this system configuration, there are some places within 1 [m] from the walls in which the illuminance does not reach 500 [lx] even if lighting is maximized. However, assuming that there is no person who reads and writes near the wall, and we leave this issue as it is. Furthermore, as described in Section II-B, there are always position estimation errors, which may cause the shortage of illuminance by the method of Fig. 3 because the miss-detection of color area occurs. Therefore, we use three additional operations; The first one is a 10 % addition of the estimated illumination in the digital dimming at all lights. The second one is to have a detection margin to prevent the miss-detection at the boundary in Fig. 3. From the result of Section II-B, about 20 cm estimation error can occur in position estimation, and then, we use a circular margin of lighting condition as shown in Fig. 6. In this example, the target is estimated at the red area, but the green area is used as the detected area. When the lighting condition is detected additively to the margin circle, the performance of the illuminance for the person near the boundaries improves in the tradeoff with the power consumption increase. From the results of Section II-B, we use the 0.25 m circular margin in this study. However, even when these two methods are used, sometimes the illuminance at hand becomes below 500 [lx]. Therefore, as the third operation, we further add the percentage of increased illumination according to the squared area, in addition to 10 % addition of the first operation. Figures 7 to 10 show the additional percentage of each areas in the parameter of various external light at 23rd measurement point, which are derived by the empirical and manual coordination. By these three additional operations, the adaptive dimming in all areas are

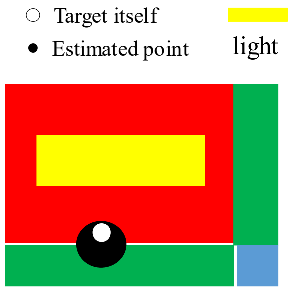

Fig. 6: Detection margin scheme to provide sufficient illumination in boundary areas.

10	50	10	20	30	50
30	50	10	20	50	50
30	30	20	50	30	30
30	30	20	40	70	70
40	50	20	70	50	70
60	40	30	90	90	90

Fig. 7: Further additional illuminance percentage when external light at 23rd point is between 0 to 350 lx.

10	20	10	10	20	20
20	20	10	20	20	20
20	20	10	40	20	20
10	10	10	30	70	50
10	10	10	30	30	50
10	30	10	50	50	50

Fig. 8: Further additional illuminance percentage when external light at 23rd point is between 350 to 500 lx.

10	10	10	10	20	20
10	10	10	20	20	20
10	10	10	30	20	20
10	10	10	30	50	50
10	10	10	30	30	30
10	30	10	30	30	30

Fig. 9: Further additional illuminance percentage when external light at 23rd point is between 500 to 700 lx.

10	10	10	10	20	20
10	10	10	20	20	20
10	10	10	20	20	20
10	10	10	20	30	30
10	10	10	30	30	30
10	30	10	30	30	30

Fig. 10: Further additional illuminance percentage when external light at 23rd point is over 700 lx.

realized.

B. *Numerical results and discussion*

We evaluate the performance of the proposed scheme in the random walk scenario. The trajectory of the target is shown in Fig. 11, the simulation conditions are shown in Table 2, the illuminance at hand on each time is shown in Fig. 12, and the comparison of the power consumption amount is shown in Fig. 13. In this simulation, the target randomly moves 1 m away from the walls in the room and the illuminance at hand and the amount of power consumption are calculated. It can be seen in Fig. 11 that the target moves around the whole room except the wall areas, and in Fig. 12 that the illuminance at hand does not fall below 500 [lx]. As shown in Fig. 13, the proposed scheme needs a slightly larger electric energies than the conventional scheme with the external light measurements at all points, due to the estimation error on external lights. However, the required number of measurements in the conventional method is 49, and in contrast, that of the proposed method is only one (23rd). Therefore, the proposed scheme realized the energy-saving dimming control system with much less measurement requirements.

Table 2: Simulation conditions 2.

Sensor Field	6.5 [m] in length, 7 [m] in width, 2 [m] in height from the ceiling
Number of sensors	9
Number of moves	100000
Used lighting	XLX440AENC Panasonic LED fluorescent lamp
Total luminous flux of one lighting	4000lm
1 power consumption	27.7W
Number of lights	18
Number of lighting	Lighting 1 at red, 2 at green and 4 at blue
External light	Change at every 50000 seconds

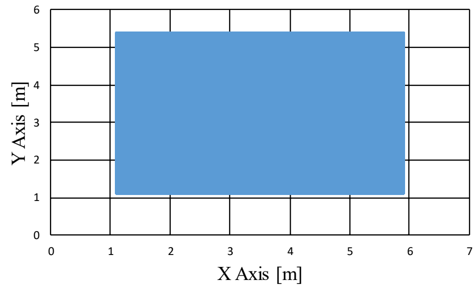

Fig. 11: Target trajectory.

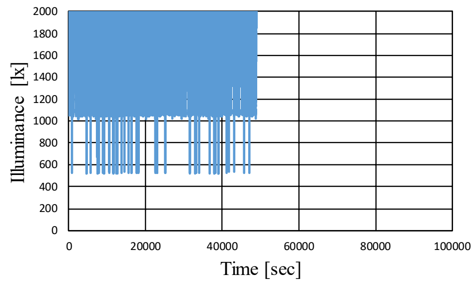

Fig. 12: Iillumination performance at person's hand.

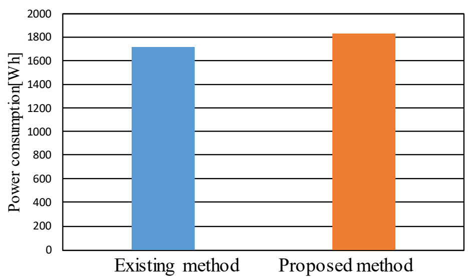

Fig. 13: Comparison of total power consumption.

V. NUMERICAL RESULTS IN PRACTICAL SCENARIO

In the previous simulation, there was nothing in the room and the target could freely move. To obtain the performance in more realistic scenarios, we conduct the numerical simulation in the real room environment and the target scenario, as shown in Fig. 14.

A. Simulation and Discussion

In the room shown in Fig. 14, it is assumed that one target person stays at any places on sofa or chairs one hour, and then moves randomly to an another sofa or chairs. The illumination dimming control is turned on in all times and the power consumption is calculated. The simulation conditions are shown in Table 3. The layout of lighting and sensors is the same as in Figs. 2 and 3. The result of illuminance at hand in each time is shown in Fig. 15, and the comparison of power consumptions in the conventional and the proposed methods is shown in Fig. 16.

In Fig. 15, it can be seen that the illuminance at hand changes on every hour according to the target position, and sometimes sways during one hour due to a position estimation error. However, it never fell below 500 [lx] and it was shown that the sufficient illuminance was provided by the proposed method. Similarly to Fig. 13, the power consumption of the proposed method ('Regularity is present') increases compared to the conventional method ('No regularity') due to the estimation error on external lights. This error might be emphasized in the scenario of Fig. 14. However, the difference of energy consumption between two methods is almost less than 100 [Wh], which is relatively small, and the effectiveness of the

Table 3: Simulation conditions 3.

Sensor Field	6.5 [m] in length, 7 [m] in width, 2 [m] in height from the ceiling
Number of sensors	9
Time	From 8 o'clock to 18 o'clock
Target position	Chair, sofa One hour stay for each
Number of persons	1 person

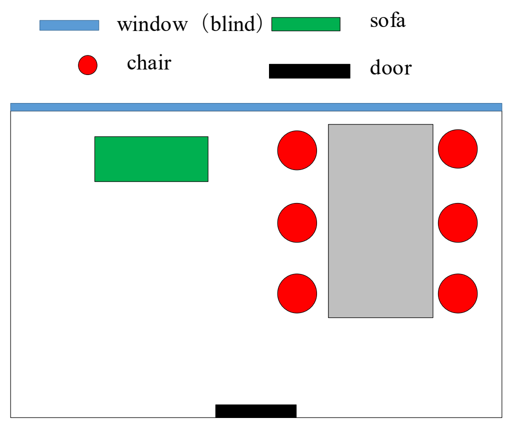

Fig. 14: Real room layout.

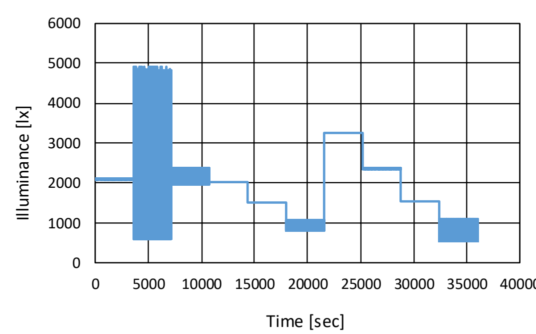

Fig. 15: Iillumination performance at person's hand.

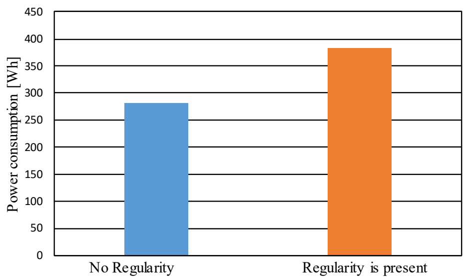

Fig. 16: Comparison of total power consumption.

proposed scheme was clarified in this practical scenario.

VI. Conclusions

In this paper, we focused on an indoor energy-saving dimming control system using the position information assisted by sensor networks. In particular, we proposed a new external light addition scheme using linear least square estimation from one measurement reference point. The proposed scheme can greatly reduce the measurement points of external light. The numerical results showed that the proposed scheme realized the energy-efficient dimming control with a slight increase of power consumption compared to the conventional scheme with many measurements.

In future studies, we consider an experiment of the proposed scheme and verify the effectiveness.

References

[1] R. Bayindir, E. Hossain, and S. Vadi, "The path of the smart grid -the new and improved power grid," Proc. International Smart Grid Workshop and Certificate Program (ISGWCP), pp. 1-8, 2016.

[2] M. Horiba, E. Okamoto, T. Shinohara, and K. Matsumura, “An accurate indoor-localization scheme with NLOS detection and elimination exploiting stochastic characteristics,” IEICE Trans. Commun., vol. E98-B, no. 9, pp. 1758-1767, Sept. 2015.

[3] I. Guvenc and C. C. Chong, “A survey on TOA based wireless localization and NLOS mitigation techniques,” Communications Surveys & Tutorials, IEEE, vol.11, no.3, pp.107-110, Third Quarter 2009.

[4] K. Nakashima, M. Horiba, and E. Okamoto, “Electric power saving in smart grid using localization with ultra wide-band signals,” 2014 IEEE 11th Vehicular Technology Society Asia Pacific Wireless Communications Symposium 28-29 Aug, 2014.

[5] K. Nakashima and E. Okamoto, “An energy-efficient adaptive lighting control scheme using indoor localization with prior position information,” Proc. International Conference on Information Technology and Electrical Engineering (ICITEE), pp. 470-475, Oct. 2015.

[6] X. Li, “An iterative NLOS mitigation algorithm for location estimation in sensor networks,” in Proceedings of the 15th IST Mobile Wireless Communications Summit, Myconos, Greece, 2006.