TDoA Based Indoor Visible Light Positioning Systems

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***Abstract*—In this paper, we propose an indoor positioning system in which the visible light radiated from LEDs is used to locate the position of receiver. Compared to current indoor positioning systems using LED light, our system has the advantages of simple implementation, low cost and high accuracy. In our system, a single photo diode (PD) receives pilot signals from LED panels on the ceiling. Then the time differences of arrival (TDOA) of these pilot signals are used to estimate the position of the receiver. Our proposed sytem is simulated in the room measuring $5\times5\times3m^3$ with considering effect of noises such as shot noise, thermal noise, and noise caused by the reflected light from the walls. The simulation result shows that our system can achieve a high estimation accuracy of $3.6cm$ in average.**

Keywords*—*visible light, LED, positioning, TDOA

I. Introduction

Indoor positioning has been studied widely in the recent years. A lot of positioning techniques using GPS, IR, RFID, Ultrasound, Bluetooth, Wifi [1,2] have been researched but there is no standard method for indoor positioning like using GPS in outdoor positioning systems. The RF based system is not safe for using in hospitals, airplanes or some hazardous environment. Infrared is more suitable for indoor positioning, but they require additional cost to implement the network infrastructure of location sensor. In additional, with RF, ultrasound or infrared, one has to deploy a costly system just for positioning function. The approach of using visible light for indoor positioning has been studied recently to overcome these limitations.

Beside the main function which is positioning, the visible light indoor positioning system undertakes the function of illuminating. While light emitting diode (LED) is considered lighting device in the future, positioning using visible light radiated from LED is cost-effective because we just need to embed the positioning function in the available illuminating system. There have been studies using visible light for indoor positioning [3-7], but neither of them achieves high accuracy nor have a simple implementation.

Many techniques including received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) can be used to locate the position of mobile node. The technique of AoA can achieve very good accuracy estimation, but require deploying an array of image sensors, which is expensive, at the receiver side. Because of the complicated effect of reflections, the technique of RSS is hard to acquire a accuracy in positioning, especially at the region near the walls. In indoor positioning, the travelling time of signal is so short due to the short distance between transmitters and receiver. This makes the ToA techniuqe difficult to be deployed since it requires the a precision of the clock at the receiver side. With TDOA, the synchronisation between LED panels and receiver is not necessary. TDOA requires the synchronisation between LED panels but it is simple since they can share the same clock in the same room. The information of time difference of arrival can be achieved accurately given that we have the proper scheme of transmitting pilot signals. Furthermore, with TDOA, the system just requires the photo diode, which is an inexpensive device, as the receiver. Hence, the technique of TDOA appears to be most suitable to use for indoor positioning system using visible light.

[7] also uses TDOA technique with visible light for indoor positioning. In this system, all pilot signals are transmitted at the same time and their optical power are time-domain cosine waves of specific angular frequencies. A complicated technique is used to seperate these signals from the mixed received signal. This approach is difficult to be applied in reality because it is very difficulty to control the transmitted optical power of LED precisely. Furthermore, choosing angular frequencies for different pilot signals is painful when a large number of pilot signal is used.

In this paper, we use the time difference of arrival of the visible light radiated from LED panels on the ceilling to locate the receiver's position. Since we use TDOA technique, no synchronisation between LED panel and receiver is needed. Importantly, our proposed system does not use any complicated modulation technique to embed unique IDs to signals from different LED panels. A inexpensive photo diode is used as the receiver. Thus, our positioning system can be deployed easily and costlessly, yet can achieve high estimation accuracy. We simulate the performance of the system with considering the reflection effects in the room measuring $5\times5\times3$ m^3.

II. System arrangement and pilot signal generation scheme

A. System arrangement

Our system is modeled in the rooom measuring $5\times5\times3$ m^3. A 3×3 lighting equipment grid is installed at the height of 0.5 m below the ceiling. The receiver can be placed at any point in the room.

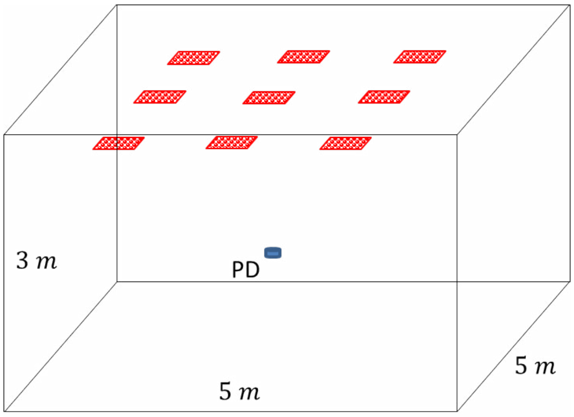


Fig. 1. The model room

B. Pilot signal generation scheme and detection method

1) Pilot signal generation scheme: Each LED panel transmits a single square pulse of pilot signal after every guard time period. All pilot signals have the same pulse width. Thus, after a period of time, the receiver receives a series of pilot signals from all LED panels in the room. Fig. 2 shows a series of pilot signals coming to the receiver.

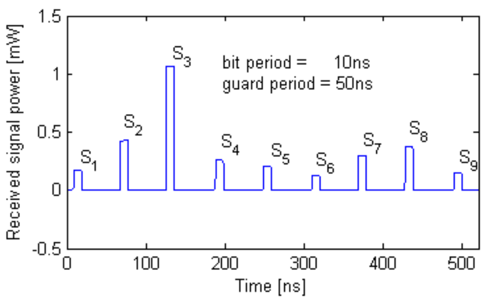


Fig. 2. Received pilot signals

The length of guard time period is chosen so that the previous pilot signal cause no or very litle interference to the next pilot signal. In this paper, the bit period of every pilot signal is 10ns. With considering the period of pilot signal as well as the room size, the guard period is chosen to be 50ns.

2) Pilot signal detection: The cross-correlation is used to detect each single pilot signal in the series of pilot signals. Then the information of arrival time of pilot signals can be obtained. Fig. 3 shows how the pilot signal can be detect using cross-crorelation.

III. Estimate receiver's position

A. Estimate receiver's position with known signal ID

By using cross-correlation, the time difference of arrival of pilot signals is obtained. From the time difference, the difference of distances from receiver to LED panels can be calculated easily by multiplying the time differences to the speed of light. Given that the signal ID is known, the position of transmitters is known also.

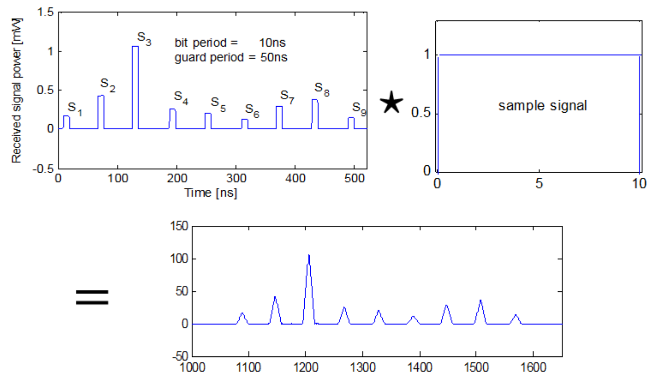


Fig. 3. Pilot signal detection

Basically, the distance difference from the receiver to two transmiters with known positions specifies a unique hyperboloid that the receiver lies in. Fig. 4 shows a hyperboloid we can draw when knowing the position of the two LED panels and the distance difference from the receiver to these two LED panels.

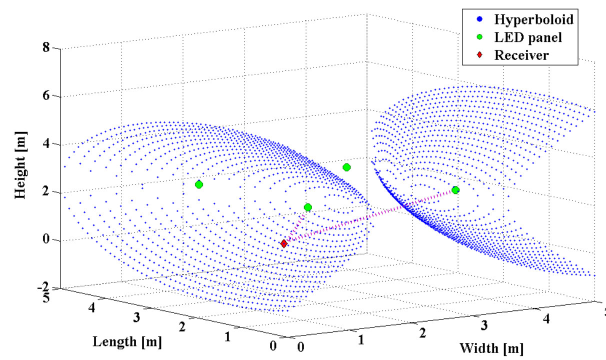


Fig. 4. Hyperboloid defined by distance difference

Assuming that the height position of the receiver is known, we can find the intersection of the hyperboloid and the Z-plane of receiver height, which is a unique conic in 2-D plane contaning the receiver. Thus with two or more time differences, we have two or more conics that the receiver lies in. The intersection of these conics is the receiver position.

B. Estimate receiver's position without knowing signal ID

We see that with the transmission scheme of pilot signal described in the previous section, signals comes to the receiver without any information about where they are from. Usually, the signal ID as well as the position of transmitters is compulsory to be known to estimate the receiver's position. However, given the number of transmitters is sufficient, the solution explained later will alow to estimate the receiver's position without knowing the signal ID.

When a series of signals is received, the possible ID combinations of these signals can be guessed. Since the pilot signals from different LED panels are transmited in a sequential way, there is only n possible combinations of signal ID we can guess if n LED panels are used.

With k received pilot signals, we have $k-1$ time differences and the same number of unique conics that the receiver is supposed to lie in can be specified. Ideally, these conics all intersect at the same point which is the exact position of the receiver. These conics, however, usually meet in more than one point due to noises. In this case, there are up to $\binom{k-1}{2}$ intersections between these conics can be found. With the correct guessed IDs of pilot signals, these intersections are supposed to be converged. On the contrary, we are expected to get divergent intersections if the guessed signal ID is incorrect.

From the foregoing, we see the idea how the receiver's position can be estimated without knowing the exact signal ID. In detail, supposing we have n LED panels, then we have the iteration of n times guessing signal IDs. A combination of signal IDs is assumed in each iteration. According to that assumption, intersections of conics that the receiver possibly lies in are found. The variation of these intersections is also calculated. After n iterations of guessing and calculating, the correct combination of signal IDs can be identified as the one giving smallest intersection variation. Finally the correct receiver's position can be easily calculated as the mean point of the intersections coressponding to the correct signal ID combination.

IV. Simulation result

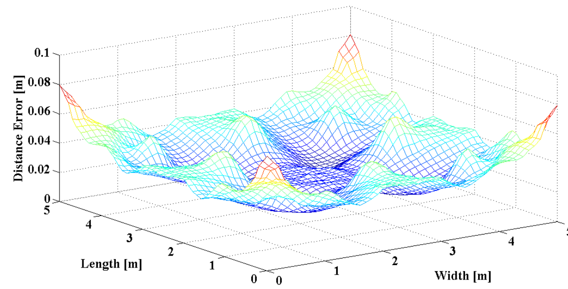
The system with the room model and LED placement described in section 2 is simulated using Matlab. In the simulation, we include all the effect of shot noise, thermal noise, and the noise caused by reflected light from the wall.

We simulate the system performance at 250×250 points equally spaced in the room. Each simulated point will be at a distance of 0.02m from its neighbours. Fig. 5a shows the distribution of positioning error in all over the room. Fig. 5b shows the histogram of the positioning error. We see that at most region in the room, the estimation error is less than 10cm. The average distance error of our system is 3.59cm.

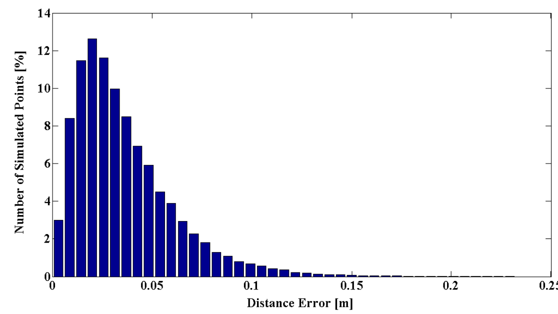
V. Conclusion

In this paper, we propose an indoor positioning system based on TDOA using the LED light. The main contribution of our proposed sytem is that no ID information about the LED panel is required to transmit along with the pilot signal. This makes the modulating pilot signal become simple. Since we use TDOA technique, it is not required that the receiver must have a good clock to retrieve the exact time of arrival of pilot signals. Also, our system uses a cheap photo diode to receive the light from LED panels. Hence, our system can be deployed easily and costlessly.

We simulate the performance of the system at all over the room measuring $5{\times}5{\times}3\ m^3$. The simulation result shows that our system can achieve a high accuracy estimation of 3.59cm in average, which is less than most existing indoor positioning system using LED light.



(a) Distribution of positioning error



(b) Histogram of positioning error

Fig. 5. The performance of the system

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