Illumination Interference Reduction System for VLC Communications

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Abstract- In this work, an illumination interference reduction technique for visible light communications (VLC) is presented. In this kind of systems an optical wireless communication is established using visible light wavelength, therefore optical filtering for interference rejection cannot be employed. Instead of the optical filtering a signal processing based solution is proposed. It consists of the equalization of the received signal by a transmission channel inverse filter in order to reduce the effects of the channel in the signal. The channel model has been approximated by linear prediction coefficients.

I. INTRODUCTION

The energy saving, and particularly, the high consumption of the traditional illumination systems, are provoking a gradual use reduction of the incandescent sources and a growing of the solid state illuminations ones. Over the last years, a fast development of this kind of sources has been done, and it is estimated that they will be the main illumination source during next years. However, this devices offer new benefits such as medium/high data transmission capability. This is known as Visible Light Communications or VLC, which is one of the most interesting working areas in wireless optical communications [1-3].

Normally, conventional optical wireless communication systems use emitters and optical receptors which work in infrared wavelengths. It was because of there were a lot of LEDs working in this band. Moreover, the main interference source of these systems, the visible light, is avoided. Even in these situations, as the receivers pick up the optical energy in a wide wavelength margin, the illuminating systems introduce high interference levels [4-5].

The interferences produced by the illumination sources introduce narrowband components at different frequencies, which depend on the used kind of lamps [6]. For instance, the incandescent lamps generate harmonics from 100 Hz to 800 Hz approximately. This phenomenon is due to the 50 Hz frequency of the power supply, which produces in the lamp the same generated light for the positive and negative. In fluorescents lamps, as the used elements and the physical properties are different to the incandescent ones (voltaic arch, Argon gas ionization and mercury atoms, visible light generated by phosphor atoms), signals with different characteristics are generated. Specifically, these interferences have harmonics from 50 Hz to nearly 2 KHz.

To reduce these interferences effects, optical filters are used in the reception system, which remove the visible emissions [7]. Filtering and electrical signal modulation techniques are also used to reduce the disruption that has not been eliminated by the filtering [8-11].

In VLC communications is not possible to introduce an optical filter stage due to the communications is carry out in this band, so it will be necessary to introduce more effective interference reduction systems in the electrical process stage of the received signal. In this work, an initial proposal of an interference reduction system based on adaptative filtering is presented. This system models the channel characteristics, mainly the interferences signals (from a fluorescent lamp in this case) that will be used later to equalize the received signal. Linear prediction coefficients techniques with a 1-NN classifier have been used to model the channel.
[12]. Next the system and the obtained results are presented.

II. MODELING SYSTEM AND CHANNEL EQUALIZER

The proposed system seeks to equalize the transmission channel as an adaptive system. The signal received at the reception is divided into temporal signal frames of 20 milliseconds. Each window of 20 milliseconds is filtered with a reverse model of the channel, where the suitable channel model is selected from a predetermined set of models of different channels. The reverse filter is selected based on spectral similarity between the temporal signal frame and the channel model.

The channel models have been obtained using linear prediction coefficients (LPC) [13] which give to a minimum phase system, which can be reversed without running the risk of becoming unstable [14]. So it can perform an inverse filtering that eliminates effect of the channel. In this work and as a first approximation, the system does an adaptation of the equalizer filter switching between several possible models.

The process carried out for the equalizer is as follows: the signal is sampled in the output of the optical receiver, the signal is divided in temporal frames of 20 ms, extracted the necessary measures to characterize the channel, and decides for each temporal frames between a free channel model (model 1) or fluorescent light-polluted channel (model 2) using a classifier. Finally, there is an inverse filtering using the model chosen. This is shown in Figure 1.

The characterization of the channel is made using the high frequency obtained the wavelet transform of the temporal frames using a Daubechies window type I.

The classifier can easily discern between channel free (model 1) and polluted channel (model 2) using the characterization based on wavelet transform. A third model (model 3) exists, which corresponds to audio voice signal. In the case of the temporal frames is classified as model 3, an inverse filtering with the newest channel detection (model 1 or model 2) is done.

III. VLC COMMUNICATION SYSTEM

The interference reduction processing here proposed has been applied to a basic VLC communication system in order to obtain actual results in a real wireless optical link. This system consists of an analogue link for the transmission of base band audio signals. As the illumination interference signals are present in the communication bandwidth, this experiment represents an excellent test for the processing algorithm. Nevertheless, obtained results and system structure are valid for other VLC systems, as higher bandwidth systems or digital transmission links for example, because the illumination interferences are the same than in this case. Besides, this scheme allows to study the proposed solution in a simple way, without the use of complex electronic circuitry. Signals to be transmitted by the VLC link are generated by means of a computer sound card. The same sound card is used for the acquisition and digitalization of the received signals (audio transmitted signal and interference signal). Finally, the processing algorithms are implemented in the computer by specific software tools. In this way, it is easy to perform reconfigurations in the system and change parameters in the software for obtaining the best scheme for the application. System block diagram is presented in figure 2

![Figure 1. Outline processing system.](image-url)
The optical emitter device is a white LED (Light Emitter Diode) lamp, which is one of the possibilities of the new solid state illumination systems. This kind of elements presents a worse performance in bandwidth than other alternatives for the white light generation, as multicolour LED (Red, Green and Blue), due to the optical persistence effect of the phosphor cover in white LEDs. This effect reduces the frequency of variation of the generated optical signal, as illumination does not extinguish abruptly when the LED excitation is off [1].

The used lamp (figure 3) was originally supply by batteries, in this way transmission circuitry can be connected directly to the LEDs, avoiding additional electronics circuits present in other typo of lamps, like those lamps which can be connected to the AC power supply.

The used lamp consists of a 20 white LEDs array in parallel connection. This LEDs are driven by an excitation circuit based on the TDA2030 driver. The basic scheme is shown in figure 4.

The polarization resistor controls the LEDs illumination intensity when there is no signal to transmit. The suitable resistor value allows to reduce to negligible levels (not detected by human eye) the light fluctuations ought to the transmission signal. Therefore, we maintain the correct performance of the lamp as illumination device in both situations, signal emission or not emission.

Reception stage, whose scheme is presented in figure 5, make use of a HAMAMATSU S5107 photodiode as optical collection device, and a HAMAMATSU C9052-01 transimpedance amplifier. The obtained signal is introduced in the line in of the computer sound card for its acquisition and processing.

This system can perform high reliable wireless optical links for distances higher than 3 meters. Figure 6 shows the transmission and reception implemented prototypes.
IV. RESULTS

As commented before, the signal processing has been performed by software algorithms implemented in a computer. So acquisition and digitalization of the signals it is necessary. In this work, optical received signal has been captured with a 44100 Hz sample rate and 16 bits quantification levels.

Lpc coefficients estimation, need different samples of the signal present in the channel: channel free of interference and channel perturbed by interference. For the non interference case, obtained signal includes the optical receiver electronic circuits thermal noise and the noise introduce by the photodiode. Channel spectral characteristic estimation has been performed with a 1 minute signal sample and 200 coefficients. Figure 7 a and 7 b show the sampled signal and the estimated channel power spectral density respectively.

For the polluted channel case, signal present in reception has been measured using a 22 W fluorescent lamp as interference source. Using, as in the previous case, a signal sample of 1 minute and 200 coefficients, the results are those presented in figure 8.

In the interfered channel estimation, a 100 HZ component has been obtained. This is the fundamental components of the fluorescent interference signals. Higher resolution can be achieved by using more coefficients, but we consider it would be a waste of computation time without a significant improvement in the obtained channel model.

The quality of the developed inverse filtering has been assessed using a temporal signal frame containing fluorescent noise. The result is shown in Figure 9. It can be observed that the interference main component has been eliminated successfully (with a reduction of 130 dBs approximately).

As initial test, a 1 KHz signal has been transmitted to a channel with the fluorescent interference on it. Figure 10 shows in a, the power spectral density of the optical received signal and in b, the obtained signal from the processing system. In can be seen as the interference component has been eliminated keeping the desired signal components without modifications.
As a general case, the proposed system has been applied to an audio signal, which has a more complex power spectral density than the previous case. In this case, the power spectral densities corresponding to the received signal in the presence of interference and processed signal are shown in Figure 11 a and b respectively, where it can be checked the proper functioning of the system even for a interfering signal power significantly higher than the desired signal.

Besides the reduction of the interfering components, it is also possible to see a significant improvement in subjective quality of the acoustic signal before and after processing.

The channel models identification system has been evaluated using different types of classifiers [15], and characterizing the temporal signal frame with the wavelet transform. The results obtain are presented in Table 1.

<table>
<thead>
<tr>
<th>Clasif.</th>
<th>Error</th>
</tr>
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<tbody>
<tr>
<td>1-NN</td>
<td>0,000</td>
</tr>
<tr>
<td>2-NN</td>
<td>0,027</td>
</tr>
<tr>
<td>3-NN</td>
<td>0,031</td>
</tr>
<tr>
<td>4-NN</td>
<td>0,063</td>
</tr>
<tr>
<td>5-NN</td>
<td>0,066</td>
</tr>
<tr>
<td>6-NN</td>
<td>0,086</td>
</tr>
<tr>
<td>7-NN</td>
<td>0,086</td>
</tr>
<tr>
<td>8-NN</td>
<td>0,106</td>
</tr>
<tr>
<td>9-NN</td>
<td>0,108</td>
</tr>
<tr>
<td>10-NN</td>
<td>0,120</td>
</tr>
<tr>
<td>Linear Bayes</td>
<td>0,089</td>
</tr>
<tr>
<td>Quadratic Bayes</td>
<td>0,012</td>
</tr>
</tbody>
</table>

Table 1. Results of different classifiers

A low computational cost alternative is to use a classifier based on assessment the cross-correlation maximum between the wavelet transform of each temporal signal frame with each one of the models (model 1, model 2 and model 3). As we detect the maximum correlation, we normalize the wavelet models regarding their energy.

$$x[n] = \frac{x[n]}{\sum_{i=1}^{N} x[i]^2}$$

The system must calculate the correlations with each of the possible channel models, it performs a peak detection and decides which channel model will be used in the inverse filtering.

Figure 12. Block Diagram of the classifier based on the autocorrelation
The classifier based on the autocorrelation has been evaluated and an estimated error probability of 0.0223 has been obtained.

V. CONCLUSIONS

In this work, a first approximation to solve one of the Visible Light Communications (VLC) problems is presented, that is the presence of persistent and high intensity interferences in the channel from the conventional illumination systems, which cannot be eliminated by an optical filter as they are over the same wavelength range used to do the transmission.

This proposal consists of performing a process to the received signal, which implements a reverse filter of the channel with the aim of removing their effects. To get the channel model, lineal prediction coefficients techniques with a bayesian classifier or wavelet transform with an autocorrelation based classifier are used.

Later versions of the system will include real time classification and filtering. Moreover, activity detection algorithms will be added, which are based on spectral techniques. With these methods, it will be able to determine the silent periods of the audio signal with the aim of sampling the channel in those moments. Finally, we are working in the system implementation on specific hardware devices, such as FPGAs or DSPs, to reach an online process without using PCs or high level software.

The fluorescent lamp is the situation that has been studied in this work, as it is one of the most common and has different frequency components. Other kinds of interferences will be analyzed in a similar way. Moreover, we are developing new systems, which will allow us to determine the kind of interference that exists in each moment, with the aim to put into practice the most suited reverse filtering.

REFERENCES