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A novel three-dimensional indoor positioning algorithm design based on visible light communication

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ABSTRACT

In this paper, a visible light communication based three dimensional indoor positioning system employing a dedicated algorithm and using the code division multiple access technique is proposed to solve the mutual interference among the reference source points. The light signal emitted from a CDMA modulated white LED, carrying LED's position information, is received by positioning terminal through intensity modulation and direct detection, and then the position of the terminal can be estimated based on the RSS-three dimensional localization algorithm. By using the orthogonality of the spreading codes, the separation of the overlap among visible identification code in time domain and frequency domain can be realized. According to the identification information, the position can be located in the associated area. And the precise location is calculated with a novel three dimensional positioning algorithm, based on the signal attenuation. The simulation results show that the proposed location algorithm has a high accuracy of under 7.06 cm and with an average positioning error of about 3.18 cm when the SNR is 30 dB. A real-time small positioning system was also demonstrate to test the performance of the system, which has a very good positioning accuracy. The proposed positioning algorithm is simple and does not require synchronization processing any more. These features outperform other existing indoor wireless localization approaches.

1. Introduction

In recent years, indoor positioning systems (IPS) is becoming the hottest issue, for this technology facilitates indoor services for humans and intelligence for robots. It's able to provide users with location information and help them find the desired goods in shopping malls and it can also be applied in some places such as warehouse, hospital, airport lobby, exhibition hall and museum. Global positioning system (GPS) technology provides satisfactory localization for outdoor environments. Services such as navigation, finding the surrounding points of interest, as well as showing the information of peripheral traffic condition are provided [1]. However, rapid positioning indoor is difficult to achieve by GPS because satellite signals suffer from attenuation and shadowing effects when penetrating through solid walls and this causes poor performance in indoor environments. Hence, users using GPS indoors face large positioning errors as well as not being able to connect to GPS satellites at all [2]. To circumvent this situation, current indoor wireless positioning systems are mainly based on two approaches. The first approach is Radio frequency (RF) based techniques, such as Zigbee, Ultra Wideband (UWB), Bluetooth, Wi-Fi and Radio-frequency Identification (RFID). These methods are prone to high attenuation and multipath and only offer accuracy from tens of centimeters to several meters [3]. Apart from the relatively poor accuracy of IPS achieved by RF-based techniques, they also add the electromagnetic interference (EMI) and are costly.

The second approach is visible light communication (VLC) based techniques which is considered an attractive technology because it can offer several advantages that other approaches do not have. First, the positioning system based on VLC utilizes the existing luminaire infrastructure realized by white light-emitting diode (LED), and this contributes to lower cost of the frontends. Second, light wave has a shorter wave length than RF wave, which results in a better immunity against multipath effects in indoor environments. As multipath fading is a serious concern for indoor communications, visible light positioning will provide higher accuracy. Third, VLC-IPS can support illumination function and location-based services simultaneously. Last but not

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the least, VLC immunity to interference from other electromagnetic waves and LED will not produce EM interference, thus it can be applied in environments where RF is prohibited. For all of the reasons mentioned above, the indoor positioning systems based on VLC are gaining more and more attraction in both academia and industry [4–6].

There exist three main techniques for indoor location sensing, namely proximity, scene analysis and trigonometry. Some indoor positioning systems (IPS) only use one positioning technique; others bind two or three positioning methods to increase the positioning accuracy. Proximity method is a very simple positioning algorithm that it relies only upon a grid of reference points, each having a known position; when a positioning terminal collects signal from a single source, it is considered to be colocated with the source. Therefore, the accuracy is no more than the resolution of the grid itself [7]. And scene analysis is a method that matches measured information to a pre-calibration database to realize positioning, thus omitting the computation process. However, this kind of positioning algorithm requires accurate pre-calibration for a specific environment and cannot be instantly deployed in a new setting [8].

Trigonometry is the general name of positioning techniques that use the geometric properties of triangles for location estimation, and it mainly consists of two branches: triangulation and trilateration. Triangulation uses relative angles to a reference point for positioning. A typical example for triangulation is the angle of arrival (AOA) method [9]. Location estimation is then performed by finding intersection of direction lines, which are radii ranging from reference points to the target [10]. However, due to the limited field of view (FOV) of the cameras, to reach good performance for a real system, a very dense set of lighting grids is required; otherwise, the system can only be deployed inside rooms with very high ceilings. The second category of trigonometry methods, trilateration, estimates the target location by measuring its distances from multiple reference points. This can be achieved by methods such as time of arrival (TOA), time difference of arrival (TDOA) and received signal strength (RSS). Among these distance measuring methods, TOA or TDOA demands strict synchronization clock cycle between the receiver and transmitter [11,12]. On the other hand, the RSS algorithm is the use of the signal from the receiver with respect to the strength of the relationship between the distance attenuation factor, which is easy to achieve and is found to achieve better accuracy than other methods [2]. However, RSS-based positioning systems are generally based on intensity modulation and direct detection (IM/DD), basically, at least three fixed position LED signals are required to calculate the receiver's coordinate. Therefore, the channel multi-access problem has to be solved and the signals that come from the LED of adjacent cells need to be separated at the receiver without inter-cell interference. For these reasons, previous researches used carrier allocation, time allocation, or wavelength allocation techniques to mitigate the inter-cell interference of signals come from the LED of adjacent cells. Kim Hyun-Seung et al. used carrier allocation to reduce inter cell interference [5]. However, additional compensation method is required when carrier allocation technique is used because frequency response of LED and receiver are not stable according to frequency. And Yang Se-Hoon et al. used time allocation [13] and wavelength allocation [14] techniques to solve the problem above, but, those systems require synchronization processing and optical filter or multiple LED. All of these methods mentioned above greatly increase the complexity of the system.

As the mentioned above, this article proposes a novel algorithm for VLC based three dimensional indoor positioning system using the code division multiple access (CDMA) technique and RSS-based trilateration method. To reduce inter-cell interference caused by the presence of multiple reference points in the positioning system, this algorithm utilizes the orthogonality of spreading codes, which realizes the code division multiplexing to separate the overlapping signals in time domain and frequency domain. A set of three light-emitting diodes (LEDs) ceiling light fixtures, sharing a common clock, transmit their three-dimensional coordinate information to the positioning terminal using a unique CDMA spreading code previously assigned to them. After receiving the three superimposed information bit streams, the receiver collects the RSS by measuring the received power of the terminal and retrieves the three-dimensional coordinate information of each LED. Unlike the traditional VLC indoor positioning system, the proposed positioning system doesn't require synchronization between the transmitter and receiver, which makes it more simple, robust and cost-effective. Based on these processes mentioned above, we show that the receiver will be able to accurately estimate its own position. Simulations demonstrate that an average positioning accuracy of less than 3.18 cm is achieved, and if 95% is assumed as an acceptable service coverage rate, the proposed system will be able to deliver an accuracy of 5 cm. A real-time small positioning system was also demonstrate after the simulation, which shows that more than 88% of the positioning points have achieved a positioning accuracy of 1.8 cm in the space with a size of $60\ \text{cm} \times 30\sqrt{3}\ \text{cm} \times 80\ \text{cm}$.

The remainder of this paper is organized as follows. Section 2 describes the indoor optical wireless channel model, the CDMA multiple access technology, and the positioning method of the system. Section 3 describes the result and analysis. Section 4 gives the conclusion of the article.

2. System principle and positioning algorithm

2.1. Indoor optical wireless channel model

In VLC-based indoor positioning systems, LED are used as data transmitters as well as positioning landmarks, while the users can receive location information using the optical receiver. A scenario in which VLC is used in a typical indoor environment to provide location-based services is presented in Fig. 1. Although the VLC channel includes both line of sight (LOS) and diffuse components, it has been reported that the energy of the reflected signal is much lower than the energy of the LOS component [15]. For simplicity, only LOS links are considered in this paper. As for the Lambertian radiation pattern [16], the optical channel gain $H(0)$of the positioning system is given by:

$$H(0) = \begin{cases} \frac{m_t+1}{2\pi d^2} \bullet A \bullet T_s(\theta) \bullet G(\theta) \bullet cos^{m_t}(\varphi) \bullet cos^{m_r}(\theta) & 0 \le \theta \le \theta_c \\ 0 & \theta > \theta_c \end{cases} \tag{1}$$

where θ and φ are the radiation and incidence angles with respect to LED and receiver, respectively. The effective area of the photodetector at the positioning terminal is given by A, d is the distance from LED to receiver in meter,θ_c is the field of view(FOV) of receiver, $T_s(\theta)$ is the

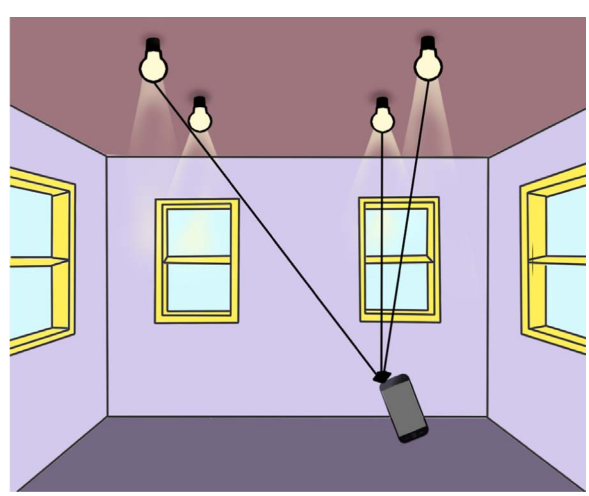

Fig. 1. Visible light communication positioning system configuration.