Paper

Indoor/Outdoor Seamless Positioning Using Lighting Tags and GPS Cellular Phones for Personal Navigation

Hiromune NAMIE[*a)], Hisashi MORISHITA[*]

Abstract The authors focused on the development of an indoor positioning system which is easy to use, portable and available for everyone. This system is capable of providing the correct position anywhere indoors, including onboard ships, and was invented in order to evaluate the availability of GPS indoors. Although the performance of GPS is superior outdoors, there has been considerable research regarding indoor GPS involving sensitive GPS, pseudolites (GPS pseudo satellite), RFID (Radio Frequency IDentification) tags, and wireless LAN .However, the positioning rate and the precision are not high enough for general use, which is the reason why these technologies have not yet spread to personal navigation systems. In this regard, the authors attempted to implement an indoor positioning system using cellular phones with built-in GPS and infrared light data communication functionality, which are widely used in Japan. GPS is becoming increasingly popular, where $GPGGS sentences of the NMEA outputted from the GPS receiver provide spatiotemporal information including latitude, longitude, altitude, and time or ECEF xyz coordinates. As GPS applications grow rapidly, spatiotemporal data becomes key to the ubiquitous outdoor and indoor seamless positioning services at least for the entire area of Japan, as well as to becoming familiar with satellite positioning systems (e.g. GPS). Furthermore, the authors are also working on the idea of using PDAs (Personal Digital Assistants), as cellular phones with built-in GPS and PDA functionality are also becoming increasingly popular.

Keyword Lighting Tag, Indoor Positioning, Seamless Positioning, GPS, Cellular Phone

1. Introduction

Recently, Japan has seen a dramatic expansion in the use of car navigation systems Since the E-911 (information about emergencies) law came into effect in April 2007 in Japan, the popularity of cellular phones (including PDAs) with built-in GPS (Global Positioning System) has been on the rise.

Figure 1 shows the external appearance of the display of a cellular phone with built-in positioning and mapping functionality, including GPS, as well as Internet browsing functionality. In recent years, personal navigation systems have been in high demand in the same way as car navigation systems. However, in contrast to cars, which can only run on roads, people are much more flexible due to their ability to access almost any available space (indoors, underground, etc.) on foot.

Although the performance of GPS is superior outdoors, there has been considerable research regarding indoor GPS involving sensitive GPS, pseudolites (GPS pseudo satellite), RFID (Radio Frequency IDentification) tags, and wireless LAN. However, the positioning rate and the precision are not high enough for general use, which is the reason why these technologies have not yet spread to personal navigation systems. A location method for indoor mobile robots using RFID was presented recently[1]. In this regard, it has been stated in some papers that knowledge of the velocity and the position is required in industrial applications (e.g. humanoid robots)[2]-[5].

Fig. 1. External appearance of a cellular phone with built-in function for positioning and mapping through the Internet.

In this paper, the authors present the experimental implementation of an indoor/outdoor seamless positioning system using cellular phones with built-in GPS functionality, infrared light data communication, and Lighting Tags.

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2. Concept of Seamless Positioning

2.1 Seamless Positioning

Figure 2 shows a conceptual diagram of the outdoor and indoor seamless positioning system using Lighting Tags and cellular phones with built-in GPS and infrared light communication functionality. In outdoor situations, such phones utilize a GNSS (Global Navigation Satellite System) implementation, such as GPS, while in indoor situations, Lighting Tags are used. In both situations, the same spatiotemporal position data is used, and seamless positioning can be easily achieved.

When a user carrying a cellular phone walks underneath a fluorescent light with a Lighting Tag, the precise spatiotemporal data, which is surveyed in advance, is received instantaneously, which allows the position of the user to be fixed automatically, in a manner similar to GPS. This system can provide seamless positioning, and it is possible to implement it as a universal service.

2.2 Core Spatiotemporal Data and Cellular Phone

GPS becomes increasingly popular for use outdoors. $GPGGA (Figure 3) sentences of the NMEA (National Marine Electronics Association)-0183 outputted from GPS receivers provide 4-dimensional spatiotemporal information including latitude, longitude, altitude, and time or ECEF (Earth-Centered Earth-Fixed) xyz coordinates. As GPS applications grow rapidly, spatiotemporal data becomes key to the ubiquitous

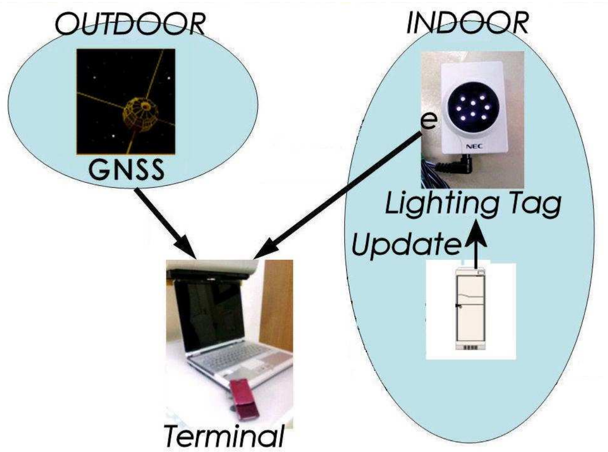

Fig. 2. A conceptual diagram of the outdoor and indoor seamless positioning system using Lighting Tags and cellular phones with built-in GPS and infrared light communication functionality.

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$GPGGA,015340.00,3515.4490,N,13943.2215,E,1,9,0.8,6.17,M,3
6.15,M,,*64
$GPGGA,015341.00,3515.4489,N,13943.2216,E,1,9,0.8,6.17,M,3
6.15,M,,*6A
$GPGGA,015342.00,3515.4488,N,13943.2216,E,1,9,0.8,6.17,M,3
6.15,M,,*6F
$GPGGA,015343.00,3515.4488,N,13943.2216,E,1,9,0.8,6.17,M,3
6.15,M,,*69
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Fig. 3. A $GPGGA sentence in the National Marine Electronics Association (NMEA) format.

outdoor and indoor seamless positioning services at least for the entire area of Japan, as well as to becoming familiar with satellite positioning systems (e.g. GPS). Furthermore, the authors are also working on the idea of using PDAs (Personal Digital Assistants), as cellular phones with built-in GPS and PDA functionality are also becoming increasingly popular.

Cellular phones with built-in infrared light data communication (IrDA: Infrared Data Association) functionality have already spread in Japan. Users often exchange their phone numbers and e-mail addresses using IrDA. If IrDA devices can connect and upload data about their current location, they can obtain spatiotemporal position data anywhere underground and indoors.

2.3 Lighting Tag

We propose a novel system for indoor/outdoor seamless positioning using cellular phones with built-in GPS functionality in combination with infrared light communication and fluorescent lights with Lighting Tags (NEC and NEC Engineering Corp. c_).

Figure 4 shows the external appearance of a Lighting Tag (height: 44.0 mm × width: 55.0 mm × depth: 25.0 mm, weight: 130 g) and a USB infrared light receiver (height: 38.7 mm × width: 16.0 mm × depth: 10.5 mm).

The Lighting Tag transmits ID according to the infrared date communication. The electric power is acquired from the inverter type fluorescent lamp lighting, and the ID transmitter is driven. Electrical work is unnecessary for usage. Because the ID transmitter does not use the electric wave, it is not influenced by the electric wave interference. We can use them between 0 and 65 degrees of temperature and between 20 and 85 percentage of humidity without the dewfall.

The receiver is already small enough for practical purposes, while the infrared light emitter consists of 8 identical infrared light-emitting parts and can be turned on or off according to the situation, respectively. The power is supplied by electromagnetic induction (voltage: 3.3 V, average power: 50-100 mW), where the white circle, consisting of a magnet and a coil (circle in Figure 4), is placed around an inverter-type fluorescent light (FHF: Fluorescent lamp High Frequency, frequency: 45-100 kHz). The Lighting Tags have collision avoidance logic. If some Lighint Tags emit at the same time, tags comes to be going to emit at the different time next respectively.

Fig. 4. External appearance of the Lighting Tag and the USB infrared light receiver.

3. Experimental Reception Indoors

3.1 Experimental Outline

Figure 5 represents an experimental ID reception from a Lighting Tag using the infrared light communication function at a fixed point indoors. The Lighting Tags were placed on the ceiling, whose typical height is about 3.0 m. The authors carried a laptop PC with the USB infrared IrDA receiver and attempted to receive the ID of the tag. The typical distance from the Lighting Tag to the receiver was about 1.5 m. Next, they attempted to obtain the ID while standing near a wall (0.5 m and 1.5 m from the wall) in order to study the influence of the reflection of infrared light from the wall.

Figure 6 shows the ID received by the PC from the Lighting Tag using IrDA communication. It shows the ID and the system time of the PC when the ID was received. The data can be obtained at a rate of more than once per second. If the capacity of the data transmission of this system is improved, it will be possible to transfer spatiotemporal data in a manner compatible with GPS/GNSS.

3.1.1 Automatic Reception

Figure 7 shows a conceptual image of automatic ID reception from a Lighting Tag using infrared light data communication. It presents a situation where the user walks beneath the Lighting Tags on the ceiling, and the operation of the system is automatic, similarly to satellite car navigation. In car navigation, the reception of radio waves from satellites is always automatic, and generally goes unnoticed by the users.

3.1.2 Manual Reception

Figure 8 shows a conceptual image of manual ID reception from a Lighting Tag using infrared light, representing a situation where the user walks beneath the Lighting Tags on the ceiling while attempting to acquire the position in a manner similar to using a cellular phone. If the carrier signal of the cellular phone is weak, the user always moves the cellular phone in search for better reception. In the same way, if the user cannot receive an ID using infrared light communication, they orient the receiver toward the Lighting Tag.

3.1.3 Results of the Reception Experiments

Table 1 shows the area where automatic and manual ID reception from the Lighting Tag is possible by using IrDA communication. The data on the left and the right side of the table represent the automatic and the manual mode, respectively.

The table shows that both automatic and manual ID reception is possible within a range of more than 10 m at right

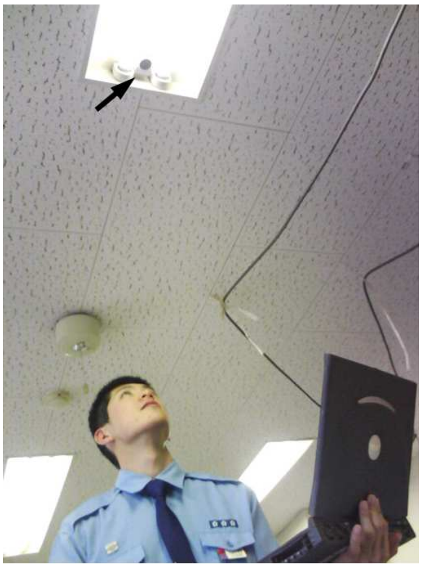

Fig. 5. Experimental ID reception from a Lighting Tag by using infrared light data communication.

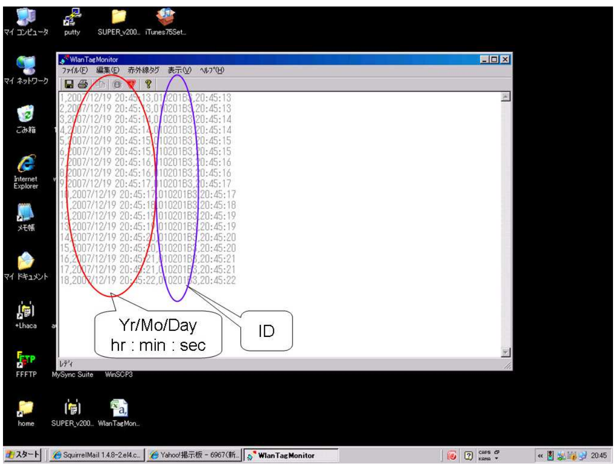

Fig. 6. ID received by the PC from the Lighting Tag using infrared light communication.

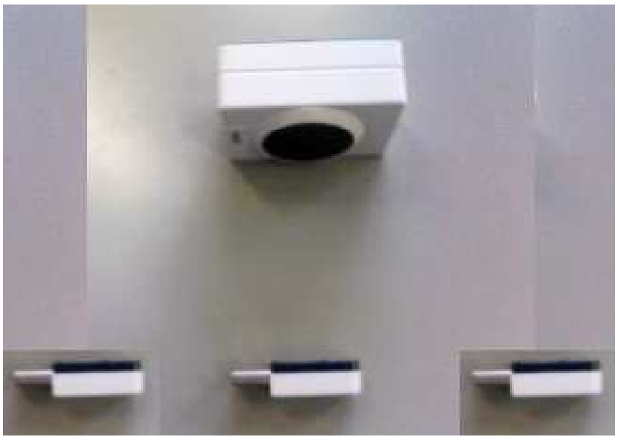

Fig. 7. A conceptual image of ID reception from Lighting Tags by using automatic infrared light data communication, similarly to the case of car navigation.

Fig. 8. A conceptual image of manual ID reception from a Lighting Tag using infrared light communication.

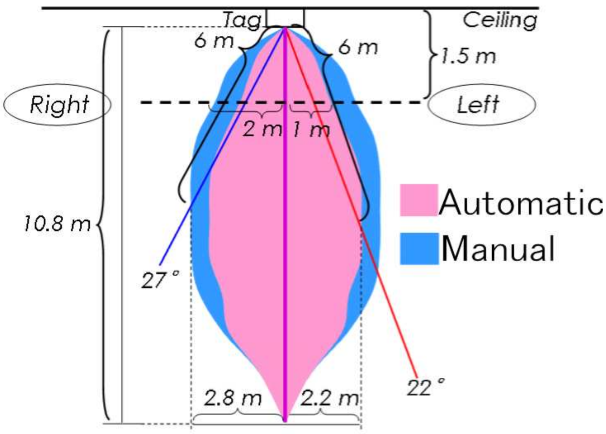

Fig. 9. Area where automatic and manual ID reception from the Lighting Tag using infrared light data communication is possible.

Table 1. Area Where Automatic and Manual ID Reception from the Lighting Tag Using Infrared Light Data Communication is Possible.

	Automatic				Manual			
Dist	**Left**	**Rt**	**Aver**	**Rad**	**Left**	**Rt**	**Aver**	**Rad**
1 m	41°	47°	44°	0.6 m	68°	61°	64°	0.9 m
1.5 m	-	-	40°	1.0 m	-	-	59	2.0 m
2 m	33°	37°	35°	1.1 m	54°	53°	53°	1.6 m
3 m	24°	35°	29°	1.4 m	41°	45°	43°	2.0 m
4 m	20°	34°	27°	1.8 m	32°	41°	36°	2.3 m
5 m	19°	32°	25°	2.1 m	27°	38°	32°	2.6 m
6 m	17°	26°	21°	2.2 m	25°	29°	27°	2.7 m
7 m	14°	22°	18°	2.1 m	22°	24°	23°	2.7 m
8 m	7°	19°	13°	1.8 m	16°	20°	18°	2.4 m
9 m	10°	10°	10°	1.5 m	15°	8°	11°	1.7 m
10 m	4°	4°	4°	0.7 m	4°	3°	3°	0.6 m

angles to the face of the tag.

Figure 9 shows the area where automatic and manual ID reception from the Lighting Tag is possible by using infrared light communication. The Lighting Tag is located on the ceiling in the upper part of Figure 9, and there is a receiver in the lower part of the Figure 9. The smaller area corresponds to automatic reception, while the larger area corresponds to manual reception. The maximum radius of the area is 2.2 m at a distance of 6 m from the Lighting Tag in automatic mode, and 2.7 m at a distance of 7 m in manual mode. If the typical ceiling height is 3 m, the typical distance from the Lighting Tag to the receiver is about 1.5 m. The radius of the area where ID reception is possible is 1.0 m in automatic mode and 2.0 m in manual mode. From these figures, it can be inferred that the area where reception is possible in manual mode is twice as large in terms of radius and 4 times as large in terms of width.

3.2 Effects of Reflection from Walls on Reception

Next, we attempted to obtain an ID from two positions near a wall (0.5 m and 1.5 m from the wall, respectively) in order to account for the reflection of infrared light .

Table 2 shows the area where manual ID reception from the Lighting Tag using infrared light is possible. The data on the left side of the table corresponds to a distance of 0.5 m from the wall, and that on the right side of the table corresponds to a distance of 1.5 m. The table shows that the ID can be received manually from a distance of more than 13 m from the tag at a right angle to the face of the tag.

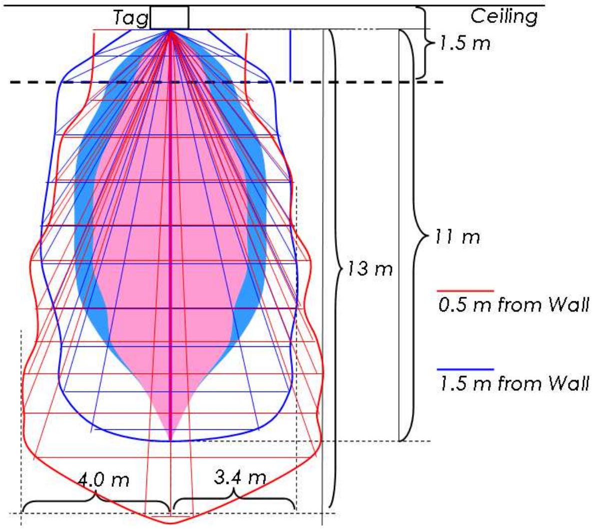

Fig. 10. Area of ID reception from the Lighting Tag using infrared light data communication near a wall.

Table 2. Area of ID Reception from the Lighting Tag Using Infrared Light Data Communication near a Wall.

	0.5 m from the Wall				1.5 m from the Wall			
Dist	**Left**	**Rt**	**Aver**	**Rad**	**Left**	**Rt**	**Aver**	**Rad**
1 m	90°	90°	90°	1.0 m	90°	90°	90°	1.0 m
2 m	90°	90°	90°	2.0 m	75	85	80	1.9 m
3 m	53°	42°	47°	2.2 m	71	60	65	2.7 m
4 m	45°	45°	45°	2.8 m	43	50	46	2.9 m
5 m	41°	38°	39°	3.1 m	39	46	42	3.3 m
6 m	35°	33°	34°	3.3 m	34	36	35	3.4 m
7 m	32°	33°	32°	3.7 m	29	29	29	3.3 m
8 m	28°	25°	26°	3.5 m	24	23	23	3.1 m
9 m	25°	25°	25°	3.8 m	20	19	19	3.0 m
10 m	25°	23°	24°	4.0 m	19	15	17	2.9 m
11 m	21°	21°	21°	3.9 m	12	10	11	2.1 m
12 m	14°	22°	18°	3.7 m	No Data			
13 m	2°	3°	3°	0.0 m	No Data			

Figure 10 shows the area where manual ID reception from the Lighting Tag using infrared light is possible at a distance of 0.5 m or 1.5 m from the wall. The figure is the same as the one presented in Figure 9. The larger and the smaller area encircled by the wavy line corresponds to a distance from the wall of 0.5 m and 1.5 m, respectively. The maximum radius of the area where ID reception is possible is 4.0 m at a distance of 10 m from the Lighting Tag and 0.5 m from the wall, and 3.4 m at a distance of 6 m and 1.5 m from the wall. It was confirmed that the area where ID reception is possible becomes wider near the wall due to the reflection of infrared light, which allows for an ID to be received by reflection even in areas where this was previously impossible.

4. Mobile Reception Experiment

4.1 Passageway

The authors attempted to receive the IDs automatically while walking beneath the Lighting Tags installed on the ceiling in the passageway.

Figure 11 shows the results of the mobile ID reception experiment, where the height of the ceiling is about 3 m and the width of the passageway is about 2.5 m. The Lighting Tags were installed in a straight line at intervals of about 1.5 m near the fluorescent lights on the ceiling.

Tables 3 and 4 show a sample of the results of the experiment regarding the automatic reception of the IDs from the Lighting Tags while walking along the passageway. The bold characters in Table 3 indicate the point where the user turned around in the passageway. The typical distance from the Lighting Tag to the USB infrared receiver is about 1.5 m, in which case an ID can be received roughly once per second.

Fig. 11. A mobile experiment of ID reception from the Lighting Tag using infrared light data communication in the passageway.

Table 3. A Sample of the Results of the Experiment Regarding the Automatic Reception of the IDs from the Lighting Tags While Walking Along the Passageway (Both Ways).

ID	Time	ID	Time
0102013F	15:56:03	0102002A	15:56:16
0102004F	15:56:04	0102002A	15:56:22
0102004F	15:56:05	0102002A	15:56:22
0102004F	15:56:05	0102002A	15:56:23
010200A9	15:56:07	**0102016B**	**15:56:24**
010200A9	15:56:07	0102016B	15:56:24
010200A9	15:56:08	0102016B	15:56:25
1020091	15:56:09	1020091	15:56:27
1020091	15:56:10	1020091	15:56:27
1020091	15:56:10	010200A9	15:56:29
0102016B	15:56:12	010200A9	15:56:30
0102016B	15:56:12	0102004F	15:56:31
0102016B	15:56:13	0102004F	15:56:32
0102002A	15:56:14	0102004F	15:56:32
0102002A	15:56:15	0102013F	15:56:34

4.2 Arcade

Next, the authors attempted to receive the IDs automatically using infrared light while walking beneath the Lighting Tags installed on the ceiling of the arcade, which is presented in Figure 12. The height of the ceiling of the arcade is about 4.5 m, and the width is about 3.0 m. Furthermore, the Lighting Tags were installed in a straight line at intervals of about 1.5 m on the ceiling (Figure 13). The typical distance from the

Table 4. A Sample of the Results of the Experiment Regarding the Automatic Reception of the IDs from the Lighting Tags While Walking Along the Passageway (One Ways).

ID	Time	ID	Time
0102002A	15:57:26	010200A9	15:57:32
0102016B	15:57:28	010200A9	15:57:33
0102016B	15:57:28	010200A9	15:57:33
0102016B	15:57:29	0102004F	15:57:35
1020091	15:57:30	0102004F	15:57:36
1020091	15:57:31	0102013F	15:57:37
1020091	15:57:31		

Fig. 12. The exterior appearance of the arcade in this mobile experiment.

Fig. 13. The exterior appearance of the Lighting Tags installed in the arcade in this mobile experiment.

Lighting Tags to the USB infrared light receiver was about 3.0 m, in which case the typical radius of the area where ID reception is possible is about 1.4 m according to table I. It was possible to receive an ID from three Lighting Tags at the same time at any fixed point in the center of the arcade since the reception areas seemed to overlap.

5. Conclusion

In this paper, the authors present the results of experiments regarding the ID reception using Lighting Tags for basic research in order to realize indoor positioning using cellular phones with built-in GPS and infrared light data communication functionality.

The Lighting Tags were installed on the ceiling, and the authors carried a laptop PC with a USB infrared light receiver in order to receive an ID. Next, an experiment of ID reception near a wall (0.5 m and 1.5 m from the wall) was performed in order to account for the reflection of infrared light. The authors attempted to obtain an ID automatically while walking beneath the Lighting Tags on the ceiling in a passageway and an arcade.

The ID was received instantaneously and automatically when the receiver passed beneath the Lighting Tag. [This infrared light data communication system allows the transmission of more data in addition to an ID.] If spatiotemporal data conforming to GPS/GNSS is used instead of an ID, this system can provide seamless positioning, and it is possible to implement it as a universal service.

In the future, the authors intend to perform a positioning experiment simulating underground shopping areas and buildings. It is thought that in order to be realized, this system must be capable of not only outputting IDs, but also of utilizing spatiotemporal data compatible with GPS/GNSS and the rapid preparation of indoor electronic maps.

It is expected that serviceable areas will grow wider for many users in the future. The authors express their hope that the present research will help promote the practical use of a global indoor seamless positioning system. Indoor positioning must be improved in order for it to be accessible to mainstream users and become ubiquitous.

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