Automated Guidance Based on indoors Visible Light Communication

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***Abstract*— Wireless communication devices have generated growing interest in indoor navigation over the past few years. The Internet of Things (IoT) and the inherent connectivity of billions of devices are making indoor localization and proximity detection increasingly attractive. Global Positioning System (GPS) has poor, unreliable performance when used in closed spaces, requiring alternative techniques and wireless technology. Due to the unlicensed free spectrum, optical wireless technologies are currently playing an important role in this field. Light Emitting Diodes (LEDs) are the basis for Visible Light Communication (VLC) technology due to their ability to simultaneously provide low energy consumption light and enable the possibility of wireless communication. These features empowered VLC as an effective communication technology due to the ubiquity of the illumination spots, especially in indoor applications. We propose the use of Visible Light Communication (VLC) to support guidance and communication for signaling in an indoor environment. The research focuses on developing guidance VLC systems, transmitting control data information, and decoding techniques. The communication system uses RGB white LEDs as emitters and pinpin photodiodes with selective spectral sensitivity as receivers. The downlink communication occurs between the infrastructure and the mobile user, while uplink communication occurs in the opposite direction. Different modulation methods, such as On-Off keying and Manchester codes, are used, allowing a comparison between them. The decoding strategy is based on accurate calibration of the output signal. We will discuss coding schemes, modulation formats, and decoding algorithms in this paper, as well as the characteristics of transmitters and receivers.**

Keywords - Visible Light Communication; positioning; footprint map, On-Off keying, Mancheste coding.

I. INTRODUCTION

Light emitting diodes (LEDs) are the basis for Visible Light Communication (VLC) technology due to their ability to simultaneously provide low energy consumption light and enable the possibility of wireless communication. Due to the widespread of the LED light spots, especially in indoor applications, these features enabled VLC as a communication technology [1][2]. The high bandwidth and immunity to electromagnetic interference of VLC make it a promising option for future generations (5G/6G) of wireless communications, as it is a good candidate for indoor interconnection and networking in parallel with radiocommunications [3][4]. In addition to its high capacity, unregulated spectrum, immunity to radio frequency electromagnetic interference, spatial confinement, and low power consumption, VLC is also an energy efficient green technology [5]. In indoor navigation it is also a promising application, where GPS signals are inefficient walls and other obstacles greatly attenuate GPS signals. As in VLC the density of optical transmitters addresses a high density of beacons, visible light enables a higher level of accuracy on location [6][7]. This is the key to provide guidance and navigation services.

The focus of this paper is the use of VLC to implement an indoor positioning system with added communication abilities. The system is composed of a pinpin heterostructure a:SiC:H [8] device to perform the photodetection of the optical signals generated by white trichromatic RGB LEDs. The photodetector [9][10] is based on a-SiC:H/a-Si:H heterostructures, operating therefore in the visible spectrum. It exhibits active filtering and amplification properties and a selective sensitivity, as its design was tailored to address a wavelength sensitive device [11][12]. When different visible signals are encoded in the same optical transmission path, the device multiplexes the different optical channels, performs different filtering processes (amplification, switching, and wavelength conversion) and outputs a multiplexed signal. Decoding of this signal enables the recovery of the modulated signal transmitted by each emitter [13]. This procedure demands accurate regulation of each photocurrent level [14] to produce a reliable calibration curve. On-Off keying modulation and Manchester codes will be used to analyze bit decoding from the multiplexed signal.

The paper is organized as follows. After the introduction (Section I), the VLC system specifications is presented in Section II covering the transmitter and receiver, data coding, modulation schemes and the calibration for decoding. In Section III experimental scenarios are detailed and the obtained results are presented and discussed. Conclusions and guidelines for future work are addressed in Section IV.

II. VLC SYSTEM SPECIFICATIONS

This section covers the specifications of the VLC system, including the transmitter, receiver, coding and modulation techniques.

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A. *VLC Transmitter*

Transmission of data is carried out by one modulated chip using white polychromatic RGB LEDs. The modulation and conversion from digital to analog data is software defined. Four LEDs are mounted in square arrangement on VLC transmitters using one red or blue emitter in each LED for data transmission. In each VLC transmitter two blue and two red emitters are modulated. The remaining emitters do not communicate.

The photodetector used in the receiver unit is a photodiode composed of a pinpin heterostructure based on a-SiC:H/a-Si:H. It exhibits active filtering and amplification properties and a selective sensitivity, as its design was tailored to address a wavelength sensitive device in the visible spectrum. In this photodiode, two a-Si:H pins are mounted on top of one a-SiC:H pin, which allows the device to be used over the full visible spectrum. The device is operated under reverse bias to improve collection efficiency. Steady state optical bias using short visible wavelength (400 nm) is used to improve amplification of the longer wavelengths and attenuation of the short ones. Fig. 1 shows the plot of the spectral emission of three optical emitters of the VLC transmitter and the spectral sensitivity of the sensing photodiode.

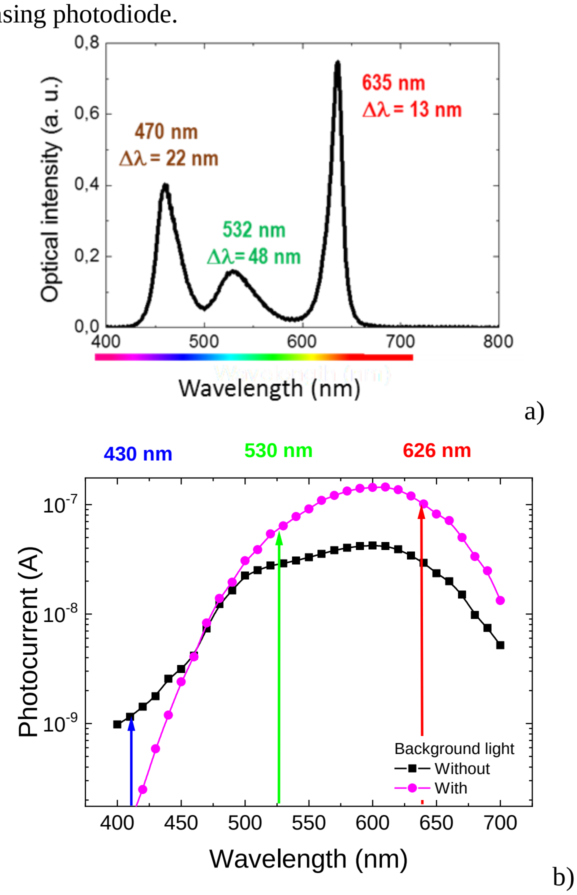


Fig. 1. a) Spectral emission of thee VLC transmitter and b) spectral sensitivity of the VLC receiver.

B. *Channel model*

A Lambertian beam distribution for each LED was used to model the VLC channel. The channel gain was computed using line-of-sight conditions that included both the transmitter and receiver devices' fields of view. Fig. 2 shows the map of the coverage signal on a 2D representation, due to the four emitters located at the corners of a square configuration. The map representation is expressed in dBm. At the center of the region, there is the highest power signal because there is contribution from all four emitters. There is less received power at the corners, as only three emitters contribute to the signal, while it is even less at the sides, where only two emitters participate.

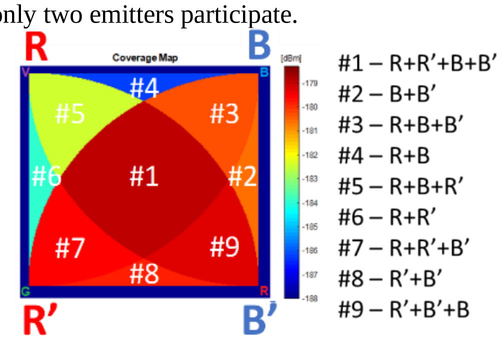


Fig. 2. Signal coverage produced by each emitter and definition of the footprints enabled by the signals transmitted by each emitter.

The optical signals reaching each position determine the spatial coverage of the VLC transmitter. Therefore, the position can be inferred more accurately inside this delimited area. In this coverage area, each optical excitation is assigned to a specific footprint. Fig. 1shows the unit navigation cell and the footprints associated with it. Those footprint regions marked #1, #2, ..., #9 correspond to the optical excitations shown also on Fig. 2.

C. *Data coding*

Specific data codes are needed to define the communication link and the type of message to be transmitted. In every channel, it was used synchronous transmission based on a data frame of fixed length. Synchronization of the frames can be enabled using different approaches. The SoT is placed at the beginning of the frame and the EoT at the end. Then a TYPE block with 4 bits is used to define the type of message (0000 in request/acknowledge mode, 0011 in standard/update mode). The complete structure of the data frame has the format displayed in Fig. 3.

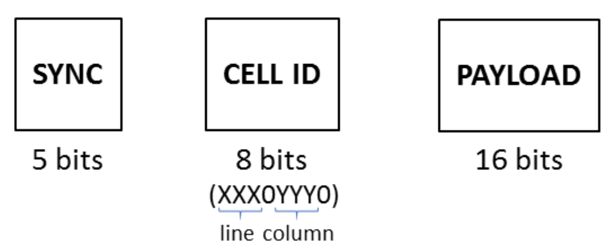


Fig. 3. Data frame structure of the VLC communication channel.

The block labelled GEO-LOCATION (16 bits) identifies the cell and footprint. The cell identification is coded as XXX0YYY0, where XXX addresses the line and YYY the column of the cell. The footprint is produced by coding the R and B emitters with four bits set to 1 and four bits set to 0, while the R' and B' emitters are coded with two bits set to 1 and two bits set to 0, and then two bits set to 1 and two bits set to 0. The 36 bits MESSAGE block addresses specific instructions transmitted to the user and depends on the type of communication mode.

D. Modulation schemes

Data transmission demands the use of a specific modulation scheme. Here we will use both On-Off Keying (OOK) and Manchester. OOK has proven to be a valuable modulation scheme in VLC due to its low complexity and ease of implementation, but it still severely limits data rates, which is further exacerbated by systems using different dimming levels. This paper aims to look at OOK and Manchester coding VLC modulation techniques with distinct levels of complexity, allowing for a comparative evaluation between the two.

OOK assigns different levels of amplitude to each of the data bits we wish to modulate, with a bit time duration of b_t. Manchester assigns both levels to each bit, one per bit time duration b_t, but it is the transitions from on to off (“on-off”) or off to on (“off-on”) that distinguish between '0' and '1' data bits. In this paper the Manchester codes use the convention of considering “off-on” transitions as ‘0’s and “on-off” transitions as ‘1’s. The representation under OOK and Manchester modulations is shown in Fig. 4.

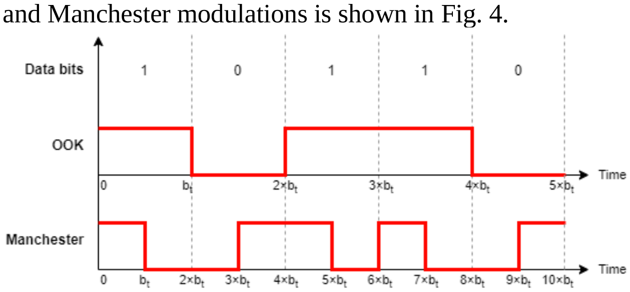


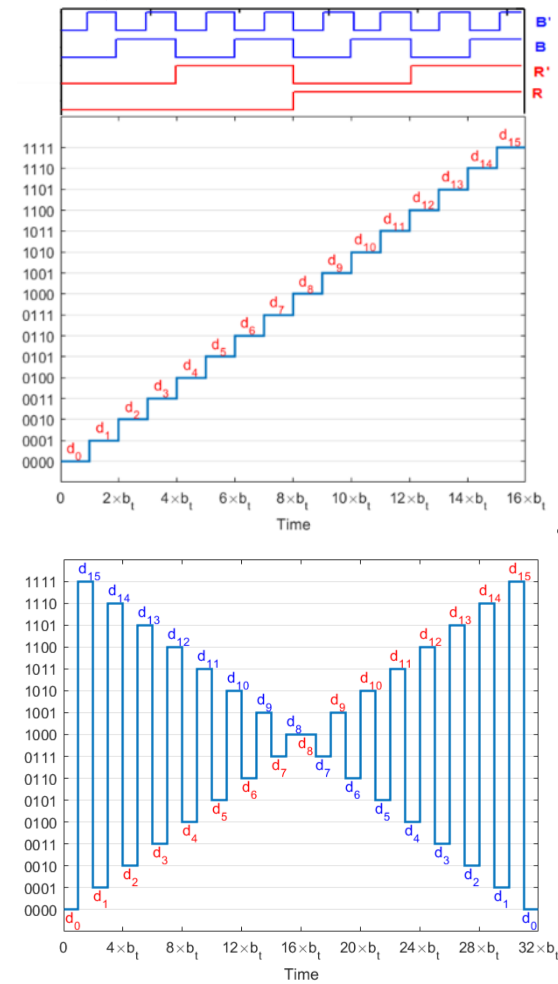
Fig. 4. Representation of data bits in OOK and Manchester, in the time domain.

Data transmission in Manchester is halved since it takes twice as long to transmit the "on" or "off" pulses that encode the same information as in OOK. In contrast, Manchester forces at least one level transition per bit of data, leading to lower levels-permanence, even in long sequences of the same bit.

E. Calibration for decoding

With each optical emitter data transmission, a multiplexed signal is produced at the photodetector. Due to the VLC transmitter's four independent emitters, the output optical signals can combine one, two, three, or four optical excitations. If the driving currents for each emitter are adjusted correctly, this can produce 16 different optical combinations and therefore 16 different photocurrent levels. The bit decoding of the multiplexed signal corresponds to the correct assignment of each photocurrent level to the respective optical excitation. This is provided using a previous system calibration, by adjusting the photocurrent levels of the multiplexed signal. Since Manchester codes demand the double of the bits to encode the same information, each 'on' or 'off' state of the LED produces two adjacent photocurrent levels.

Fig. 5 shows the calibration signal with 16 levels assigned to each input optical state. The optical signal transmitted by each emitter is displayed on top of the picture. The multiplexed signal is shown under OOK and Manchester modulations.



a) b)

Fig. 5. Calibration curve for a) OOK modulation; b) Manchester codes.

In OOK modulation (Fig. 5a), the set of 16 distinct calibration levels produce a staircase-like shape in the MUX signal, each associated with a particular optical excitation type. The left side of Fig. 6 a) indicates the correspondence of the optical state RR'BB' and the level label (d_i, i =0, 1, …, 15) using binary notation. When using Manchester codes (Fig. 5b), the same data bit sequence takes twice as long as OOK, which half the data rate. The calibration curve takes on a very different shape. This occurs because of how

Manchester uses 2 bits to represent each data bit, leading to the calibration curve having a shape of two alternating OOK calibration curves with one rising branch and the other falling branch.

III. RESULTS AND DISCUSSION

In this study, different optical signals were generated by the four optical transmitters of each LED lamp, using OOK and Manchester codes to infer about the decoding process. The transmitted frame has 29 bits, including a 5 bit synchronization header followed by the cell ID with 8 bits and a 16 bit randomly generated message.

Fig. 6 shows the acquired multiplexed signal under OOK and Manchester coding. On top of the figure the optical signals transmitted by each transmitter are also represented. The signals of the R and B LEDs are represented by the solid red and blue lines, and R' and B' LEDs by the red and blue dashed lines, respectively.

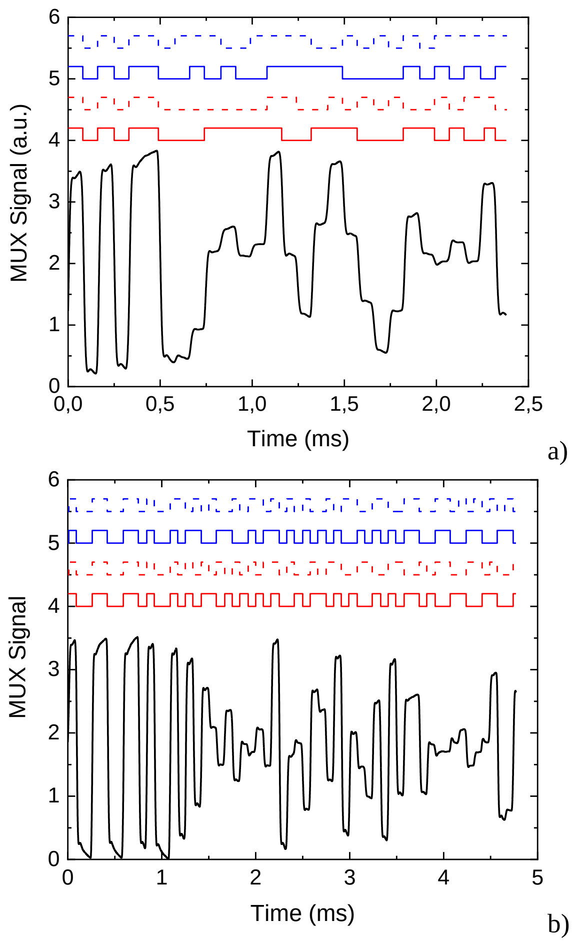


Fig. 6. Transmitted data message using: a) OOK and b) Manchester modulations (R and B are represented by the solid red and blue lines, and R' and B' by the red and blue dashed lines, respectively).

The output resultant signal acquired by the receiver device shows different levels of photocurrent that can be assigned to the correspondent optical excitation. As the device exhibits capacitive effects, the photocurrent level exhibits a rising or falling slope, dependent whether the transition occurs from a lower to an upper level, or vice-versa. Consequently, this effect becomes more evident when two or more adjacent bits have the same state.

In OOK modulation as the bit states are simply represented by '0's or '1's, it is possible that the signal contains many similar adjacent symbols ('1s' or '0s'), which reinforce this effect. It is clear from Fig. 6a) that, for example, the upper levels achieved by every single 'on' bit are lower than those obtained by two adjacent 'on' bits. This may induce errors in the bit decoding process. When using Manchester coding, Fig. 6b) each state is represented with a transition between different states. Therefore, no more of two similar bits occur during the transmission and the limitations imposed by the capacitive effects of the sensing device are attenuated.

On the other hand, frame synchronization that is established by the heading block transmitted in the beginning of each frame is crucial to ensure correct data transmission. As this block is composed of a sequence of 5 specific states ('on'-'off'-'on'-'off'-'on') followed by the identification labels of the transmitting cells, the correct identification of the block among the transmitted frames is not a hard issue to complete successfully. Nevertheless, under Manchester coding a level transition is less likely to coincide with the start of a frame due to the halved data rate, or even with the start of a data bit since a transition is forced to occur in the middle of each data bit. An effective way of ensuring synchronization is to allocate more bits to the synchronization header block at the cost of the payload length.

Direct comparison of the signal levels with the calibration signal is achieved by assigning the bit level to the level closest to the calibration signal. Bits represented by close values may be improperly decoded. This is especially important when using OOK modulation, since capacitive effects can mislead the decoded level, whereas Manchester modulation minimizes this problem. Parity check bits are a possible solution to reduce the bit error decoding.

IV. CONCLUSIONS

The proposed application focuses on the technique of decoding the multiplexed signal measured by the VLC receiver using OOK and Manchester modulations. The VLC transmitter uses RGB white LEDs to illuminate the space and to transmit information defining footprints inside each navigation cell. Coding uses frames coded with different information blocks. As the multiplexed signal results from multiple optical channels, its waveform is complex. It is necessary to use decoding techniques to determine the correct bits transmitted by each optical channel. Improvements to the decoding technique include parity check error control. The imposed state transitions for the representation of each bit used in Manchester coding minimizes the capacitive effects of the sensing photodiode. As a result, photocurrent levels were better defined for each state.

Improvements to the decoding technique include parity check error control. More experimental data and different operating scenarios can be used to further enhance the decoding techniques.

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