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Deep Learning based Adaptive Predistorted for Nonlinear LED Compensation Invisible Light Communication

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ABSTRACT:

In a visible light communication (VLC) system, the light-emitting diode (LED) is the major source of nonlinearity. The nonlinear effects in the VLC system are different from the conventional wireless communications system. The channel separation in the VLC system is significantly larger than the signal bandwidth. Thus, the adjacent channel interference is not an issue. Predistortion technique may not be a cost-efficient approach since it needs additional feedback physical circuits at the transmitter. In this paper, we propose a post distortion technique to estimate and compensate for the LED's nonlinearity at the receiver. The post distortion technique only needs some additional computational resources. In addition, the proposed approach significantly improves the error-vector-magnitude and bit-error-rate performance of the VLC system. Simulation results validate the theoretical analysis.

KEYWORDS: VLC, nonlinearity, memory effects, Wiener model, post-distortion, Memory polynomial model.

I. INTRODUCTION

The wireless spectrum of the conventional radio frequency (RF) system is very limited and is not able to meet the increasing demand for mobile data traffic. VLC (Visible Light Communication) is an attractive alternative as it has many advantages, such as almost unlimited bandwidth, license-free operation, chip front-end, etc. To achieve a high data rate transmission, orthogonal frequency-division multiplexing (OFDM) technique has been widely used in VLC systems. The OFDM signals are modified to other specific OFDM signal formats, such as DC biased optical OFDM (DCO-OFDM) and asymmetrically clipped optical OFDM (ACO-OFDM), to accommodate the fact that the LED in the transmitter only works with real and positive input. Such signals are sensitive to the LED's nonlinearity in the VLC system due to their high peak-to-average power ratio (PAPR). In above points, the nonlinear behavior of the LED was discussed in detail. The nonlinear characteristics of the LED's V-I curve are shown in the blue line in Figure 1.1. The LED has a turn on voltage (TOV). If the input voltage is smaller than TOV, the LED is considered as cut-off and is not conducting current. Therefore, a DC bias is applied to guarantee that the input signal works.

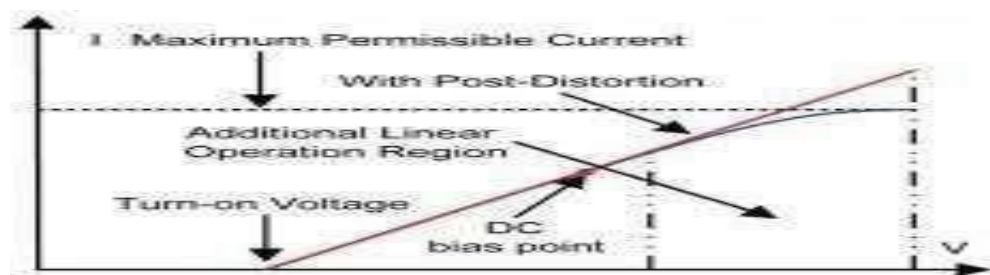


Figure 1. Nonlinear and linear transfer characteristics of the LED

Post-Distortion helps to linear the V–I curve of the LED. However, the LED's response exhibits nonlinearity for large input signals. Increasing the magnitude of the signal will drive the LED into the nonlinear region, thus exhibits nonlinear effects. In addition, the LED has a maximum permissible current, which limit the maximum magnitude of the input signal. Moreover, the carrier-density response is indeed frequency depended, thus introducing memory effects to the LED. Previous works of the LED, presented predistortion methods to mitigate the nonlinearity of the LED. The authors designed a predistortion circuit, which only consists of diodes and resistors, to compensate for the nonlinearity. From that, the authors measured the forward voltage and forward current of the LED and estimated the inverse characteristic of the LED's V–I curve with memory less polynomial model by using these electronic measurements. AV–V block with inverse nonlinear behavior of the LED was inserted before the LED to compensate for its nonlinearity. However, these predistortion methods may not be cost-efficient approaches as they need additional physical circuits at the transmitter. In addition, the memory effects of the LED's nonlinearity were neglected. In the above discussion, the authors applied the Volterra equalization for the compensation of the LED's nonlinearity with memory effects. However, solving the Volterra coefficients needs a lot of computational resources, especially for high order Volterra kernels. In addition, the data rate decreases as the Volterra equalizer converges with a great deal of training sequences. In this project, we propose an adaptive post-distortion technique to mitigate the LED's nonlinearity with memory effects at the receiver. On one hand, unlike the wireless communications system, the channel separation in the VLC system is significantly larger than the signalbandwidth, thus the ACI performance is not an issue. On the other hand, the adaptive post-distortion only needs some computational resources without any additional physical circuits at the receiver. The adaptive post-distortion technique is more cost-efficient than the adaptive predistortion technique and is easier for implementation compared to the Volterra equalizer. The red line I Figure 1.1 shows the linear zed V–I curve with the post-distortion technique. The rest of paper is organized as follows. The upcoming section introduces the VLC system with adaptive post-distortion technique. The Wiener model is applied to describe the LED's nonlinearity with memory effects and the memory polynomial model is utilized to track and compensate for the nonlinearity with memory effects. The followed section validates the effectiveness of adaptive post-distortion technique with an AWGN channel in terms of EVM, BER, and constellation diagram performance. The final section concludes this project.

II. LITERATURE SURVEY

A predistortion method using the adaptive normalized least mean square (NLMS) algorithm is proposed for the estimation of light-emitting diode distortion. The light emission characteristic could change nonlinearly depending on conditions of the physical environment, such as temperature variation, which cannot be ignored, especially in the case of high-power emissions. Instead of using the fixed values of the conventional memory look-up-table (LUT) for nonlinearity compensation, the proposed adaptive NLMS-based predistorter immediately estimates the distortion change according to environmental changes. The simulation results show that the proposed method has better performance than the conventional predistorter employing an LUT. By modulating the optical power of the light-emitting diode (LED) in accordance with the electrical source and using a photo detector to convert the corresponding optical variation back into electrical signals, visible light communication (VLC) has been developed to achieve lighting and communications simultaneously, and is now considered one of the promising technologies for handling the continuing increases in data demands, especially indoors, for next generation wireless broadband systems. During the process of electrical-to-optical conversion using LEDs in VLC, however, signal distortion occurs due to LED nonlinearity, resulting in VLC system performance degradation. Artificial neural networks (ANNs) are thought to be capable of achieving universal function approximation, which was the motivation for introducing ANN predistortion to compensate for LED nonlinearity in this paper. Without using additional training sequences, the related parameters in the proposed ANN predistorter can be adaptively updated, using a feedback replica of the original electrical source, to track the LED time-variant characteristics due to temperature variation and aging. Computer simulations and experimental implementation were carried out to evaluate and validate the performance of the proposed ANN predistorter against existing adaptive predistorter schemes, such as the normalized least mean square predistorter and the Chebyshev polynomial predistorter.

a. Advantages of VLC

Visible light communication (VLC) is one of the main technologies driving the future 5G communication systems due to its ability to support high data rates with low power consumption, thereby facilitating high speed green communications. To further increase the capacity of VLC systems, a technique called non-orthogonal multiple accesses (NOMA) has been suggested to cater to increasing demand for bandwidth, whereby users' signals are superimposed prior to transmission and detected at each user equipment using successive interference cancellation (SIC). Some recent results on NOMA exist which greatly enhance the achievable capacity as compared to orthogonal multiple access techniques. However, one of the performance-limiting factors affecting VLC systems is

the nonlinear characteristics of a light emitting diode (LED). This paper considers the nonlinear LED characteristics in the design of pre-distorter for cognitive radio inspired NOMA in VLC, and proposessingular value decomposition based Chebyshev precoding to improve performance of nonlinear multiple-input multiple output NOMA-VLC. A novel and generalized power allocation strategy is alsoderived in this work, which is valid even in scenarios when users experience similar channels.

III.EXISTING TECHNOLOGY

As the LED only works with real and positive input voltages, the conventional OFDM signal are modified to other formats, such as ACO-OFDM and DCO-OFDM. In the transmitter Path, the information bits are modulated and assigned to all positive subcarriers and the data on negative subcarriers are complex conjugate of the data on positive subcarriers. By adding a high DC bias, the bipolar signal is converted to unipolar signal before modulating the LED intensity. Training signal $x(n)$ is the input of the LED whereas $z(n)$ is the output of the LED. The output voltage of the PD is $y(n)$, which is considered as linear with the light intensity. The training signal (n) and its corresponding receive signal $y(n)$ are used to estimate the inverse characteristics of the LED. A copy of the estimation block is inserted between the PD output and the traditional receiver path to compensate for the LED's nonlinearity with memory effects. The LED exhibits nonlinear effects as the number of emitted photons is not proportional to the injected current amplitude. Moreover, the carrier-density response is indeed frequency depended, thus giving rise to memory effects of the LED. In above discussion, it is verified that the Volterra series models achieved better accuracy than the static approaches to describe the commercial LED's nonlinearity with memory effects. The nonlinearity with memory effects can be described by Volterra model, memory polynomial model, Wiener model, Hammerstein model, etc. In this project, we assume that the LED's nonlinearity with memory effectsfollows a Wiener model, which consists of a linear time-invariant (LTI) block and a memory less nonlinear (NL) block. The BER performance can be significantly degraded as there exists interference among different constellation points. This project propose the new data driven CAP-VLC simulated environment to collect the open data sets which are then used to study the characteristics of receiver end of CAP-VLC demodulation technique. An open dataset for CAP- VLC systems is truly taken. High Speed Feed forward Neural Networks based demodulators were designed. The working principle of extreme learning machines (ELM) were deployed in proposed neural network with 15 hidden layers and 100 neurons. Then modulation features were extracted to implement the ELM basedintelligent CAP demodulators. This project also shows the design of reconfigurable and scalable CAP-VLC software test beds for the extraction of different features which can be used for experimentation. Moreover, the main objective in designing software test beds to reduce the cost and computational complexity.

IV.PROPOSED WORK

The proposed methodology consists of different phases such as System Model Design (Transmitter and Receiver), Feature extractions and finally implementation of ELM based demodulators. The working mechanism of the each and every phase is discussed in the preceding section.

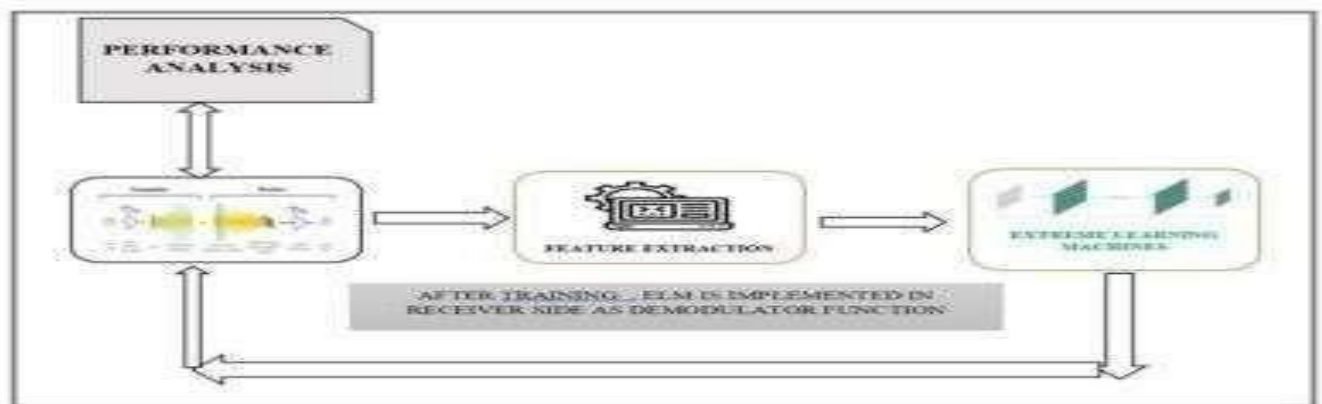


Figure. 4.1. Proposed Methodology for the ELM based CAP-VLC systems

Model of the system

A flexible end-to-end VLC system is as shown in figure 4.2. As suggested in figure 4.2 the self generated digital

signal $v(n)$ which is considered as 1010100... is modulated using CAP modulation in the base of QAM scheme. With the filter size of 31 and tap value of 3 or 5 the system performance can be improved. The real part of the signal is fed to LED and wireless channel. Those signals before transmission will get added with bias for balancing system. But the addition of forward current and DC bias introduced non-linearity in the transmission signal. Also this addition of DC bias leads to greater device bandwidth. The digital modulation process in this paper is CAP comes out with $X(t)$ as follows,

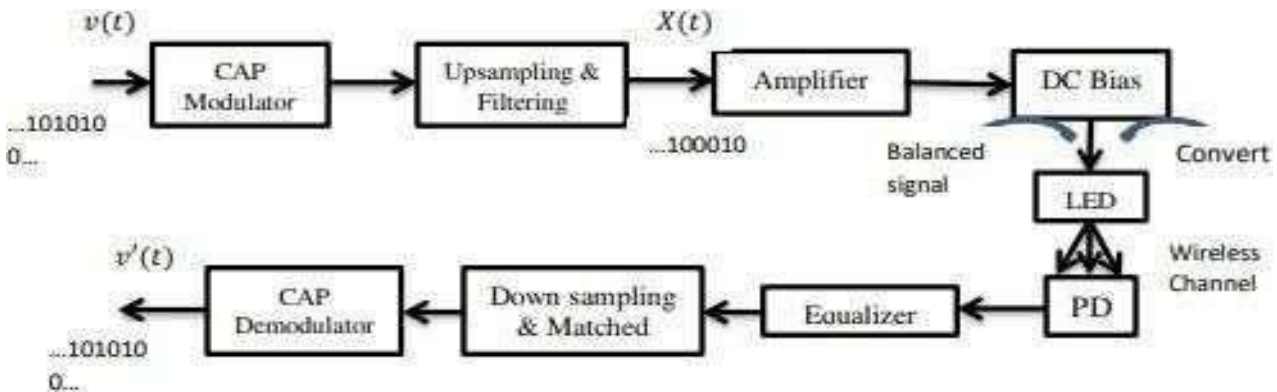


Figure. 4.2. Basic CAP modulator Designs

At the detector point the optical signals with AWG noise is filter and down sampled. The size of filter and tap is same as in transmitted side. Then the synchronized signal is fed to pre equalizer to mitigate linear distortion. After CAP demodulation and decoding the original signal can be received.

The Proposed Scheme

The diagram of the proposed DL-NPE for OFDM-based VLC system is shown in Figure 4.3. Compared with the conventional OFDM receiver in Figure 4.1, the DL-NPE replaces the traditional module, i.e., channel estimation and the constellation de-mapping, and employs two subnets, i.e., S 1 and S 2, for channel impairment compensation and symbol detection, respectively. Note that the network S 1 is composed by the cascaded sub-layer block including dense layer and activation function. As for S 2, it is made up by a cascaded sub-layer block containing dense layer, a normalization layer, and an activation function. In addition, different amounts of neurons can be used in different dense layers for both S 1 and S 2. Furthermore, the proposed scheme incorporates the traditional solution of the channel estimation and symbol detection algorithm into the system architecture.

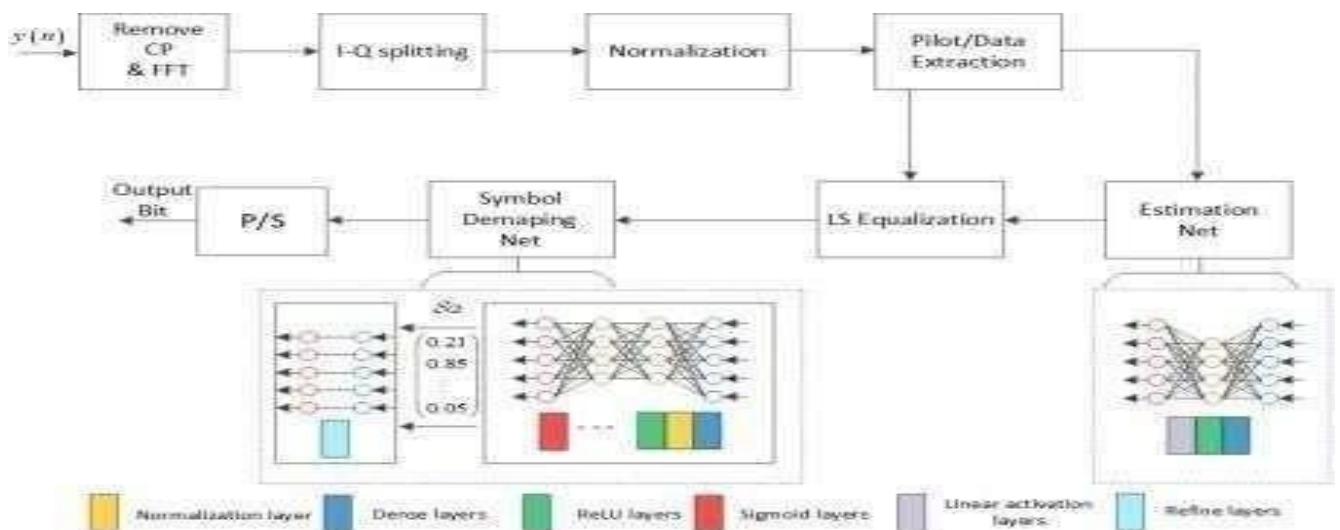


Figure. 4.3. Diagram of the proposed DL-NPE scheme for the OFDM-based VLC receiver

V. RESULTS AND DISCUSSION

In this section, simulation results based on the setup described above are presented and the corresponding discussions are also provided. Figure 5.1 depicts the normalized signal amplitude vs. the normalized input current for different MI (Modulation Index) values, where DI (DC-biased Index) = 0.5 and the length of the saw tooth-based TS is $N = 64$. As we can observe, for both $MI = 0.6$ and 0.8 , the amplitude of the received TS has a significant variation due to the additive noise in the VLC system. However, after performing PBL (Probabilistic Bayesian Learning) regression, the predicted power-current curve of the LED becomes much smoother which matches the actual power-current curve of the LED very well. Indicating an accurate estimation of the LED nonlinearity by using only a single saw tooth-based TS. We further analyze the impact of the number of TSs (Training Symbols) on the estimation accuracy of both the conventional TDA scheme and the proposed PBL-based scheme. Figure 5.2 shows the average estimation error vs. the number of TSs with $MI = 0.8$, $DI = 0.5$ and $N = 64$. For the conventional TDA (Time Domain Averaging) scheme, it can be seen that the average estimation error is gradually reduced with the increase of the number of TSs and it becomes stable at about 1.7×10^{-3} when the number of TSs reaches 20. In contrast, for the proposed PBL regression scheme, a comparable average estimation error can be achieved by using only single TS. Finally, we analyze the computational complexity of the proposed PBL-based LED nonlinearity estimation and compensation scheme. For the fast PBL regression model adopted here, PBL regression is initialized with the bias only and the basic functions are iteratively added, updated or deleted to increase the marginal likelihood. Since adding basis functions requires most of the computations, the worst-case is that a new basis function is added at each iteration and the worst-case computational complexity is given by $O(NitM^2)$ with Nit being the iteration number and M being the number of basic functions. However, the worst case scenarios are highly impossible to occur due to the inherent sparsity of PBL regression. As introduced in the above point, for common cases, an approximation of the computational complexity is about $O(NitNnz)$ with Nnz being the number of non-zero elements in the weight vector w_{MP} . More specifically, by using the fast marginal likelihood maximization method, only three elements out of totally $M = 65$ elements in w_{MP} are non-zero, i.e., $Nnz = 3$. Consequently, the proposed PBL-based LED nonlinearity estimation and compensation scheme is computational efficient which is suitable for the implementation in practical VLC systems with computing capability-limited user terminals.

VI. CONCLUSION AND FUTURE SCOPE

In this project, we have proposed a novel LED nonlinearity estimation and compensation scheme based on PBL regression for OFDM-based nonlinear VLC systems. The performance of the proposed PBL-based scheme has been evaluated by numerical simulations and further compared with the conventional TDA scheme. The obtained simulation results have shown that the proposed PBL-based scheme can accurately estimate the nonlinear power-current curve of the LED and hence efficiently compensate the adverse effect of LED nonlinearity. More specifically, the proposed PBL-based scheme with single TS can achieve a comparable BER performance as the conventional TDA scheme with totally 20 TSs. Therefore, the required training overhead for LED nonlinearity mitigation can be substantially reduced and the overall system spectral efficiency can be greatly improved by adopting the proposed PBL-based scheme. It is also shown that the proposed PBL-based LED nonlinearity estimation and compensation scheme is computational efficient, which is suitable for potential application in practical VLC systems. Even the proposed ELM based CAP-VLC system has maintained better BERs of 92.4% than all other ML based demodulators at higher SNR of 10dB and varied distances (50cm, 100cm, 125cm and 150cm). Also it clearly shows that the proposed ELM based demodulator can find as better suitability of n-CAP-VLC systems. The performance accuracy can still be improvised by the usage of self-adaptive deep learning algorithms for higher order CAP-VLC systems. Visible light communication (VLC) is a promising research field in modern wireless communication. VLC is a wireless method that enables high-speed transmission of data with visible light. This data is transmitted by modulating the intensity of light given off by a light source. Visible light communication work on low power consumption and emits low energy. VLC technology is an alternative of radio frequency, especially in those environments where radio-frequencies are considered hazardous like aero planes, hospitals, mines, etc. VLC has its irreplaceable strength including rich spectrum resources, no electromagnetic disturbance, and high-security guarantee. However, VLC systems suffer from the non-linear effects that exist in almost every part of the system. As a part of artificial intelligence, machine learning (ML) is showing its potential in non-linear mitigating for its natural ability to fit all kinds of transfer functions, which may dramatically push the research in VLC.



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