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VLC-beacon detection with an under-sampled ambient light sensor

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ABSTRACT

LEDs will replace in a near future the current worldwide lighting mainly due to their low production-cost and energy-saving assets. Visible light communications (VLC) will turn gradually the existing lighting network into a communication network. Nowadays VLC transceivers can be found in some commercial centres in Europe; some of them broadcast continuously an identification tag that contains its coordinate position. In such a case, the transceiver acts as a geolocation beacon. Nevertheless, mobile transceivers represent a challenge in the VLC communication chain, as smartphones have not integrated yet a VLC customized detection stage. In order to make current smartphones capable to detect VLC broadcasted signals, their Ambient Light Sensor (ALS) is adapted as a VLC detector. For this to be achieved, lighting transceivers need to adapt their modulation scheme. For instance, frequencies representing start bit, 1, and 0 logic values can be set to avoid flicker from illumination and to permit detecting the under-sampled signal. Decoding the signal requires a multiple steps real-time signal processing as shown here.

1. Introduction

High efficiency of solid-state light sources provide important energy savings. Additionally, these sources offer other benefits in several applications such as a controllability of their spectral power distribution, and their colour temperature; moreover, temporal modulation is also possible [1]. Such controllability has permitted to use light emitter diodes (LED) as transmitters by modulating the switching process between on and off states [2]. Thus, LEDs can be used not only as highly efficient light sources but also as transmission devices. Furthermore, the available radio-frequency (RF) bandwidth will not be sufficient to meet the ever increasing demand for wireless access [3] which turn into an opportunity for LED as transmitters. Communication rates in Gbps (Giga bits per second) order in visible light communications (VLC) have been reported in last few years [4,5]. The use of the electromagnetic spectrum covering the visible light, envisaged in 5G networks [6], will certainly generalize VLC technology. There are several applications of VLC that do not require high transmission rates, for instance geolocation. Indoor geolocation is a good complement to outdoor GPS-based geolocation services. Indoor requires a network of beacons with full coverage; LED-based lighting can offer this functionality as LED lighting sources will eventually replace other lighting technologies. Since LED-based lamps are converted in beacons then smartphones can be used as geolocation instruments. Currently, smartphones do not integrate photodetectors to detect a VLC luminous signal and dongles should be used to carry out this process. Different approaches to reconvert a smartphone into an indoor geolocation instrument consist on using its image camera [7–12]. Other smartphone's applications include payment by using its low-speed xenon flashlight at transmission rates under 1 kbps [13]. Supermarkets, exposition halls, hospitals and air transports are interested on VLC although for different reasons: in supermarkets, reflecting metallic surfaces produce interference when using Wi-Fi, in exposition halls, a high concentration of Wi-Fi routers saturates the available channels. In hospitals, the use of communications bands with frequencies next to those used by medical instruments is to be avoided for safety reasons. Finally, in airplanes RF interference is a security issue during take-off and landing. In this article, we will show how to adapt smartphones to VLC geolocation solutions by using the phone's ambient light sensor.

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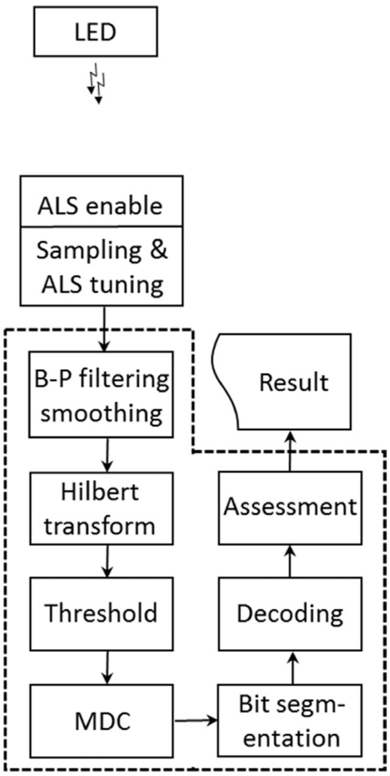

Fig. 1. Proposed scheme for acquisition, conditioning and the visible light signal decoding.

2. Signal conditioning

The ambient light sensor integrates a low speed and high photo-sensitivity PIN photodiode. Its sensitivity peak to visible light fits the human eye photopic response as it also rejects strongly IR. These sensors have been extensively integrated in most of the smartphones. The proposition presented here, consists in the use of this smartphone's integrated sensor together with indoor LED-lamp-based beacon facilities to carry out geolocation services.

The LED-lamp transmission system –or VLC beacon– comprises a router capable to continuously transmit an identifier (ID) that contains the exact position of the lamp in an indoor space. The emitted ID signal is formed by 10 bits from which the first one is the start bit followed by 9 data bits. In Fig. 1, the steps followed to condition and decoding the received signal are shown.

As shown in Fig. 1, the signal is detected by the cell-phone ALS. Algorithmically, the sampling module samples the transmitter frequency until the entire signal is completely captured, then the detected signal is band-pass filtered to reject harmonics present in the signal and to reduce noise. Some signal characteristics are needed to correctly interpret the ID; to extract these characteristics, the start bit detection is fundamental to carry on with the ID detection process. By using Hilbert transform a threshold is set to define the interval where the start bit is surely contained. The next step includes a minimum distance classifier used to assess the extracted signal characteristics. This will permit the start bit to be found and the last 9 bits to be decoded by using the fast Fourier transform (FFT).

3. Transmission

The router used in this experiment, pulse-width modulates (PWM) the LED-Lamp with a 50% duty cycle and variable frequency. The ID frame transmitted by the lamp has been codified in frequency; this means that each bit has a different associated frequency. The frame consists on 10 different bits whose first one is the start bit indicating the receiver that the following bits contain data. The start bit has a duration of 1000 ms and the remaining bits have a period of 500 ms as shown in Fig. 2. As the identification process results easier when the start bit duration double that of other bits, the method proposed here has prompted changes in coding the transmitter router; this results in a simpler recovering of signal characteristics. Yet, the coding frequencies representing the bits have been elected after a meticulous frequency sweep that has permitted to differentiate them all. From there we also observe the ALS sensing each frequency.

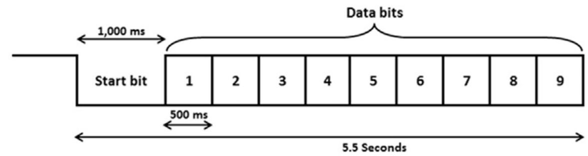

Fig. 2. Frame configuration. Note the duration of the start bit.

Attention is drawn to the fact that lighting frequencies under 170 Hz result in a slight flicker that can be perceived by human eye. Moreover, as it has been pointed out in Section 2, ALS' PIN photodetector slow-sampling frequency constrains the selection of the transmission frequency. The Nyquist sampling theorem cannot be fulfilled when lighting-embedded transmitter frequencies over 2 times the ALS sampling frequency are used. In Table 1 the chosen frequencies are shown; a start bit and 9 bits comprising logic 0 s and 1 s compose the frame. The frequencies for set start, 1 and 0 bit are selected according to the following criteria: *i*) to avoid visual flicker effects, and *ii*) to find frequencies having left available by LED lighting fabricants. Indeed, after extensively studying drivers used by lamps fabricants we realized that they have protection against short-circuits and open-circuits; the consequence of this is the inability to modulate LEDs at lower frequencies than those chosen in this experiment.

4. Reception

In this experiment, we have used the ambient light sensor of a Samsung® Galaxy S4 operating under Android 5.0.1 and 99 Hz of sampling frequency. From Fig. 3(a) and according to the Nyquist theorem [14], we can see at first glance that the detected frequencies are far under-sampled with respect to the transmission frequencies. As a matter of fact, it is an aliased signal what is detected by the ALS. A discrete time signal $x[n]$ can be obtained from a continuous signal $x(t)$, sampling, for example the continuous signal at certain time intervals $x[n]=x(nT)$, where T is the sampling period. Then $f_s=1/T$ is the sampling frequency. According with the sampling theorem, a limited bandwidth signal can be completely reconstructed if the sampling frequency is at least the double of the maximum frequency component in the original signal $f_s > 2f_{max}$. If the expression is satisfied the sampling frequency is known as the Nyquist frequency, on the contrary, the aliasing effect appears. Taking this into consideration, the aliased under-sampled signal has been simulated. In Fig. 3 the signal emitted at each of the three transmission frequencies (in blue) and their respective sampled signal (in red) can be seen. The amplitude of blue signal was set to 48 V equivalent to the output voltage from the driver. The sampling rate of the phone is no stable and it varies around 98.8 Hz and 99.2 Hz, which have also been considered in the simula-

Table 1
Frequencies used in coding the transmitted frame.

Bit	Frequency [Hz]
Start	198
1	208
0	213