PAPER *Special Section on Emerging Technologies for Practical Ubiquitous and Sensor Networks*

Research of Practical Indoor Guidance Platform Using Fluorescent Light Communication

Xiaohan LIU[†], **Hideo MAKINO**[††a)], ***Members***, **Suguru KOBAYASHI**[†], ***Nonmember***, ***and*** **Yoshinobu MAEDA**[††], ***Member***

SUMMARY This article presents an indoor positioning and communication platform, using fluorescent lights. We set up a practical implementation of a VLC (Visible Light Communication) system in a University building. To finalize this work, it is important that we analyze the properties of the reception signal, especially the length of the data string that can be received at different walking speed. In this paper, we present a model and a series of formulae for analyzing the relationship between positioning signal availability and other important parameters, such as sensor angle, walking speed, data transmission rate, etc. We report a series of real-life experiments using VLC system and compare the results with those generated by the formula. The outcome is an improved design for determination of the reception area with more than 97% accurate signals, and an optimal transmission data length, and transmission rate.

key words: *Visible Light Communication, fluorescent light, indoor guidance system, simulation formula, data transmission speed, walking speed*

1. Introduction

In the past 20 years, a number of research projects have focused on the efficacy of the navigation properties of electronic devices. There are two basic approaches: (1) use of global satellite systems to obtain location coordinate information and (2) the addition of environmental details using a variety of location identifiers.

GPS (Global Positioning System) is the most widely used location-sensing and navigation system [1], [2]. However, GPS has problems inside building because satellite signals are blocked.

For the second method, there are a variety of interesting approaches and devices [3], [4]. Talking Signs [5], [6] and Active Badge are applications of Infrared Communication (IrDA) [3]. However, infrared cannot be seen, and has a line-of-sight requirement with risk of damage to eyes among the general public. These are limitations to a practical application, indoors, using location sensing. Although RFID enables remote communication [8]–[10] using active type, the distance for the passive types is too short [9]. However, present RFID applications have not made a comprehensive or sufficient system for practical use [8]–[10]. Ultrasound serial systems, like Cricket and Active Bat, are not cost effective to most users at this time [3]. The overall accuracy of the IEEE 802.11 serial systems is not yet optimized [3], [16].

In this paper, we have proposed the use of a Visible Light Communication (VLC) system, using fluorescent light. The idea of using VLC, had occurred to Alexander Graham Bell back in the late 1870s, after the successful experiment of a photo phone, and some warships began to use Search Light for communication, but Bell did not have a way to generate a useful carrier frequency or a way to transmit the light from point to point [7]. Fluorescent light has been regarded as a potential medium for a VLC indoor guidance system for some time. In 1983, Shin-ichi Nakada presented a data transmission method by light [13]; in 2001, Steven Leeb (MIT) suggested and developed such an application of Talking Lights [14], [15], but little or no further practical progress has been forthcoming from him. LED also can be used in the VLC system [7], [17], [18].

We have developed an indoor guidance VLC system and set up practical experimental apparatus using fluorescent light. The fluorescent light is used as a communication device and as a lighting device [19]–[22]. Since 2006, we have established an experimental fluorescent light communication system. Two large public indoor guidance experiments have been undertaken for the visually impaired in the *Information Engineering Building, Niigata University* in November, 2006 and February, 2007. Figure 1 shows the situation.

The VLC system using fluorescent light (FLC) appears

Fig. 1 VLC guidance experiment for visually impaired people.

Manuscript received February 6, 2008.
Manuscript revised June 3, 2008.

[†]The authors are with the Graduate School of Science and Technology, Niigata University, Niigata-shi, 950-2181 Japan.
[††]The authors are with the Department of Information Engineering, Faculty of Engineering, Niigata University, Niigata-shi, 950-2181 Japan.
a) E-mail: makino@ie.niigata-u.ac.jp

DOI: 10.1093/ietcom/e91–b.11.3507

to have many advantages [13].

(1) Fluorescent light is an existing technology in most buildings and we only have to replace a *converter* behind the *in situ* fluorescent light to complete the communication system. (2) The cost is low, and the installation is easy. (3) Information sent to the user includes simple guidance instructions (the position, destination, route, etc.). So we can send the entire information string to the user in an acceptable time at a low data transmission speed. (4) VLC using fluorescent light can not be interfered by electromagnetic waves. (5) This research should be very helpful, especially for visually impaired users. Most blind persons have at last some light perception. They can therefore sense the direction from which a widely spread fluorescent light is shining.

Typically, when a user travels under the lights in a building, the moving speed of the user will be variable, speeding up, slowing down and so forth. Here is a problem: is such variable speed likely to interrupt reception of data from fluorescent light sources?

The first objective of this paper is to find out the relationship between the data transmission speed and the user's walking speed for reliable guidance data reception. In this paper the "reliable" data means more than 97% decodable data in 200 experimental trials.

There are two types of data for the indoor environment: (1) basic positioning information data, here the length is short, up to 20 bytes (similar to longitude and latitude data in GPS), in this case, relative database is necessary to translate the data to a text file in the user part; (2) additional text data, like emergency information or short news, in this case, the user part does not need a database, the data length ranges from 100 bytes to 200 bytes, or even longer. Different signals are sent out from different fluorescent lights.

So, additional to the first objective there are three necessary research questions: (1) what is the optimal data length that the receiver can interpret? (2) What is the size of the data reception area? (3) What is the practical feasibility of the platform?

In Sect. 2, we will describe the Visible Light Communication system as used in our building and the simulation model and formula that are proposed in order to demonstrate the relationship between the relative parameters. Section 3 then introduces the verification experiment in the actual environment, and we compare the experimental results with the theoretical results calculated from the formulae. In Sect. 4, on the basis of the analysis of these results, we focus on the positive outcomes and outline some other aspects of our on-going research.

2. System Description

This section includes two parts: (A) VLC system setup; (B) Introduction of the simulation formulae showing the relationship among different parameters, such as data transmission speed, user's moving speed, etc.

A. VLC System Setup

We use frequency modulation to send position signals without flickering in a commercial use. Figure 2 shows the system's configuration and execution process. The system includes three components: (1) *server* component; (2) Inverter type *fluorescent light* component; and (3) the *receiver* component.

In the server component, we use a microcomputer board system to control and set the information (such as a unique position ID) that is sent to the fluorescent light through a RS232C port (Step 1), the signals are then sent through the fluorescent light component, using FSK (Frequency Shift Keying) as the communication method (Step 2). The user holds a receiver (the component is a photo sensor with a reception circuit) to decode the signals. The reception software in the PDA (Personal Data Assistant, with Bluetooth function) analyses the data, obtains location ID (in the case of the short data type like GPS data), then searches in the database that is embedded in the PDA. If

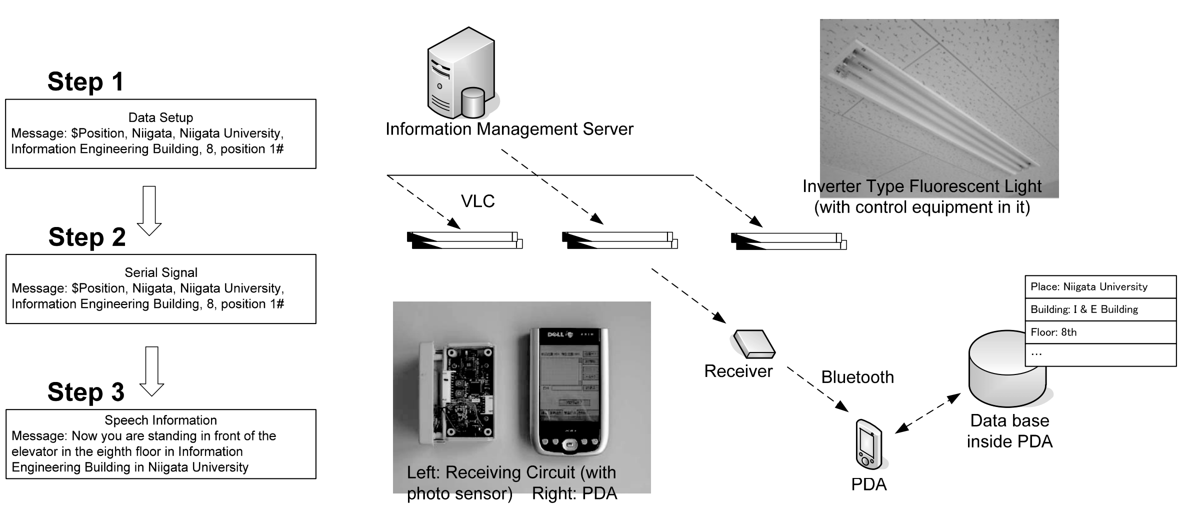

Fig. 2 VLC system configuration.

the ID matches a location in the database, the information is then spoken out by the PDA (Step 3).

B. Simulation Formula

In our system, we use a photo sensor (TOSHIBA: TPS601A) to detect the light signals. For one photo sensor, the half-receiving angle is 10°, so it can only receive signals from a very small area. This characteristic can effectively prevent the interference from other light sources.

1) Parameters: We developed a theoretical model that simulates the relationships among the complex parameters. Figure 3 shows the model for the experimental condition. Meanings of all the parameters are shown in Table 1.

The parameters can be divided into four categories: (1) Distance parameters: h_1, h_2, d, d_m; (2) Sensor angle parameters: α, θ; (3) Speed parameters: s, v; and (4) Data length parameters: L, L_P, L_T.

R is an evaluation parameter, $R = 1$ means that we can get complete reliable information from the fluorescent light under some circumstance, otherwise, $R = 0$ means we can not get entire reliable data.

2) Simulation Formula

The formula is built around 'time':

(1) When the user travels at a fixed speed in an orthogonal direction to the fluorescent light axis, we can calculate the time taken to traverse the route, and we define the time as T_1.

$$T_1 = d/v$$

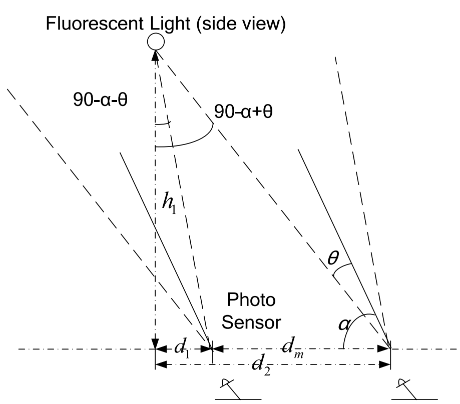

Fig. 3 Simulation condition.

Figure 3 shows the geometric relationship. The two angles from which the photo sensor can obtain all the data is calculated as shown below. We define the biggest angle β_1, and the smallest angle β_2, here we suppose the number of the photo sensors is one.

$$\beta_1 = 90 - \alpha - \theta$$
$$\beta_2 = 90 - \alpha + \theta$$

By such relationships, we can obtain the longest and the shortest distances over which the sensor can receive reliable signals. "d_1" means the minimum distance and "d_2" means the maximum distance. They can be calculated by:

$$d_1 = h_1 \cdot \tan\beta_1$$
$$d_2 = h_1 \cdot \tan\beta_2$$

And d_m can be calculated by:

$$d_m = d_2 - d_1 \tag{1}$$

(2) In the fluorescent light component, when the light transmits a fixed length of information data using a fixed transmission speed, we can also calculate the transmission time, which we define as T_2.

$$T_2 = L/s$$

On most occasions, we can use $L = 10L_T$ (one character bits: 10, plus safety margin). T_1 should be longer than T_2 if we want to get a complete data record. On the basis of the relationship between T_1 and T_2, we get (2).

$$R = \begin{cases} 1, & v \le \dfrac{s}{L} d_m \\ 0, & v > \dfrac{s}{L} d_m \end{cases} \tag{2}$$

Table 1 Experiment parameter.

Parameter	***Meaning***	Data
h_1 (h_2)	Distance between the sensor and the fluorescent light (the ground) in the vertical direction	140 cm (95 cm)
d (d_m)	Distance between the sensor and the fluorescent light (the maximum distance that the sensor can catch the light signals) in the horizontal direction	———
α	Angle between the sensor and the horizontal direction	———
θ	Sensor's half receiving angle (photo sensor: Toshiba TPS601A)	10°
s	Data transmission speed from the fluorescent light	1200-9600bps
v	User's walking speed (or sensor's moving speed)	0.2 -3 m/s
L_P (L_T)	Effective data length received by the sensor (Practical result and Theoretical result)	20-1k bytes
L	Length of data (in bits) that the sensor can receive	———
R	Result of the experiment: whether the user can get reliable signals	0 or 1

Theoretically, the parameters have dependency with each other. When one parameter varies we therefore also need to change others to ensure that we can receive a complete data string.

In this paper, our main focus is on the single photo sensor. The multi sensor receiver will receive signals from a bigger range and we will discuss the multi sensor design elsewhere.

3. Practical Verification Experiment

The experiment consists of two parts: first, to measure the maximum effective range to obtain reliable signals from the fluorescent light and then to compare it with the theoretical condition; second, to change the variable parameters to verify the formula within the effective ranges.

A. Effective Range Measurement

The theoretical effective range for data reception can be calculated from the formula as presented.

Figure 4 shows some basic parameters for the fluorescent light. Some light related factors can have an effect on the results obtained and they include (1) fluorescent light reflection and diffraction, (2) the specific characteristic for each fluorescent light and the associated ageing effect.

We use fluorescent light without louvers (i.e. the front cover which reduces the diffraction problem). The two-tube fluorescent light (with the cover, which can be worked as a reflector), as is shown in Fig. 4, can be worked as a rectangular light plane.

Due to the data transmission method (frequency modulation) and the distance between the receiver and the light in normal indoor conditions, the influence of the differences between each light is not significant.

Figure 5 shows the photo sensor's output voltage-distance diagram for a single fluorescent light (FL65) along the moving route. For the angle setting, the receiving angle is 20° (θ = 10°), so we set the angles at 20° intervals (90°, 70°, and 50°). Figure 6 shows a coordinate status-distance diagram for FL65. Each sensor was assigned a data status identifier, using the numbers "1, 2, 3, 4." Status "4" means the sensor can receive reliable information. Status "3" means the sensor can get more than 50% but less than 97% decodable information; Status "2" means the sensor can receive less than 50% decodable information; Status "1" means the sensor can not receive any signals. The examples of the receiving signals for each of the four status are shown in Table 2, parameter "*sr*" means the success rate.

In Fig. 5 and Fig. 6, we marked the effective ranges for reliable signals for each of the three angles. It is clear that the changes in signal strength are aligned to changes in signal reception status. The theoretical effective ranges can be calculated by Formula (1), the experimental effective ranges are the ranges when the signal reception status is "4."

Figure 7 shows the experimental environment in the university building. 22 specially designed fluorescent lights (FL61–FL82, with VLC function) are used in the experiment.6

Here we introduce some near-by environmental influences. General reflection (walls, floors, etc.) does not cause

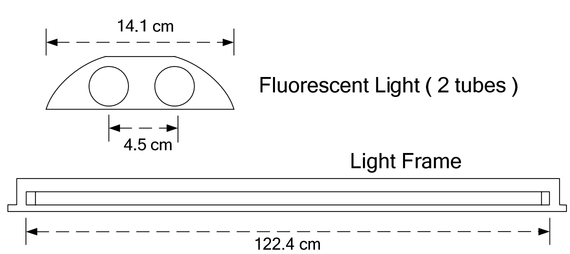

Fig. 4 Fluorescent light.

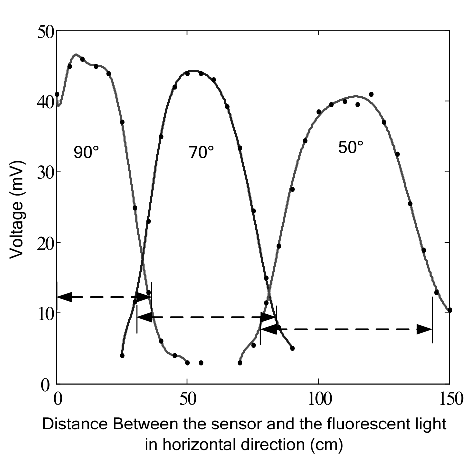

Fig. 5 Voltage-distance diagrams for single fluorescent light (FL65) in different angles (90°, 70°, 50°).

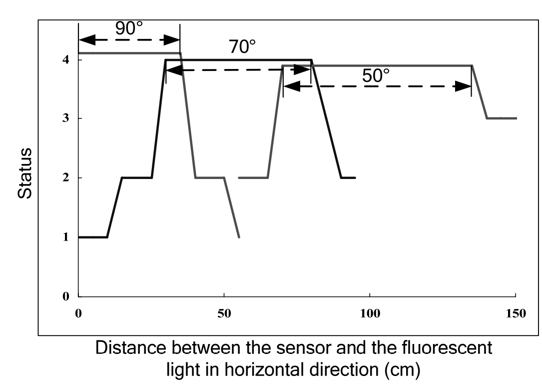

Fig. 6 Status-distance diagrams for single fluorescent light (FL65) in different angles (90°, 70°, 50°).

Table 2 Example of the receiving data.

Status	Receiving Data	Success Rate (*sr*)
4	You are standing in front of elevator	$sr \geq 97\%$
3	Yo・a~e sta・ning in fr_nt o~ le~at_r	$50\% < sr < 97\%$
2	・a・・~・・・・__・・_・°	$sr \leq 50\%$
1	(no signals)	$sr = 0\%$

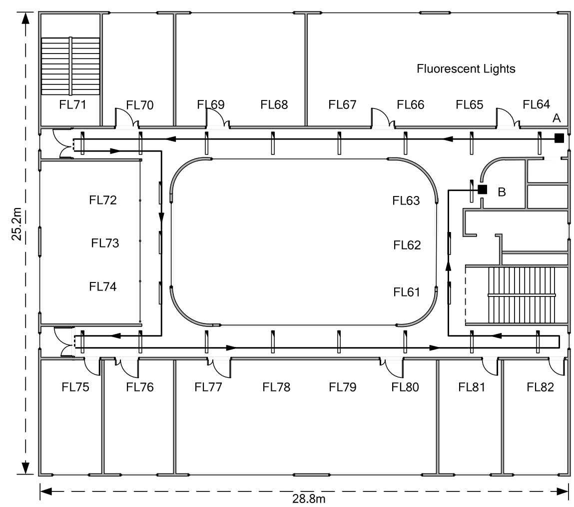

Fig. 7 Fluorescent light (with VLC function) configuration in the university building. An experimental route is set from point A to B.

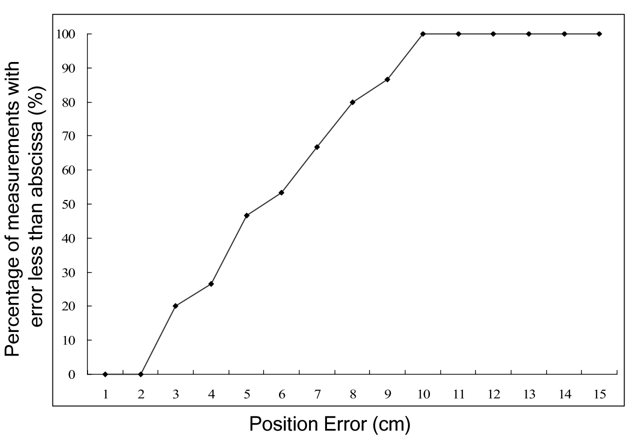

Fig. 8 Measurements error distribution.

a significant impact [11], [12] on the direct illumination. The natural light from the window can have some significant influence, when the photo sensor is near a window in daylight. Some measurements show that the natural light intensity will decay exponentially as distance from a window increases, and the window has a transmissivity of at most 50% [11], [12].

Figure 8 shows the distribution condition of the error between the theoretical effective range and the practical average effective range when $\alpha = 90°$ for 16 lights in Fig. 7 (FL64-FL71, FL75-FL82, here we do not concern the other 6 lights because the light direction is different).

The biggest distance error was under 10 cm.

B. Results of the Formula Verification

According to formula (2), we change three data parameters for the verification experiment.

The angle setting is the same as the settings already described. We set the angles at 20° intervals (90°, 70°, and 50°). For the sensor's *moving speed* setting, we use a motor to change the sensor moving speed with 0.26 m/s, 0.53 m/s,

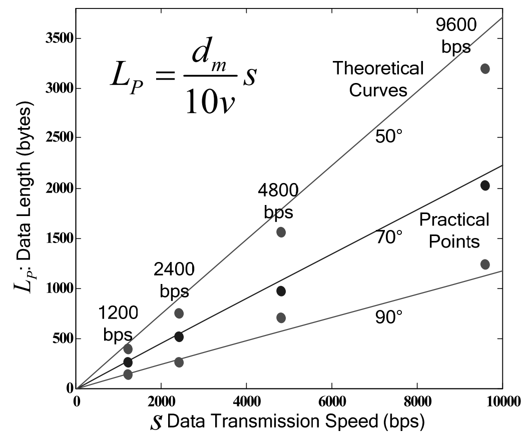

Fig. 9 Data length- transmission speed diagram (v = 0.27 m/s) using FL65.

and 0.81 m/s, as slow speed. Also we ask volunteers to move a handcart with the receiver placed under the fluorescent light at normal or fast speed (1.0–2.5 m/s). We set data transmission rate as 1200 bps, 2400 bps, 4800 bps, and 9600 bps.

The information we send out using fluorescent light is re-set continuously. A typical sample data setting would be "$Niigata, Niigata University, Information and Engineering Building, 8th floor, position 1#," where "$" is the start character, and "#" is the end character of the spoken string, informing the user of an initial position. The data are using the same format as is used in the familiar GPS system, GPGGA (Global Positioning System Fix Data).

Here we introduce some user/handcart influences in the experiment. When the user uses a PDA or mobile phone, it is held in the hand. However during the public experiment, we put the receiver on the visually impaired person's shoulder. However, under normal hand-held use hand movements, the height of the user, the length of user's hair, the shadow caused by the user's head, the clothes, could each cause variable and inter-connected influences.

To avoid these influences, we use a handcart which carries the receiver, a protractor and a pc for the experiment. Volunteers are asked to push the handcart at different speed.

The accuracy of the results is high when compared to the theoretical results (Fig. 9 and Fig. 10) for FL65. In Fig. 9, the experimental results show the relationship between L_P (length of the data reception) and s (the data transmission speed) when other parameters (v, d_m, α) are fixed. L_P and s present a strong linear correlation.

In Fig. 10, the experimental results show the relationship between L_P (length of the data reception) and v(the sensor's moving speed) when other parameters (s, d_m, α) are fixed. L_P and v present a strong inverse corporation correlation. We use three reference points in this experiment, which are all slow speed: 0.27 m/s, 0.53 m/s, and 0.81 m/s, we changed the speed by means of a motor.

Also we asked volunteers to walk under the 22 fluorescent lights in the corridor at different speeds (here we use average speed of the user). 150 groups of data at different speeds in 8 days were collected. Relative results are shown in Fig. 11, using the average speed of a visually impaired user. Two types of curve are generated for comparison: theoretical curves and empirical curves. The theoretical curves are derived from Fig. 10. In Fig. 11, for the 90° and 70° situation, the empirical result conforms well to the theoretical curves. However, in the case of 50°, the receiving data length does not conform to the theoretical curve well because of two reasons:

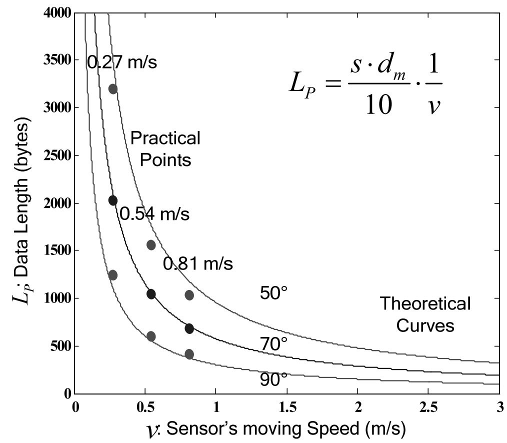

Fig. 10 Data length- sensor's moving speed diagram (s = 9600 bps) using FL65.

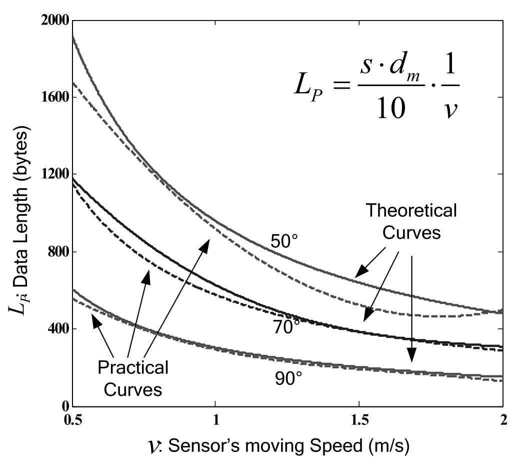

Fig. 11 Data length- sensor's moving speed diagram (s = 9600 bps).

(1) As the distance from the light source increases, the signal power weakens (as is shown in Fig. 5) and causes some error and the empirical receiving data length becomes shorter.

(2) The fluorescent light is assumed to be a light frame in this paper. In fact, the fluorescent light is inlaid in the ceiling. As the angle of the sensor decreases, it becomes more difficult to obtain suitable light signals.

Figure 12 shows the experimental situation in the building. There are fluorescent lights on the ceiling in the corridor. Measurement unit, containing receiver, oscilloscope, and other instruments, moves under the lights.

4. Discussion

This part includes two aspects: (A) problems encountered in the experiment; (B) Comparison with VLC and other technologies.

A. Problems encountered in the experiment

Here we introduce 5 topics: (1) the simulation formula and its limitations, (2) the practicality of the research, and associate discussion relating to data transmission speeds and data length, (3) the sensor design, (4) the estimation of precise location, and (5) relative parameters.

(1) Simulation Formula and its limitations

In the design of the simulation formula, to make the situation simple and clear, fluorescent light length is assumed to be adequate.

In the case of a receiver with one sensor, the angle α is supposed to be 90° (we can put the receiver on the user's shoulder). In this case, the effective area is consecutive, and the distance can be calculated by:

$$d = 2h_1 \cdot \tan\theta$$

Our experimental results show that, in measurable

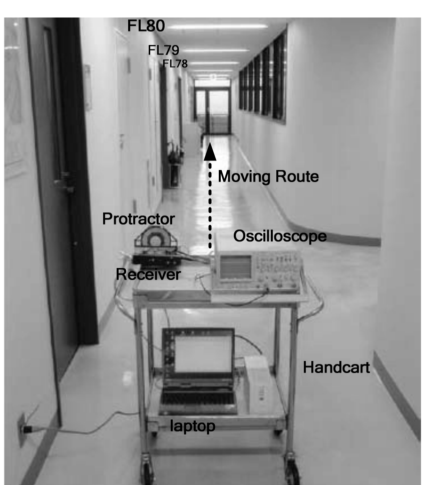

Fig. 12 Experiment situation.

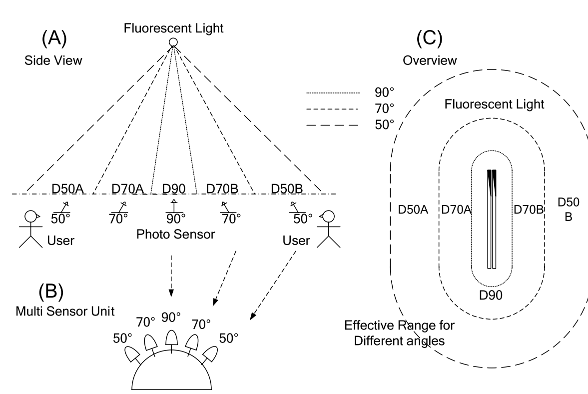

Fig. 13 Sensor design.

Table 3 Comparison with VLC and relative current location sensing technologies.

Technology	*Technique*	*Accuracy*	*Scale*	*Cost*	*Limitations*
FLC	*VLC*	Less than 1 meter	Inverter type fluorescent light for each location	Control board installation fee	Sunlight, indoor reflection interference
RADAR	*802.11*	3-4.3m	3 bases for 1 floor	802.11 network installation fee	Performance degradation by noisy license-free band and multi-path fading, wireless NICs
Talking Signs, Active Badge	*IrDA*	Room size	Several transmitters for each direction per area	Administration cost, cheap tags, sensors	Sunlight, fluorescent light interference, dead spots
LANDMARC	*RFID*	About 2 meters	Reference Tag for each location, 1 RF reader per 10 square meters	Installation, hardware cost	Proprietary, 802.11 interference
Active Bats	*Ultrasound*	9cm (95%)	1 base per 10 square meters	Administration cost, cheap tags, bases	Required ceiling sensor grid, difficult to maintain

ranges (the experiments are all performed along the middle line of fluorescent lights), the parameters (data transmission speed, receiver's moving speed, etc.) follow the simulation formula. However, in present formulae and experiment, we do not yet concern about the walking route along other directions. The effective range shape is shown in Fig. 13. Formula (2) will still be suitable for these cases, but the effective distance calculation will be changed according to the shape and power of the light. Some relative research will be performed in the future.

(2) Consideration for Practical Use

Here we concentrate on two parameters: data transmission speed and optimal data length.

Since the user's walking speed should not be very fast in the corridor or station, according to Formula (2), the total optimal data length could reach a range of 304 bytes to 1521 bytes (with the walking speed 1 m/s to 0.2 m/s).

The fastest data transmission speed at present is 9600 bps. In future research, we need to be able to transmit more data and the faster, the better.

(3) Sensor Design

As was outlined in the System Description Sect. 2 above, we use only one photo sensor in the receiver circuit and this effectively reduces the interference from other lights. Our experiments (Fig. 5 and Fig. 6) show that these angles cover a continuous effective range around the fluorescent light, as is shown in Fig. 13. On the basis of this research, we can design how to set more sensors in a receiver to get an all-direction and wide-angle covered effective range [23].

Figure 13(A) is the side view for effective ranges for each angle. (B) is multi sensor design according to the angle-range situation in (A). (C) is the overview of the situation. We divide the area into five domains: D90 ($\alpha = 90°$), D70A, D70B ($\alpha = 70°$), D50A, and D50B ($\alpha = 50°$).

(4) Precise Indoor Positioning and Guidance

This research considers the relationship between reception signals and a user's walking speed. Also, the purpose of the VLC system is for the all guidance field. For positioning, in the present experiment, the FLC system can provide position information for a range around 200 cm × 80 cm for each fluorescent light.

The two formulae derived from (2) can be used to calculate the distance of the sensor to each fluorescent light in different angles.

$$d_1 = h_1 \cdot \tan\beta_1$$
$$d_2 = h_1 \cdot \tan\beta_2$$

And some precise location estimation can be performed on the received signals from different lights. This research is now being performed, and we plan to focus on improving detail and precision using adjusted combinations of more technologies to support more information in this system, like the sign of door, window, etc. [22].

(5) Relative Parameters

Although some parameters changes according to each individual, we can still use some range to cover most of the conditions. For example, we can use 160 cm ± 20 cm to cover the height of the user's shoulder, and we can use 90°±15° to cover the angle of the sensor, also we can use 1.5 m/s ± 1 m/s to cover the user's walking speed in the building. In this case, the formula can be used in most of these conditions for indoor navigation.

In the future, we also would like to add the direction estimation part to this system.

B. Comparison with other technologies

We talked about some basic comparison in the Introduction part. Here we use similar comparison mode as is presented by Jeffrey Hightower [3], and outline some representative methods in terms of the cost, accuracy, scale and limitations in Table 3.

Compared with other technologies, FLC could cover most part of the indoor environment with least dead points. It is easy to install and the accuracy is high.

We are trying to reduce the cost for the system. A Japanese company is undertaking related development of the fluorescent light itself for future commercial release and therefore this paper has not included the properties and parameters of the related data transfers, due to *commercial-in-confidence* restrictions. The basic research is being done by

Kobayashi [20].

The sunlight and other reflections cause difficulties some time, and we want to add coordinate filter above the photo sensor to solve this problem.

5. Conclusion

For an indoor guidance system, this paper presents a model which considers important parameters, such as the user's walking speed, the data transmission rate from the fluorescent light. This model and the simulation formula is not only useful for the fluorescent light communication, but also can be used as a reference for the research using next generation LED lights, and other indoor communication methods, like Infrared Communication, Ultrasonic, RFID, etc.

The suggested simulation formula described in the paper provides optimal conditions for analyzing reliable signals and reception area for practical applications using fluorescent light communication. A series of experiment using 22 fluorescent lights and 3 different angular degree sensors suggests that the empirical results conform satisfactorily at each position, to the theoretical expectations.

This research should have practical and useful application in at least three following areas:

(1) Providing guidelines for calculation of the appropriate service area for establishing an indoor way-finding facility.

(2) Providing precise information on a user's location.

(3) Providing guidelines for specialized VLC sensor and receiver designs to enable a wider detection range.

The setup of the real-world FLC system and the introduction for the relative effects (reflection, sunlight, user movement, etc.) in the experiment provide useful information for the ubiquitous world in the future.

Acknowledgments

This research was partially supported by the Strategic Information and Communications R&D Promotion Program, Ministry of the Internal Affairs and Communications of Japan.

We would like to express our appreciation to Professor D. Parkes for assistance in preparing the manuscript.

References

[1] P. Misra and P. Enge, Global Positioning System: Signals, Measurements, and Performance, Ganga-Jamuna Press, Lincoln, Massachusetts, US, 2006.

[2] J.M. Loomis, J.R. Marston, R.G. Golledge, and R.L. Klatzky, "Personal guidance system for people with visual impairment: A comparison of spatial displays for route guidance," J. Visual Impairment & Blindness, vol.99, pp.219–232, April 2005.

[3] J. Hightower and G. Borriello, "Location system s for ubiquitous computing," Computer, vol.34, no.8, pp.57–66, Aug. 2001.

[4] T. Pfeifer, "Redundant positioning architecture," Comput. Commun., vol.28, no.13, pp.1575–1585, Aug. 2005.

[5] B.L. Bentzen and P.A. Mitchell, "Audible signage as a wayfinding aid: Comparison of 'Verbal Landmarks' with 'Talking Signs'," in Accessible Design for the Blind (Sept. 1993), [Online] Available: http://www.ski.org/Rehab/ WCrandall/General/ACBPAPER.htm

[6] W. Crandall, B.L. Bentzen, L. Myers, and J. Brabyn, "New orientation and accessibility option for persons with visual impairment: Transportation applications for remote infrared audible signage," Clinical and Experimental OPTOMETRY, vol.84, no.3, pp.120–131, May 2001.

[7] N. Nakagawa, ed., World of Visible Light Communication (in Japanese: Kashikou Tsushin no Sekai), Tokyo: Kogyochosakai, 2006.

[8] L.M. Ni, Y. Liu, Y.C. Lau, and A.P. Patil, "LANDMARC: Indoor location sensing using active RFID," Wirel. Netw., vol.10, no.6, pp.701–710, Nov. 2004.

[9] R. Want, "An introduction to RFID technology," Pervasive Computing, vol.5, no.1, pp.25–33, Jan.-March 2006.

[10] K. Tanaka, Y. Kimuro, K. Yamano, M. Hirayama, E. Kondo, and M. Matsumoto, "Self-localization with RFID system and tag arrangement," IEICE Trans. Inf. & Syst. (Japanese Edition), vol.J88-D-II, no.9, pp.1759–1770, Sept. 2005.

[11] J. Randall, O. Amft, J. Bohn, and M. Burri, "LuxTrace: Indoor positioning using building illumination," Personal Ubiquitous Computing, vol.11, pp.417–428, March 2007.

[12] J. Randall, Designing indoor solar products, John Wiley & Sons, New York, ISBN 0-470-01661-2, 2005.

[13] S. Nakada, "Data transmission method by light," Syowa60-#32443, Patent application report in Japan, Application date: Aug. 3rd, 1983.

[14] S. Leeb, "Talking lights," http://www.talking-lights.com (2001), US patent: #6198230, #6400482, #6426599, #6504633

[15] W. Loughborough, "Talking lights," J. Visual Impairment and Blindness, vol.6, p.243, June 1979.

[16] H.C. Chu and R.H. Jan, "A GPS-less, outdoor, self-positioning method for wireless sensor networks," Ad Hoc Networks, vol.5, no.5, pp.547–557, July 2007.

[17] T. Komine and M. Nakagawa, "Fundamental analysis for visible-light communication system using LED lights," IEEE Trans. Consum. Electron., vol.50, no.1, pp.100–107, Feb. 2004.

[18] T. Komine and M. Nakagawa, "Integrated system of white LED visible-light communication and power-line communication," IEEE Trans. Consum. Electron., vol.49, no.1, pp.71–79, Feb. 2003.

[19] H. Makino and Y. Maeda, "Positioning method using fluorescent light and application of assistive device for the blind (in Japanese)," Proc. Symp. Biomedical Engineering., vol.43, no.1, pp.3–7, Sapporo, Japan, Sept. 2004.

[20] S. Kobayashi, H. Makino, X. Liu, J. Kudo, and Y. Maeda, "Fluorescent light communication: A study of waveform characteristics and decoding methods," IPSJ SIG Technical Reports on 2006-UBI12, pp.109–116, 2006.

[21] X. Liu, H. Makino, S. Kobayashi, and Y. Maeda, "An indoor guidance system for the blind using fluorescent lights — Relationship between receiving signal and walking speed," Proc. 28th IEEE- EMBS Int. Conf., pp.5960–5963, New York, US, Autumn 2006.

[22] X. Liu, H. Makino, S. Kobayashi, and Y. Maeda, "Design of an indoor self-positioning system for the visually impaired — Simulation with RFID and bluetooth in a visible light communication system," Proc. 29th IEEE- EMBS Int. Conf., pp.1655–1658, Lyon, France, Sept. 2007.

[23] H. Makino, "Information retrieve and management system," Japan patent pending: 2003-162859, 2003.

Xiaohan Liu received the B.E. degree in the Department of Computer Science from Harbin Institute of Technology, China, in 2003, and the M.E. degree in the Department of Information and Engineering from Niigata University, Japan, in 2006. He is currently working toward the Ph.D. degree in the Department of Information and Engineering, Niigata University. His research interests include visible light communication and indoor guidance system. He is a student member of IEEE and IEEJ.

Hideo Makino graduated from the Department of Electronic Engineering, Niigata University, in 1976, completed the M.S. program in 1978, and joined the staff of the Department of Information Engineering. He became an associate professor in 1990 and a professor in 1995. He was on leave at the Research Institute of Applied Electrical Engineering, Hokkaido University, in 1983 and at the Medical School, University of Toronto, in 1989. He has been engaged in research on welfare medical information equipment. He holds a D.Eng. degree, and is a member of the Japan BME Society, the Institute of Electrical Engineers of Japan, and IEEE. He is a council member of the Japan Heart Rhythm Society and a director of the Geographical Information Systems Society, Japan.

Suguru Kobayashi received a B.A. and M.A. degree in information engineering from Niigata University, Japan, in 2006 and 2008, respectively. He has been engaged in research on decoding method for digital signal processing in visible light communication using fluorescent lights.

Yoshinobu Maeda received a M.S. (1995) and a Ph.D. (1998) in Biophysical Engineering from Osaka University. He was JSPS Research Fellow (1995–1997) in Osaka University, Research Associate (1998–2005) in Niigata University, and Visiting Associate Professor (2007) in Hiroshima University. Presently, he is Associate Professor in Graduate School of Science and Technology, Niigata University. His research fields are neuro- and socio-dynamics, human interface and assistive technology. He is a regular member of JSMBE, IPSJ, JSWSAT and RESJA.