Indoor navigation and Positioning using visible light Communication

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Abstract: High power white LEDs are expected to replace the existing lighting technologies in near future which are also suggested for visible light communication (VLC). We proposed an algorithm for high precision indoor positioning using lighting LEDs, VLC and image sensors. In the proposed algorithm, four LEDs transmitted their three-dimensional coordinate information which were received and demodulated by two image sensors near the unknown position. The unknown position was then calculated from the geometrical relations of the LED images created on the image sensors. We described the algorithm in details. Simulation of the proposed algorithm was done and presented in this paper. This technique did not require any angular measurement which was needed in contemporary positioning algorithms using LED and image sensor. Simulation results showed that the proposed system could estimate the unknown position within the accuracy of few centimeters. Positioning accuracy could be increased by using high resolution image sensors or by increasing the separation between the image sensors.

Keywords: Indoor positioning, LED, Image sensor, VLC

I. INTRODUCTION

Mobile or wearable computers and augmented reality technology are finding applications in human position guidance and navigation. Commonly, GPS sensors have widely been used with these interactive technologies for navigation and positioning. For example, GPS-based positioning for wearable computers has been used in the application of outdoor augmented reality (AR). AR merges virtual objects or text information into a real environment and displays this combination in real time. Unlike virtual environments, AR supplements reality, rather than completely replacing it. This property makes AR particularly well suited as a tool to aid the user’s perception of and interaction with the real world. The information conveyed by the virtual objects helps a user perform real-world tasks.

Although AR technology combined with wearable GPS is mature, the information transmission method for wearable GPS cannot provide information indoors or in crowded urban areas since the signals from the satellite would be shielded by the armored concrete structure of the building. One might instead use active badges or beacon architectures, but installing and maintaining such systems involves substantial effort and high expense. Hence, indoor tracking system development becomes useful to seamlessly extend outdoor tracking into indoors.

Some forms of indoor positioning, such as magnetic and ultrasonic sensing, are also available, but they are normally for a short range and expensive and require complex hardware installations. Thus, there is a problem that such commercially available sensing systems for indoor tracking of mobile and wearable computers are accurate but impractical and expensive for wide areas. As a research contribution, this paper presents a novel method of indoor sensing and tracking for mobile and wearable computers by using fluorescent-light-based sensors. This system can provide indoor tracking very cheaply with an accuracy on the similar order as outdoor wearable GPS sensors and can be used in very wide indoor areas. It does not require complex installations and is thus highly practical. Wearable AR and interactive technologies can use this system as a valuable alternative for advanced indoor navigation systems.

II. TRANSMITTER SECTION

![Figure 1: Transmitter Section](image)

The hardware for the developed transmitter is shown in Figure, and the schematic circuit diagram is depicted in Figure. As shown in this figure, the electronic ballast circuit used for the transmission purpose consists of three parts: the ac–dc rectifier, the dc–ac converter (inverter), and the resonant filter circuit. The lighting of the fluorescent lamp is due to the arc current running through the lamp. When the amplitude
and frequency of the arc current is appropriate, the lamp will light up. Amplitude and frequency are the two key factors for the lamp output. Therefore, changing the frequency of the arc current may encode all the information into the fluorescent light. If the modulation frequencies are high enough, the information will be transmitted without flickering due to the characteristic of human vision. To design a very cheap and economic circuit for indoor tracking, a commercial electronic ballast system for a fluorescent lamp is modified on the circuit. As shown in Figure, the only components that added to the original circuit were a microcontroller, a low-power MOSFET, and a simple capacitor (80 pF). The MOSFET is used for switching purposes and is controlled by the microcontroller. Whenever the MOSFET is on, the 80-pF capacitor is parallelized with the original 270-pF capacitor, which will change the lighting frequency from 40 to 35 kHz. Therefore digital data can be simply transmitted through the light.

Since simple and very cheap modifications on an available electronic circuit are made, by changing the frequency, it is observed that the amplitude of the light is slightly changed as well. Consequently, after transmitting a byte such as “00001111,” a flickering effect will be sensed by normal human eyes. To solve this flickering problem, the first solution was to change design and add more components to the circuit, but it would increase the total cost of the hardware. The second solution is to solve the problem in software. Since microcontroller is used in this circuit, data can be encoded in such a way that data level frequently changes in a short time, and therefore, human eyes cannot sense the changes in the light.

One of the encoding protocols for this solution is the Manchester coding method. In this method, the signal edge in specific time periods is used to indicate the 0 or 1 logic. The bit pattern of Manchester coding is illustrated in Fig. 4. To transmit a byte using this code, a start pattern is sent first to synchronize the receiver. After sending the start pattern, the 8-bit data are transmitted. Figure shows a coded serial data pulse corresponding to the byte “01110001.” In this system, the signal period $T_{sw}$ is 1 ms. It is quite easy for almost all types of microcontroller to respond during this period. Bit 1 to stand for the frequency shifting from 40 to 35 kHz and bit 0 to stand for the shifting from 35 to 40 kHz. Note that the period of every bit is 2 ms ($2 \times T_{sw}$) with a 0.5 duty cycle. Therefore, the total time taken for transmitting a byte is $8 \times 2 + 6 = 22$ ms. This means that the average data rate for this system will be $8/22$ ms = 363 b/s.

### III. RECEIVER SECTION

The receiver detects the fluorescent light and transforms the analog signals to the digital ones that can be sent to the user’s mobile/wearable device. Figure shows the block diagrams of the receiver part with a wearable computer. The core part of this receiver system is the receiver circuit, which is shown in Figure. As can be seen in Figure, the main parts of the receiver circuit are as follows:

- **a)** Bandpass filter: The bandpass filter is designed to remove noise that is received together with the Manchester-coded information in the light.
- **b)** Zero-crossing detector: This block converts the analog input signal to digital signal. Note that only the frequency of the signal contains information and not its amplitude.
- **c)** Phase-locked loop (PLL): This block converts the incoming digital signal to an analog voltage proportional to the frequency of incoming signal.
- **d)** Comparator: Finally, a comparator in the last stage to compare the voltage level of the PLL output to see whether the incoming frequency is for the 35-kHz or 40-kHz signal.

The light sensor, i.e., photodetector 2N5777(MOD), which is to provide an output voltage proportional to the light level, is used in receiver system to detect the output from the fluorescent lamp in this prototype. Because the light intensity detected by the photo detector varies with the arc voltage magnitude and not by its phase, the received signal frequency is doubled. While the arc frequency is from 35 to 40 kHz, the received signal’s frequency is from 70 to 80 kHz. Figure presents the comparison between the arc voltage waveform of the lamp and the band pass filter output, which clearly shows that the frequency is doubled when the light is detected.
Figure shows the output of the band pass filter and how clearly it smoothens the signals received by the photo detector, and Figure displays the result of digitizing after the zero-crossing block.

The output of the receiver circuit in comparison with the data output from the microcontroller in the transmitter circuit is illustrated in Figure. As can be seen from this figure, the received information is exactly the same as the original digital signals but in negative logic. Note that since all these waveforms are directly measured on the printed circuit board, the signals are mixed with noise.

IV. CONCLUSION

In this paper, we propose an algorithm for indoor positioning using lighting LED array and image sensors. White LEDs are used as optical transmitters in which at least four spatially separated non-collinear LEDs send their known position information. The image sensors located at the unknown position receive and demodulate the light signal through lenses. The unknown position is then calculated using the geometric relations of the LED image distances. Mathematical formulations for the proposed algorithm are discussed in details. A series of simulations are explained to understand the positioning error characteristics. Simulation results indicate that by using the proposed algorithm, the positioning error can be minimized within the range of a few centimeters. The proposed technique has the benefits of device simplicity.

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