Positioning Using Visible Light Communication Footprints

Paula Louro, Manuela Vieira, Manuel Augusto Vieira
DEETC/ISEL/IPL,
R. Conselheiro Emídio Navarro, 1959-007
Lisboa, Portugal
CTS-UNINOVA
Quinta da Torre, Monte da Caparica, 2829-516,
Caparica, Portugal

e-mail: plouro@deetc.isel.pt, mv@isel.ipl.pt, mv@isel.pt

Pedro Vieira
DEETC/ISEL/IPL,
R. Conselheiro Emídio Navarro, 1959-007
Lisboa, Portugal
Instituto das Telecomunicações
Instituto Superior Técnico, 1049-001,
Lisboa, Portugal
pvieira@isel.pt

Abstract— **Global Positioning System (GPS) cannot manage indoor positioning because the strong attenuation of the signal by walls and infrastructures results in a lack of signal or poor accuracy. Oher technologies based on RF, optical, magnetic or acoustic signals can be used for this purpose. Visible Light Communication (VLC) is a good alternative, providing good positioning accuracy. In this work, we propose a system using commercial tri-chromatic LEDs that illuminate and transmit modulated data that is used to infer the user's position. The receiver is based on a dedicated pinpin heterostructure photodiode with selective response in the visible spectrum. The positioning system includes multiple, identical navigation cells. In each cell, the optical pattern created by the VLC transmitters defines specific spatial areas which are assigned to different optical excitations determining the cell footprints. The photocurrent signal measured by the photodetector is demodulated and decoded to provide identification of input optical excitations and enable position detection. The footprint model is evaluated under Line of Sight (LoS) conditions, assuming the Lambertian model for the LED light distribution. The channel gain is computed adjusting the model parameters related to gains and losses to experimental data to calibrate the system. Bit decoding algorithm provides data transmission recovery. Experimental data obtained in a prototype model scale confirms that the proposed VLC architecture is appropriate for indoor positioning application.**

Keywords*- Visible Light Communication; positioning;white LEDs; navigation cell; footprint map.*

I. INTRODUCTION

Indoor positioning can be addressed by several technologies based on the use of different techniques [1][2]. Visible Light Communication (VLC) is a good alternative since white lighting solutions based on LEDs have become commonplace in most buildings.

VLC is a technology based on the use of visible light in the 400 to 800 THz for the visible light from 750 to 400 nm [3][4]. The main advantages of VLC are its wide bandwidth, free and unlicensed spectrum, lack of electromagnetic interference, communication security, human health safety, and compatibility with other technologies. VLC systems use modulated LEDs to transmit information and single photodiodes or camera devices in the receiver units.

In this paper, we propose the use of a multilayered a:SiC:H [5] device to perform the photodetection of the optical signals generated by white trichromatic RGB LEDs [6], [7]. The system was designed for guidance [8][9], and the emitters of each white LED were specifically modulated at precise frequencies and coding bit sequences [10][11]. The proposed lighting and positioning/guidance system involves wireless communication, computer-based algorithms, smart sensor and optical sources network, which constitutes a transdisciplinary approach framed in cyber-physical systems. The paper is organized as follows. After the introduction (Section I), the VLC system architecture is presented in Section II. In Section III, models for the footprint characterization using both geometrical and propagation assumptions are analyzed. In Section IV, the communication protocol and the encoding/decoding techniques are analyzed and discussed. At last, conclusions are addressed in Section V.

II. VLC SYSTEM SPECIFICATIONS

The specifications od the VLC system described in this paper include the characterization of the transmitter and receiver units, respectively with the optical signal sources and the dedicated photodiode. Besides, the characterization of the channel will also be discussed using the Lambertian model do describe light propagation from the LEDs in Line-of Sight conditions.

A. VLC Transmitter and Receiver Units

The transmitter uses commercial white LEDs with tri-chromatic emitters (red, green, and blue). In the lamp, four white LEDs are arranged in a square geometry with a quadrangular topology (Figure 1).

Only one emitter of each white LED is modulated. Other emitters operate only with DC current to provide white color illumination [12]. In this specific case, the modulated emitters are the red emitters of the LEDs on the left side of the lamp, and the blue emitters on the right side.

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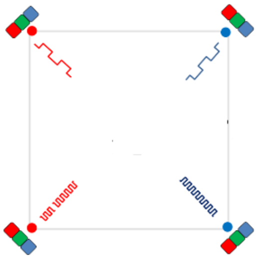

Figure 1. Configuration of the VLC emitter with 4 RGB white LEDs.

The pinpin photodiode of the receiver unit transduces light into an electrical signal that can be demodulated and decoded. This device is a monolithic heterojunction composed of two pin structures based on a-Si:H and a-SiC:H built on a glass substrate and sandwiched between two transparent electrical contacts. The front structure based on a-SiC:H absorbs mainly the short wavelengths (violet and blue), while the back structure based on a-Si:H absorbs the long waveleng8ths (red). Intermediate wavelengths as green light are absorbed by both pin structures, A reverse bias (-8 V) and short wavelength (400 nm) illumination are used to tune the device selectivity externally.

B. *Channel*

LEDs are modeled as Lambertian sources with uniform distribution of luminance in all directions, and luminous intensity dependent on the direction. The luminous intensity for a Lambertian source is given by the following equation [13]:

$$I(\phi) = I_N \cos^m(\phi) \qquad (1)$$

where m is the order derived from a Lambertian pattern, I_N is the maximum luminous intensity in the axial direction and ϕ is the angle of irradiance. The Lambertian order m is given by:

$$m = -\frac{\ln(2)}{\ln(\cos(\phi_{1/2}))} \qquad (2)$$

As the half intensity angle ($\phi_{1/2}$) is of 60º, the Lambertian order m is 1. The light signal is received by the photodetector, generates a binary sequence of the received signals and convert data into the original format. It is assumed Line of Sight (LoS) conditions, which considers that the signal propagation occurs in a direct path from the source to the receiver.

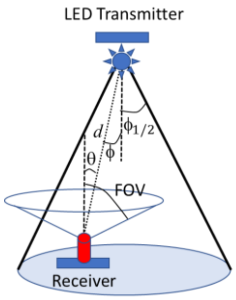

Figure 2. Transmitter and receiver relative position.

Figure 2 shows the relative position of the transmitter and receiver units with specification of the geometrical parameters needed to infer the signal coverage of the LED in the illuminated indoors space [14].

The channel gain (G) of this VLC link given by equation [15]:

$$G = \frac{(m+1)A}{2\pi d^2} I_N \cos^m(\emptyset)\cos(\theta) \qquad (3)$$

where A is the area of the photodetector, d the distance between the emitter and the receiver, and FOV the field of view of the detector (angular extension for signal detection).

Figure 3 illustrates the coverage map produced when only the red and blue emitters of each LED are used for data transmission.

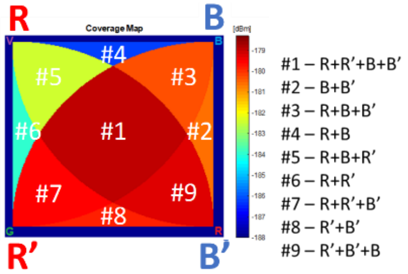

Figure 3. Coverage map of the fine-grain footprint inside the navigation cell, considering as VLC optical sources the top red and bottom blue emitters.

The optical signal produced by each modulated LED confers a maximum of delivered power signal at the central region of the cell, that receives contribution from four modulated channels. The regions at the corners contain optical signals from three LEDs, exhibiting a decrease on the received power signal, while the side regions correspond to the lowest values of received power. Each of these regions constitute footprints of the delivered power. Each footprint region labelled as #1, #2, …, #9 is assigned to the correspondent optical excitation illustrated on the right side of Figure 3.

III. POSITIONING ALGORITHM

The positioning algorithm is based on the identification of the navigation cell and on the footprint where the mobile user is located. Thus, bit coding of the information transmitted by each modulated emitter and bit decoding at the receiver is mandatory to infer from the multiplexed signal at the receiver the input optical signals and the correspondent identification of the cell and footprint.

A. *Coding and modulation*

The data is converted into byte format and then converted into light signals emitted by the VLC transmitter. On–Off Keying (OOK) modulation is used to modulate the data bit stream. To ensure proper coding and decoding at the transmitter and receiver units, the data format used to transmit information, namely the length of each frame, the blocks that make up each word and its contents, is previously defined. The communication codes use 64 word frames. The structure of the data frame used in each channel is displayed in Figure 4. Transmitted data can have a passive role (standard mode) with continuous transmission of lamp identification to ensure positioning, or an active role (request mode) transmitting additional information to guide the user.

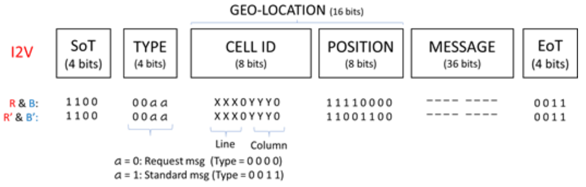

Figure 4. Data frame structure the coded word.

The TYPE block (4 bits) is used to identify the type of transmitted message, either if it is to acknowledge the reception of any request or to transmit updated information. This block is transmitted equally by all active emitters of the transmitter (R, R', B and B'). The GEO-LOCATION block of the I2V channel has 16 bits and can be divided into two sub-blocks. A block of 8 bits with the identification of the cell (CELL ID block) and a second block of 8 bits with the position inside the cell (POSITION block). The block labelled as CELL ID is a word of 8 bits. It provides the identification of the unit navigation cell. The format of the word code is XXX0YYY0, where XXX addresses the line and YYY the column of the cell. The block POSITION (8 bits) is encoded with 4 bits set to 1 and 4 bits set to 0 in channels R and B, while, for the bottom emitters, R' and B', the frequency of this word is doubled, corresponding to the sequence of 2 bits set to 1, 2 bits set to 0, 2 bits set to 1 and 2 bits set to 0. This block provides accurate position information inside the navigation cell. The MESSAGE block (36 bits) contains different blocks depending on the type of message being transmitted. In the request mode it contains info to guide the user inside the building and additional bits reserved for future transmission specifications. In acknowledge mode the block is initially set to null, containing also additional reserved bits.

B. *Bit decoding*

In the receiver unit, it is necessary to decode the photocurrent signal, which identifies the footprint inside the cell and, therefore, enables the determination of the position. To establish this assignment, a calibration curve is defined beforehand. In Figure 5, the calibration curve is plotted with 16 different photocurrent thresholds resulting from the combination of the four modulated signals from the white VLC emitter.

Different levels of photocurrent were generated by adjusting the driving current of the LED emitters. On the top it is displayed the waveform of the emitters modulation state used to produce the calibration curve. The right hand side of Figure 5 illustrates how each footprint corresponds to a photocurrent level. The correct use of this calibration curve demands a periodic retransmission of curve to ensure a accurate correspondence to the output signal and an accurate decoding of the transmitted information.

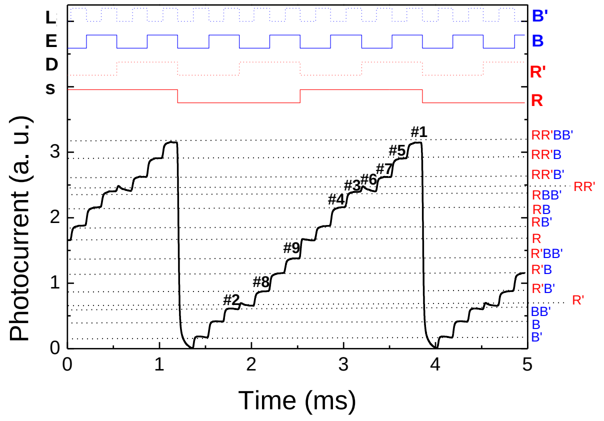

Figure 5. Calibration front photocurrent signal using two red and two blue optical signals modulated with multiple frequencies.

IV. RESULTS AND DISCUSSION

In Figure 6, the photocurrent signal measured by the mobile receiver unit is depicted at two different locations within the cell covered by RR'BB' and R'BB' optical signals, which correspond, respectively, to footprints labelled #1 and #9.

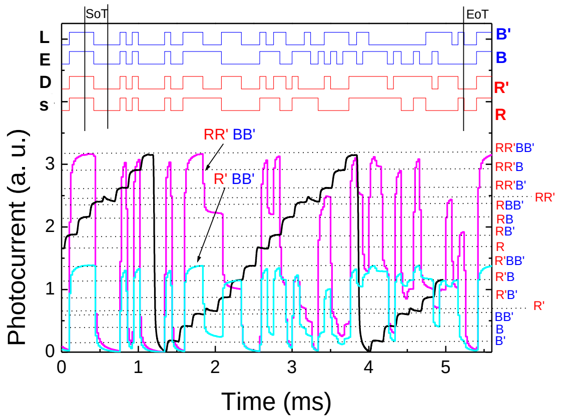

Figure 6. Photocurrent signal measured by the mobile receiver unit at footprints #1 and #9 inside the navigation cell (RR'BB' and R'BB'). The calibration curve is displayed in the background.

On the right side of the graph it is stated the optical state assigned to each step of the calibration curve. Frame synchronization is detected by the blocks SOT and EoT. Due to the simultaneous operation of all emitters in both measurements, either inside footprints #1 and #9 (RR'BB' and R'BB'), the presence of these blocks corresponds to maximum values of the photocurrent. To decode the photocurrent levels, the calibration curve is used to identify which emitters are active during the duration period of each bit. Input optical signals are decoded based on the observed correspondence between the different thresholds of the measured signal and the calibration steps. When threshold levels are close, decoding errors are more likely, which requires error control techniques.

V. CONCLUSIONS

In this paper, a VLC system for indoor positioning and guidance was presented. A theoretical analysis of irradiation patterns is presented to establish the footprints of the cells and support the position accuracy of the proposed system.

The Lambertian model was used to describe the light distribution. Each footprint of the cell was predicted using the channel gain model of the transmitter-receiver link.

Predicted results of the MatLab simulations were supported by experimental data measured with a laboratory prototype. Future work will comprise a more detailed and complete description of the decoding methodology.

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