An Indoor Positioning System Based on Visible Light Communication Using a Solar Cell as Receiver

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Abstract. This paper studies an Indoor Positioning System (IPS) based on Visible Light Communication (VLC) using the solar cell as an optical receiver unlike conventional receivers. Due to the advantage of the solar cell such as: low cost, flexibility, and high light sensitivity, the proposed system is capable of simultaneous communication and energy gathering. The studied system is considered like an environmentally friendly and a promising technology in the next years.

Keywords: Visible light communication · IPS · Solar cell · Energy gathering Trilateration

1 Introduction

The operation of positioning people and objects has always been important and will be more important in the next years. The recent technology to detect targets is the visible light communication (VLC), where it's very remarkable [1] as a new type of wireless communication technology with less energy consumption. In addition, the no effected to Electromagnetic Interference (EMI) allows VLC to be applied in many sectors like hospitals, airplane, smart cities, smart homes, offices, etc., where the radio frequency (RF) communication is in interference with equipment's signals. Hence, VLC has attracted many interests recently [2–5]. Classical receivers used in VLC systems are (PIN) photo-diode (PD) or avalanche photodiode (APD). Energy harvesting and signal detecting system is a new conception which was proposed in [6] as a solar-panel VLC receiver system and in [7] the authors used a solar cell as a simultaneous receiver of solar power and visible light communication (VLC) signals. Besides, the modulated VLC optical signal can converted into electrical data signal without having to supply external power, by the solar cell arrays or solar panels Rx. This electrical signal can be

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used to fill the battery of the receiver. It should be noted that the silicon-based solar cells can receive VLC data and recover energy at the same time. In our work, to locate the receiver we uses Trilateration technique and to estimate the receiver's distance from transmitters on the ceiling, the information from the received signal is used. Unlike conventional VLC positioning system, a solar cell is used as a positioning receiver. The Field Of View (FOV), light sensitivity and detection area are significantly enhanced compared to the performance of PIN Photodiode (PD). In addition to needless of external power supply, it can provide energy efficiency to the receiver side [8]. This work can be exploited for asset and people tracking in several indoor sectors as tracking patients in hospitals or security guards in malls. A study of I-V and P-V curves of solar cell under visible light is done, a similar model to the real lighting conditions are solved with MATLAB simulations. The results indicate that we can receive data and collect energy by the same solar cells.

2 Proposed Model of Visible Light Positioning System

2.1 Description Model

The proposed model of the visible light positioning system is shown in Fig. 1, where a four LEDs function as transmitters placed on ceiling. The LEDs transmit a unique ID signal to the receiver using the On-Off-Keying (OOK) modulation. The location of the receiver can be estimated after demodulating the ID signal from four LEDs. When the target moved, a new ID signal will be detected, hence a new position can be estimated due to the varying of the received power with the distance between receiver to LEDs. The assumed distance between the 2×8 solar cell array and the 15 W LED is 2 m.

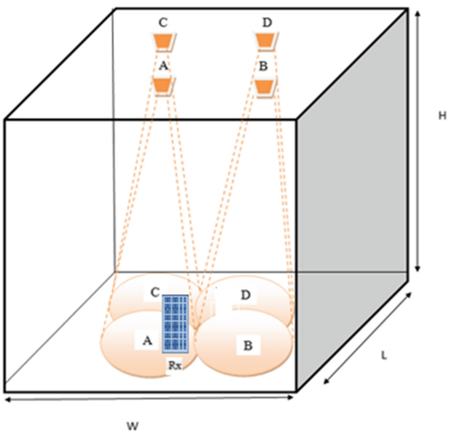

Fig. 1. Proposed model.

2.2 Model Analysis

In order to analyze relationship of the LED's transmitter model and the solar cell detector an approximation is formulated.

2.3 LED Light Model

According to [9], the channel DC gain is given by

$$H(0)_{LOS} = \begin{cases} \frac{m+1}{2\pi d^2} A_s \cos^m(\phi)\cos(\psi)T_s(\psi)g(\psi), & 0 \le \psi \le \psi_c \\ 0, & \psi > \psi_c \end{cases} \tag{1}$$

Where A_s is the physical area of the photodetector, ψ is the angle of incidence with respect to the receiver axis, ψ_c is the field of view (FOV) of detector, ϕ is the angle of irradiance with respect to the transmitter perpendicular axis and d is the distance between transmitter and receiver. The Lambertian order m is given by: $m = -\frac{\ln 2}{\ln\left(\cos \phi_{\frac{1}{2}}\right)}$ and $\phi_{\frac{1}{2}}$ is the half power angle of the LED bulb. $T_s(\psi)$ is the gain of optical filter, $g(\psi)$ is the optical concentrator gain.

The total received optical power of i LEDs is given by

$$P_{rx,LOS} = \sum_{i=1}^{LEDs} P_{tx} H^i_{LOS}(0) \tag{2}$$

2.4 Solar Cell Model

The model of the solar cell shown in Fig. 2 can be expressed as [10]

$$I = N_p I_p - I_0 \left\{ \exp\left[\frac{q(V + IR_s)}{N_s AKT}\right] - 1 \right\} - C\frac{dV}{dt} - \frac{V + IR_s}{R_{th}} \tag{3}$$

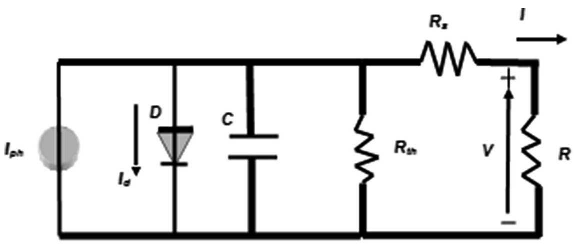

Fig. 2. Typical solar cell model.

Where N_p is the number of solar cells in parallel, N_s is the series number, I_p is the light current, I_0 is the diode saturation current, V is the output voltage of solar cell, I is the output current, and A is a constant which is typically in the range 1 to 3, assuming that

$$K_0 = \frac{AKT}{q} \tag{4}$$

As $R_{th} \gg R_s$, (3) can be written by

$$I = N_1 I_p - I_0 \left\{ \exp\left[\frac{(V + IR_s)}{N_2 K_0}\right] - 1 \right\} - C\frac{dV}{dt} \tag{5}$$

I_p is positively proportional with received illuminance power for solar cell, hence,

$$I_p = \frac{S}{1000} I_{sc} \tag{6}$$

Where S is the illuminance power of solar cell. I_{sc} is the short circuit current. All the parameters are considered in Standard Test Conditions (STC). The solar cell worked in the open state if $I = 0$, (5) becomes

$$N_p I_p = I_0 \left[\exp\left(\frac{U_{oc}}{K_0 N_s}\right) - 1\right] \tag{7}$$

Hence,

$$I_0 = \frac{N_p I_p}{\exp\left(\frac{U_{oc}}{K_0 N_s}\right) - 1} \tag{8}$$

2.5 Overall System Model

In the case where $P_r = S$, the two precedent models can be connected. Hence, by combining (5), (6) and (7) the final relationship between U of solar cell side and LED power side can be expressed as

$$U = \begin{cases} P_t \frac{m+1}{2\pi d^2} \cos^m(\phi) \cos(\psi) T_s(\psi) g(\psi) \frac{1}{K_1} \left[1 - \frac{1}{K_2 R_h} \exp\left(\frac{U}{K_3}\right)\right], & 0 \le \psi \le \psi_c \\ 0, & \psi > \psi_c \end{cases} \tag{9}$$

Where R_h is the load resistance of solar cell, K_1, K_2 and K_3 are constants depended of parameters N_p, N_s, I_{sc} and U_{oc}.

3 Principle of Positioning

Using Trilateration technique in order to locate the target by calculating the accurate position and to achieve the distance a received signal power is exploited. Applying the linear least square estimation for 2-D positioning, the receiver location is obtained [11].

$$(x - x_A)^2 + (y - y_A)^2 = d_A^2 \tag{10}$$

$$(x - x_B)^2 + (y - y_B)^2 = d_B^2 \tag{11}$$

$$(x - x_C)^2 + (y - y_C)^2 = d_C^2 \tag{12}$$

$$(x - x_D)^2 + (y - y_D)^2 = d_D^2 \tag{13}$$

Where $[x_A, x_B, x_C, x_D]$ and $[y_A, y_B, y_C, y_D]$ are the coordinates of LEDs, $[d_A, d_B, d_C, d_D]$ are the horizontal distances from the receiver to LEDs, (x, y) is the receiver's position to be estimated.

4 Results and Discussion

The solar cell AM-5308 parameters are chosen for this work, according to Eqs. (5), (6) and (7) we represent our curves. Figure 3(a) represents I-V curves for different solar cell arrays, noting that the Open Circuit Voltage U_{oc} for 4 × 4 array is half of values for 4 × 8 U_{oc} and the short circuit current I_{sc} for 2 × 8 array also is half of values for 4 × 8 of I_{sc}. The values of U_{oc} of 2 × 8 and 4 × 8 are between 3 to 3.5 V, which it's enough to charge Lithium battery. Figure 3(b) shows I-V curves of 2 × 8 array under different illumination 300, 500 and 1000 Lx, which is according to the International Organization for Standardization (ISO) from 300 to 1500 Lx, where it is sufficient for office work [12].

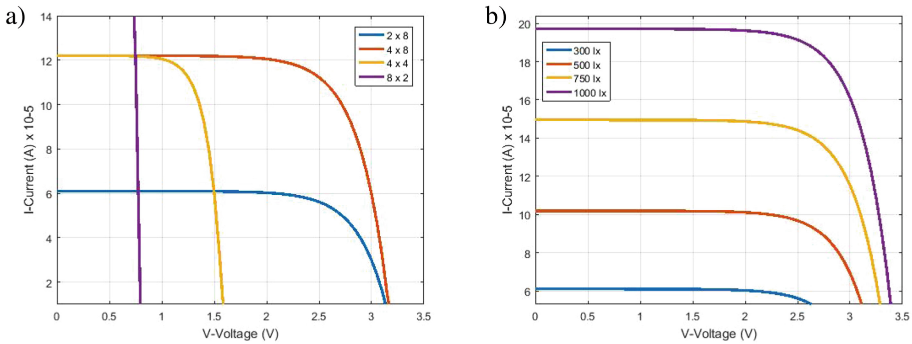

Fig. 3. (a) I-V curves for different solar cell arrays, (b) I-V curves with different illumination of 2 × 8 array (T = 298 K).

In Fig. 4(a) a P-R curves for different solar cell arrays are illustrated. The resistance corresponding for output power 1.4×10^{-4} W under 300 Lx is 50 $k\Omega$. Power properties of 2×8 array under different illumination values are simulated in Fig. 4(b). The amplitudes recorded from the four frequencies transmitted by LEDs are used to get the distance between Rx and each LED. In order to obtain the results of positioning it is necessary to solve the equations system (10), (11), (12) and (13). The estimated position of the target at the center is illustrated in Fig. 5. Due we need a value at 500 Lx of the illuminance of the typical room, an enhance of illuminance of LED lamps must done.

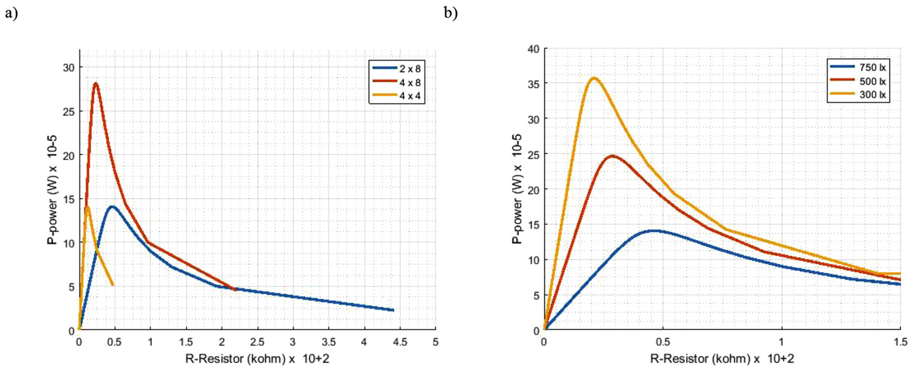

Fig. 4. (a) P-R curves for different solar cell arrays, (b) P-R curves with different illumination of 2×8 array (T = 298 K).

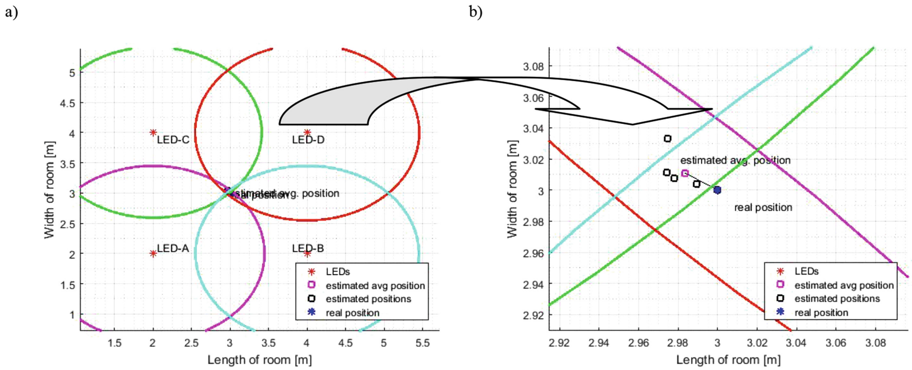

Fig. 5. Results using Trilateration positioning method at the center: (a) Global view, (b) Eye diagram

5 Conclusion

In our work we studied an indoor positioning system using solar cell as an optical receiver unlike conventional VLC positioning system. As we know the solar cell is a passive component, hence it does not require an external power supply and this is the difference compared with the PIN photodiode PD. Energy gathering and VLC signal detection simultaneously can be realized. The Trilateration technique and the ID signal information are used in this paper to achieve a suitable accuracy. The studied receiver can be integrated with wearable device to obtain an indoor positioning device with low cost and eco-friendly. Many factors were ignored in this model like response of solar cell to frequency and the channel impact, in the next works we take them into consideration and an optimization of the model will be done.

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