Navigation Cells Based on Visible Light Communication for Indoor Positioning

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Abstract—**White Light emitting Diodes (LEDs) revolutionized the field of illumination technology, mainly due to energy efficiency. In addition, LEDs can also be used in wireless communication systems when integrated in Visible Light Communication (VLC) systems. Indoor positioning for navigation in large buildings using Global Positioning Service (GPS) systems is limited by signal attenuation. The motivation for this application is also supported by the possibility of taking advantage of an existing lighting and WiFi infrastructure. In this work, we propose an indoor navigation system based on the use of VLC technology. The proposed system includes tri-chromatic white LEDs with the red and blue chips modulated at different frequencies and a pin-pin photodetector with selective spectral sensitivity. Optoelectronic features of both optical sources and photodetector device are analyzed. The photodetector device consists of two pin structures based on a-SiC:H and a-Si:H with geometrical configuration optimized for the detection of short and large wavelengths in the visible range. Its sensitivity is externally tuned by steady state optical bias. The localization algorithm makes use of the Fourier transform to identify the frequencies present in the photocurrent signal and the wavelength filtering properties of the sensor under front and back optical bias to detect the existing red and blue signals. The viability of the system was demonstrated through the implementation of an automatic algorithm to infer the photodetector cardinal direction.**

Keywords- amorphous SiC; optoelectronic; spectral sensitivity; white LEDs; visible light communication; indoor positioning.

I. INTRODUCTION

Indoor lighting is being driven by white LED luminaires that provide high efficiency, low power consumption and long life span [1]. This provided a large development of the LEDs market for lighting purposes. Additionally, LEDs can switch to different light intensity levels at a very fast rate, which can be used for communication where data to be transmitted is encoded in the emitting light supplied by the LED. This is the basis of Visible Light Communication (VLC) [2][3][4], which is a technology holding an increasing importance as the visible light spectrum corresponds to license free bandwidth. Besides, it is a line of sight technology, and consequently not prone to interference. This confers high reliability for secure wireless communication [5]. Moreover, the reuse of the lighting infrastructure for the additional functionality of data communication is a very attractive advantage. Currently, VLC is considered an attractive technology to complement the RF-based mobile communications systems [6][7][8][9].

VLC applications were initially developed to supply access network in homes, but rapidly progressed to support hand-held devices and transport vehicles [10][11][12]. Other fields where VLC is growing include indoor localization, human computer interaction, device-to-device communication and vehicular applications. Outdoor location services are largely dependent on Global Positioning System (GPS). However, for indoor scenarios this technology is no longer feasible due to the strong attenuation of the GPS signal. Thus, alternative solutions are demanded. Currently, indoor localization technology is based on WiFi and VLC. Main difference between the use of these technologies is related to the location accuracy. In WiFi, the accuracy is limited by the number of available wireless access points, while in VLC it is determined by the number of LED luminaires. As, typically in a building, there are 10 times more LED luminaires than the number of WiFi access points, the accuracy is naturally improved using VLC. Most of the location approaches based on VLC described in literature report the use of LED sources transmitting specific identity and location information and receivers that detect the transmitted signal by multiple optical sources. Based on the distance evaluation, trilateration is used for location assessment.

In this paper, we propose an indoor localization system [13] designed with white RGB LEDs and a heterostructure pinpin photodiode based on a-SiC:H/a-Si:H with a simple On-Off modulation scheme. The tri-chromatic LEDs provide three channels for data transmission. Blue and red emitters are modulated at two different specific frequencies that correspond to different cardinal directions. The green emitter is used for identification of the LED transmission unit [14][15]. The photodetector is designed for operation in the visible light spectrum. The different bandgap semiconductors of each active region of the pin structures allow selective absorption of the light spectral components [16][17]. This is used in the decoding strategy to infer the optical signals received by the photodetector [18].

The proposed lighting and positioning/navigation system involves wireless communication, computer-based algorithms, smart sensor and optical sources network, which constitutes a transdisciplinary approach framed in cyber-physical systems.

The rest of the paper is structured as follows. In Section II, the design of the VLC system is described. Section III contains results and respective discussion. Section IV presents main conclusion and a few guidelines for future work.

II. DESIGN OF THE VLC SYSTEM

The proposed VLC system includes an indoor scenario of infrastructure-to-device communication. The LED luminaires are used to perform three tasks, namely, room illumination, position/navigation services and data transmission.

The proposed system is composed by the transmitter and the receiver modules, located respectively at the infrastructure and at the device. The transmitter includes white RGB LEDs, the coder and the modulator. This unit is responsible for the modulated optical transmission of coded data. The receiver consists of the photodetector, the demodulator and the decoder. The transmission channel of the optical link is free space propagation with the constraint of line of sight condition.

The transmitter proposed in this VLC system uses ceiling lamps based on commercial white LEDs with red, green and blue emitters (w-RGB LEDs). Each LED luminaire at the ceiling is composed by four white LEDs framed at the corners of a square (Figure 1).

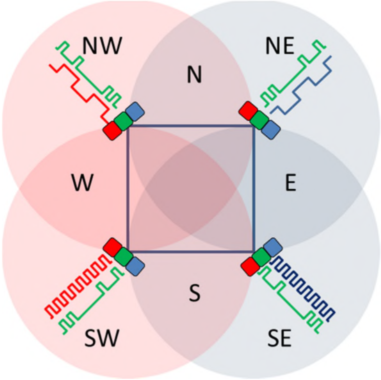


Figure 1. Configuration of the LED luminaire.

Each navigation cell is assigned to a unique identifier supplied by the green emitters that make the correspondence between the device and the emission area. Increased position accuracy within each navigation cell is obtained through the modulation of the blue and red emitters of the luminaire LEDs that map different spatial regions by the correspondent illumination pattern. The top emitters, assigned to the north direction, are modulated at half frequency of the bottom emitters, assigned to the south direction. The left emitters (west direction) are the red emitters while the right emitters (east direction) are the blue chips of the RGB LEDs.

The optical sources used for the dual function of lighting and data transmission through VLC are commercial RGB white LEDs of high intensity light output and wide viewing angle. Data from datasheet specifications indicate peak wavelengths located in the ranges 619 nm – 624 nm, 520 nm – 540 nm and 460 nm – 480 nm for the red, green and blue emitters. The codification of the optical signals includes the transmission of information related to navigation data and to the message to broadcast.

In every transmission channels each frame is a word of 32 bits, divided into four blocks: START SYNC block (4 bits), INFO block (8 bits), MESSAGE block (16 bits) and STOP SYNC BLOCK (4 bits).

An on-off keying modulation scheme was used with a 32-bit codification (logical state 1: light on and logical state 0: light off). A dedicated three channel LED driver with multiple outputs was developed to modulate the optical signals. The modulator converts the coded message of each transmission channel into a modulated driving current signal that actuates the emitters of each tri-chromatic white LED. In every LED, the driving current of each emitter is controlled independently of the other emitters.

The photodetector used for the transduction of the optical signal is a monolithic heterojunction composed by two pin structures built on a glass substrate and sandwiched between two transparent electrical contacts (Figure 2).

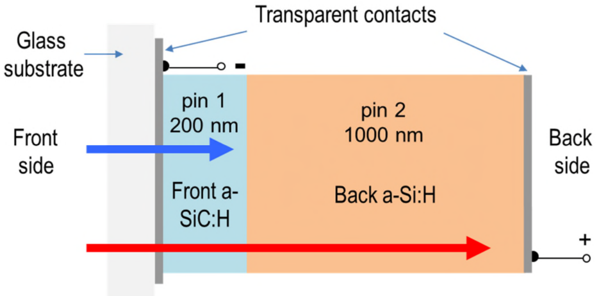


Figure 2. Configuration of the photodetector at the receiver module.

The intrinsic absorbers of the device are based on a-Si:H and a-SiC:H, which provide high sensitivity in the visible range. Both intrinsic layers were designed to detect separately short and long visible wavelengths. The front intrinsic layer is narrow (200 nm) and exhibits a higher bandgap material (2.1 eV, a-SiC:H). The back intrinsic layer is thicker (1000 nm) and has a lower bandgap semiconductor (1.8 eV, a-Si:H). This design confers high absorption of the blue light (shorter wavelengths) and high transparency of the red wavelength to the front absorber (pin 1) and high absorption of longer wavelengths (red light) to the back absorber (pin 2).

The filtering properties of the pinpin photodetector assigned to each pin structure are demonstrated in Figure. 3, that displays the transient photocurrent output of the device under excitation of the RGB white LEDs using different optical biasing conditions (back and front optical bias of 400 nm and no optical bias).

As shown in the graph of Figure 3, the photocurrent signals for each optical excitation show different trends dependent on the optical biasing conditions. Long wavelength light from the red and green emitters are amplified under front optical bias and attenuated (70%) under back optical bias. For the short wavelengths (blue light), the photocurrent signal is increased when the optical excitation is on the back side and attenuated from the front side.

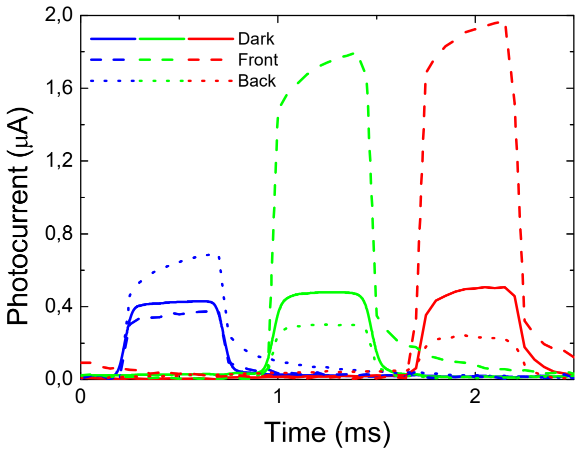


Figure 3. Transient photocurrent output of the photodetector under excitation of the RGB white LEDs using different optical biasing conditions.

The quantification of the signal amplification under front and back bias is determined by the optical gain, defined at each wavelength as the ratio between the signal magnitudes measured with and without optical bias. For the red, green and blue light the front optical gain under violet background light is, respectively, 5, 3.5 and 1.3, while for the back optical gains, the values are 0.6, 0.6 and 1.7.

The decoding unit processes the output signals, measured with front and back optical bias, incoming from the oscilloscope to extract the input optical signals. The decoding strategy starts with the identification of the triggering event, given the idle and start bits, that ensures the synchronization of the process. Then, it follows the identification of the unit navigation cell, which demands the extraction of the green signal from the multiplexed signal. After this identification, the green signal contribution is subtracted from the front and back photocurrent signals. Then, the next 8 bits assigned to the position INFO word of both front and back photocurrents are processed to evaluate the modulus of the complex Fourier coefficients. When the calculated coefficient is above a certain threshold the signal is considered to be present at the respective frequency, otherwise it is discarded. The photocurrent signals measured under front and back optical bias are used to infer, respectively, the red signal and the blue optical signals. This procedure allows the identification of the wavelengths and frequencies assigned to the optical excitations, which corresponds to a specific spatial position. The next 16 bits contain the message transmitted by each emitter channel. It is decoded using the front optical photocurrent to identify the red contribution and the back photocurrent signal to classify the blue excitation.

III. RESULTS AND DISCUSSION

A. Information coding

The test case used to validate the proposed communication scheme is displayed in Figure 4 that shows the specific words sent in the Position INFO and DATA blocks of each emitter, which correspond to the second and third blocks, respectively.

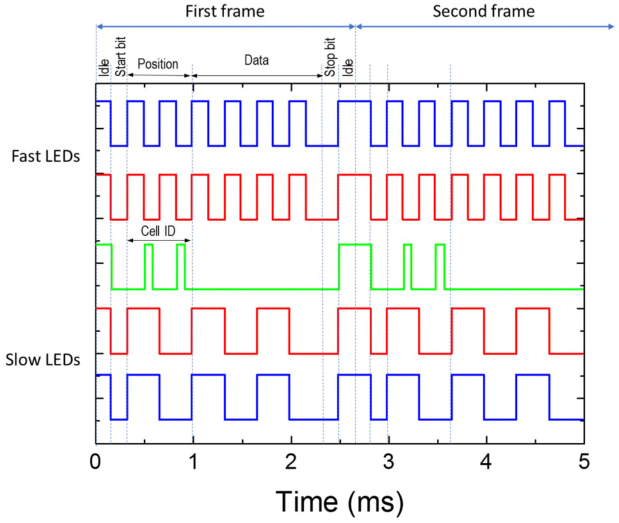
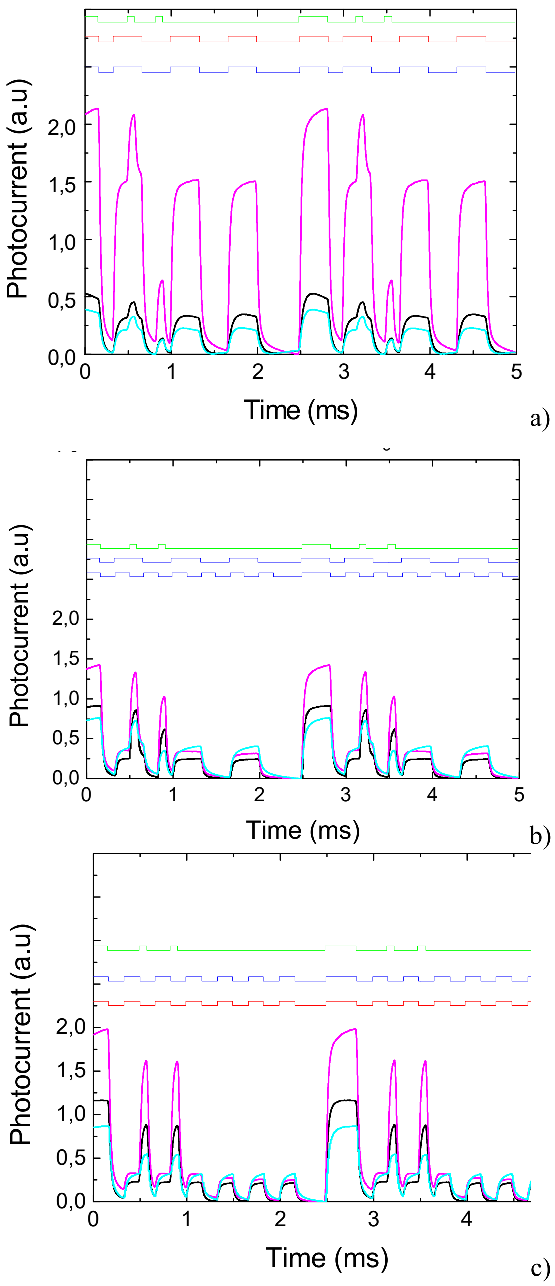


Figure 4. Codification of the optical signals in test conditions.

The Position INFO word is set to the code word 10101010 in the fast emitters, to 11001100 in the slow emitters and to 00100010 in the green emitter, corresponding therefore to the navigation cell located in line 1 and column 1. The DATA word is set to 00000000 in the green channel, as predicted by the adopted codification scheme and to the words 11001100 and 10101010 in the slow and fast emitters, respectively.

Figure 5 displays the acquired photocurrent signal by the pinpin photodiode, biased at -8 V and under variable conditions of optical bias (without and with front/back steady state background light).

The signal was acquired in different positions of the navigation unit cell, exhibiting in each case a different pattern due to different lighting excitations. In all graphs the trigger event allows easy synchronization and identification of each transmitted frame. This is clearly noticeable by the high peaks of the front photocurrent (represented in the graphs by the magenta line), as in the idle bits all emitters are set to ON and this combination results in photocurrent amplification when the device is soaked by steady state illumination from the front side. In contrast, the same signal under back background light is decreased.



a)

b)

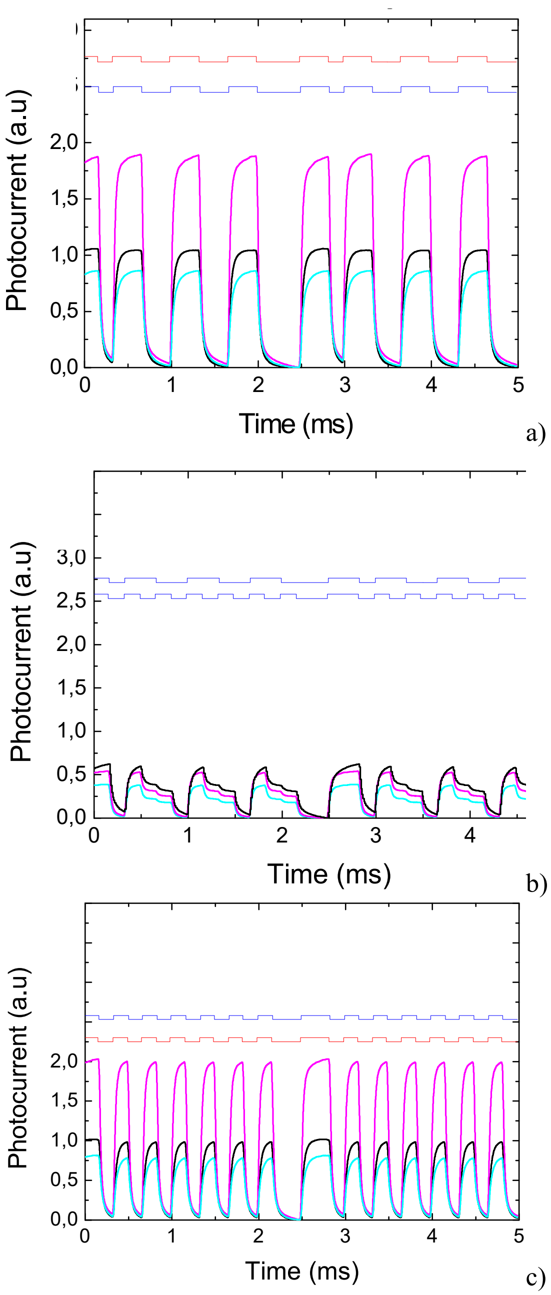
c)

Figure 5. Photocurrent signal by the pinpin photodiode, biased at -8 V and under variable conditions of optical bias (without and with front/back steady state background light).

B. Information recovery

Figure 6 displays the photocurrent signals after the removal of the green excitation contribution.

The next step is the identification of the transmitted frequencies, which requires the computation of the modulus of the complex Fourier coefficients over the 8 bits data sent next to the idle and start bits. When the calculated coefficient is above a certain threshold the signal is present at the respective frequency. In this step the front photocurrent is used to identify the red light and the back photocurrent for the blue light.



a)

b)

c)

Figure 6. Photocurrent signals without the contribution of the green signal at positions: a) #1, b) #2 and c) #3.

This procedure enables the identification of the position within the navigation cell, which mixed with the cell identification by the green channel enables the absolute position recognition. The message is decoded using the adjacent 16 bits of the slow and fast emitters. The algorithm assumes that in the front photocurrent the highest levels correspond to the presence of the red light, while the lowest ones to its absence, which allows the immediate recognition of the ON-OFF states for the red channel. Attending to the back-photocurrent signal, the same reason can be used. Here, the highest levels are assigned to the presence of the blue input signal and the lowest levels to its nonexistence, which allows the immediate decoding of the blue channel. Thus, both red and blue channels can be immediately tuned by using adequate biasing light for the background. Using this simple key algorithm, the independent red and blue bit sequences of the message can be decoded.

IV. CONCLUSION AND FUTURE WORK

Simultaneous navigation and data transmission based on visible light communication was presented and discussed. The use of RGB white LEDs and a-SiC:H pinpin photodiodes for indoors navigation was extended to add data transmission functionality to the VLC system. Codification of the optical signals ensured synchronization between frames and was also designed to shield the decoding process from errors that might provide wrong identification of the correspondent spatial position. The transmitted data is encoded in a 32 bits word, but the length can be easily expanded. Future work comprises the analysis of the system in a wider range of optical fluxes, as well as the decoding of different random transmitted messages.

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