Système de localisation à Lumière Visible avec compensation du bruit environnemental

Antonio Costanzo, Valeria Loscrì

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Antonio Costanzo[1] † et Valeria Loscri [1] ‡

[1] *INRIA-Lille Nord Europe, 40 Avenue du Halley, Villeneuve d'Ascq France*

Les systèmes de localisation basés sur la Communication à Lumière Visible (VLC) sont des bonnes candidates pour les environnements intérieurs, parce qu' ils offrent la possibilité de réutiliser les infrastructures existantes pour l'illumination et la localisation en même temps. Toutefois, la lumière du soleil compromet les prestations de ces systèmes. Une nouvelle approche, fondée sur le paradigme "software defined", a été proposée pour évaluer facilement le bruit ambiant. Une adaptation de la technique FDM (Frequency Division Multiplexing) a été exploitée pour partager le débit total en différents sous-débits, chacun correspondant a l'intervalle de fréquences de chaque transmitteur. Le bruit ambiant et les autres sources optiques interférentes sont estimées en utilisant des mesures en temps réel. La validation expérimentale, effectuée en deployant des simple lampes LED à faible puissance, démontre une précision améliorée par rapport aux approches FDM classiques et confirme l'exactitude de la technique proposée.

Mots-clefs : Visible Light Communication, Indoor Positioning Systems, Signal Processing

1 Introduction

Visible Light Communication (VLC) [1] is an emerging technology which allows the employment of Light Emitting Diodes (LED) for providing wireless data transmission, exploiting light sources normally used for illumination purposes. This paradigm can potentially offer extremely low cost communication and power consumption, a large unlicensed bandwidth and ubiquitous reuse of existing infrastructures. It can be employed in those environments where Radio Frequencies are not allowed, like hospitals, mines or petrochemicals plants. Furthermore, VLC received signal can also be used for achieving high accurate indoor positioning systems without additive devices. Since VLC overcomes the low accuracy achieved by Wi-Fi and the high latency performed by Bluetooth, it represents one of the most attractive approaches for low cost indoor positioning. However, the main problem is due to interference sources, like sunlight. Sudden changes in natural light conditions during the day, indeed, can completely prevent a correct position detection. Several works have been carried out in recent years on VLC indoor positioning, following different approaches ([2]), but few of them are supported by experimental validations. In this work, a new Software-Defined approach based on real time monitoring and correction of environmental noise has been designed in order to compensate errors due to external optical sources. Our technique has been implemented on real devices and tested in the context of the FUI project §StoreConnect at Silab¶. The main contributions of this work are represented by 1) a theoretical derivation of noise power impact on distance detection, 2) its exploitation for reducing positioning error in a Visible Light Indoor Positioning system 3) experimental validation of the approach in a real indoor environment. The proposed architecture and the main functionalities performed by the system are described in section 2, experimental setup and results evaluation are provided in section 3. Finally, we conclude the paper in Section 4.

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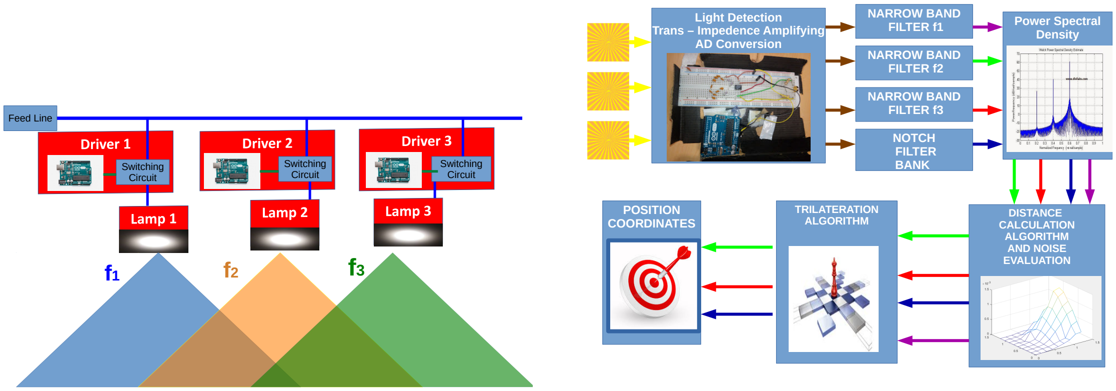
§. https ://www.pole-scs.org/projets/storeconnect/

¶. http ://www.si-lab.fr



(a) Transmitting system (b) Receiving system

FIGURE 1: Software Defined Visible Light Indor Positioning System

2 System description

A simplified scheme of our low cost illuminating-positioning architecture, describing transmitting light devices is depicted in Fig. 1 (a). A power line network feeds all the components of the system in the transmitting stage, namely the lamps(LEDs) and the LED drivers, composed by a micro-controller and few other hardware components (resistances and transistors). In particular, warm white single LEDs are chosen for providing a good illumination and control of blinking to generate signals at different frequencies. In fact, the receiver is able to distinguish beams from different transmitters, following a modified version of an FDM Technique. It also includes out of band measurement components needed for estimating in-band noise. The main actions performed by the Software Defined Visible Light Indoor Positioning System are resumed in the block diagram in Fig. 1 (b).

In particular, optical signal is detected, pre-filtered and amplified. Analog to digital conversion, buffering and timing are further performed by a low cost single board. Signal is sort out in three different paths, each one containing a high Q factor peak filter, which properly separate the contribution of power radiated by each lamp. In particular, being $i = [1,3]$ the index of the i^{th} transmitter, corresponding received power values P_{ri} are calculated as following :

$$P_{ri} = \int_{fi-\frac{f_i}{Q_i}}^{fi+\frac{f_i}{Q_i}} PSD[x_i(t)]df \tag{1}$$

where $x_i(t)$, is the time domain signal coming from the i^{th} transmitter after acquisition, amplifying, conditioning and filtering. Q_i, is the quality factors of related peak filter and the operator PSD[.] indicates Power Spectral Density of the signal. A fourth additional path is implemented in order to roughly evaluate environmental noise outside the bandwidth. Since thermal noise and sunlight incident power affect the system at all frequencies, spectral noise components outside the transmitting ranges are integrated in order to provide an estimation of total noise in the system. In particular, being $x_N(t)$ the noise component measured after filtering transmitting source signal (the fourth stage in Fig. 1), and B the total bandwidth of the system, the overall estimation of the environmental power, N_{out}, is calculated as follows :

$$\begin{aligned} N_{out} = \int_{0}^{f1-\frac{f_1}{Q_1}} PSD[x_N(t)]df + \int_{f1+\frac{f_1}{Q_1}}^{f2-\frac{f_2}{Q_2}} PSD[x_N(t)]df + \\ + \int_{f2+\frac{f_2}{Q_2}}^{f3-\frac{f_3}{Q_3}} PSD[x_N(t)]df + \int_{f3+\frac{f_3}{Q_3}}^{B} PSD[x_N(t)]df \end{aligned} \tag{2}$$

In order to have an estimation of the noise inside the bandwidth of each transmitting frequency range, a simple proportion has been used. Namely :

$$N_{ri} = \frac{2f_i}{Q_i B} N_{out} (1 + \frac{\sum_{k=1}^{n} \frac{2f_k}{Q_k}}{B}) \tag{3}$$

According to path loss by a LED signal propagating in the air, distances between the receiver and each transmitter are calculated considering a Received Signal Strength Indicator (RSSI) measurement for each stage [3], according to optical channel characteristics, namely :

$$d_i = \sqrt{\frac{(m+1)A\zeta cos^m P_{Topt}(\phi)T(\psi)g(\psi)}{P_{ri} - N_{ri}}} \tag{4}$$

where A is the effective area of the photodiode, d the distance between transmitter and receiver, ϕ the angle of irradiance with respect to the axis normal to the transmitter surface, ψ the angle of incidence with respect to the axis normal to the receiver surface, $T(\psi)$the gain of optical filter and m the order of the Lambertian Radiation. Differing from other works in current literature, the quote of noise in received path N_{ri} has been taken into account in order to compensate its effect on distance calculation. In [3], indeed, we demonstrated that the relative error committed using only the term P_{ri} in Eq. 4 is equal to :

$$\Delta d_i = 1 - (1 + \frac{1}{SNR})^{-\frac{1}{m+2}} \tag{5}$$

where $SNR = P_{ri}/N_{ri}$ is the Signal to Noise Ratio of the system. Compensated distance values are finally given in input to a trilateration algorithm for estimating the position of the receiver. In particular, trilateration algorithm chosen in our work, follows the approach in [4].

3 Experimental validation

An experimental setup, for validating the proposed visible light positioning approach, is provided in this section. We provide a comparison between :

- measurements according to classical FDM approach, without compensation of the noise power ;
- measurements according to the proposed noise awareness approach, where environmental noise level is measured in each point of the xy plane, simultaneously with the power associated to the transmitting blinking ranges, in order to compensate positioning errors, according to the description provided in previous section.

Three identical transmitters have been used, each one composed of a commercial warm white LED (XLamp MC-E warm, produced by CREE), an Arduino Uno board and a passive circuit driving the led, and a 12V power supply.

The receiver is composed by a commercial photodiode (OSD15-5T, fabricated by Centronic), a trans-impedance amplifying and pre-filtering circuit composed by a low cost operational amplifier (LTC1050), low cost resistors and capacitors. An Arduino board is used for data acquisition and analog digital conversion. Low frequency square waves, but guaranteeing no flickering problems (125Hz, 166.7Hz and 200Hz) have been chosen for LED blinking. The receiver has been placed on each point of a grid made up by 9x9 points, with an extension of 120x120 cm. Both compensated and uncompensated positions have been determined for each point of the grid in the xy plane and compared with the real position of the receiver, for evaluating the accuracy of the system. In order to provide a validation of the proposed Light Indoor Positioning technique in a critical noisy environment, the setup shown in Fig. 2 a) has been considered. In particular, a typical use case, where the position of an item (the receiver) on a table has to be detected using illuminating lamps on the ceiling, has been realized. Distance between the table and the ceiling is equal to 2m. Considering this setup, a daily measurement campaign (from 8 :00 to 20 :00) has been carried out in a sunny day, with windows facing north in the North Hemisphere, sunrise at 5 :53 and sunset at 21 :36. In particular, three measurement sessions of two hours have been carried out, where receiver position has been recorded each 15 minutes and a mean has been calculated for each session. Averaged values between

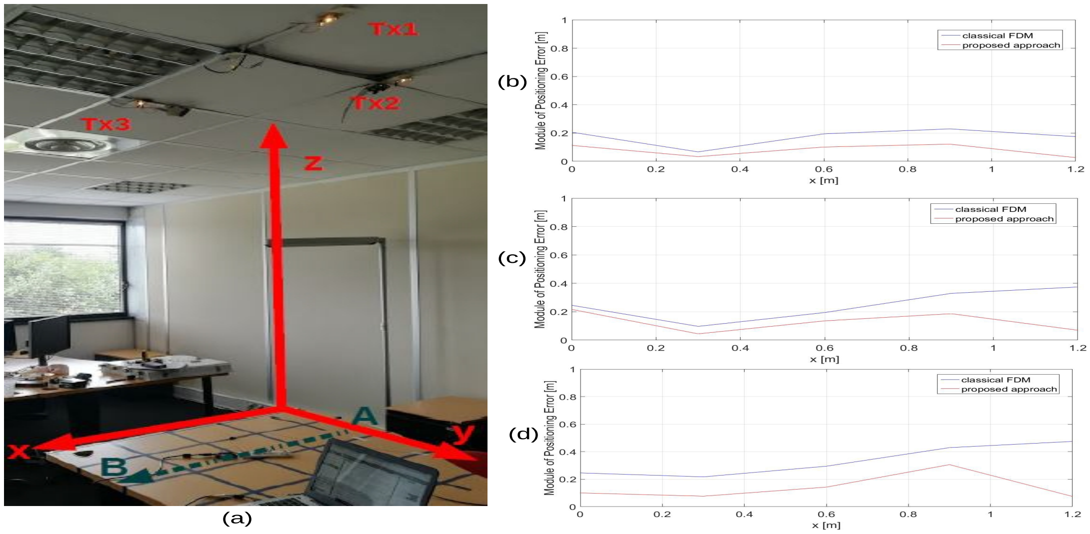


FIGURE 2: Experimental Tests : a)Setup, b)Average Distance Error, Time 08 :00-10 :00, c) Time 13 :00-15 :00 d) Time 18 :00-20 :00

measures taken each 15 minutes, have been considered for each session and shown in Fig. 2 b),c) and d), considering the path between point A=[0,60,0]cm and point B=[120,60,0]cm. Results show that, even in extremely hard noisy conditions, proposed noise aware approach significantly mitigates error positioning in respect to the classical FDM-RSSI approach,. If we compare our results with last experimental validations recently appeared in literature according to the survey in [2], our system overcomes other FDM systems and achieves, in general, a competitive level of accuracy, nevertheless the extremely low cost hardware employed.

4 Conclusions and future works

A low cost indoor positioning system, based on a real time monitoring of environmental noise, has been proposed in this work. Low cost equipment has been used in our architecture and a competitive accuracy in positioning, in comparison with a classical FDM-RSSI, has been performed. The proper manipulation of measured received power spectral density inside frequency ranges allocated for LED transmissions, and outside these ranges for environmental noise, represents a novel way to face the problem of disturbing signals in the scenario, mainly due to sunlight. Competitive positioning results in accuracy have been achieved with no hybrid architecture or auxiliary devices. A further extension of this work will deal with the integration of the effects of multi-path in the channel model.

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