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# VOICE TRANSMISSION BASED ON MACHINE LEARNING USING VISIBLE LIGHT COMMUNICATION SYSTEM

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*Abstract*— **In this paper, we investigate the design and implementation of machine learning (ML)-based demodulation methods in the physical layer of visible light communication (VLC) systems. We build a flexible hardware prototype of an end-to-end VLC system, from which the received signals are collected as the real data. The dataset is available online, which contains eight types of modulated signals. Then, we propose three ML demodulators based on convolutional neural network (CNN), the deep belief network (DBN), and adaptive boosting (AdaBoost), respectively. Specifically, the CNN-based demodulator converts the modulated signals to images and recognizes the signals by the image classification. The proposed DBN-based demodulator contains three restricted Boltzmann machines to extract the modulation features. The AdaBoost method includes a strong classifier that is constructed by the weak classifiers with the knearest neighbor algorithm. These three demodulators are trained and tested by our online open dataset. The experimental results show that the demodulation accuracy of the three data-driven demodulators drops as the transmission distance increases. A higher modulation order negatively influences the accuracy for a given transmission distance. Among the three ML methods, the AdaBoost modulator achieves the best performance.**

*Keywords*— **Visible light communication, machine learning, demodulation, CNN, DBN, AdaBoost.**

## I. INTRODUCTION

With the rapidly increasing number of mobile digital devices and the soaring high volume of wireless data traffic, the high speed wireless transmission is also highly demanded. Visible light communication (VLC), with advantages like huge unregulated spectrum, high security and immunity to electromagnetic interference, has sparked significant research attention as a promising solution. Short range wireless communications. Through massive deployment of light-emitting diodes (LEDs), VLC typically employs the intensity modulation and direct detection technique for both the illumination and data transmissions where the information is represented by the real and nonnegative light signals. Lighting is a major source of electric energy consumption. Visible light communication is a data communications medium using visible light between 400 THz-800THz. Traditional radio frequency (RF) systems are currently facing spectrum crisis, which is the bottleneck of enhancing the network capacity. VLC typically employs the intensity modulation and direct detection technique for both the illumination and data transmissions where the information is represented by the real and nonnegative light signals. Demodulation of radio signals plays a fundamental role in VLC systems. In general, the traditional demodulators could be categorized into two classes: coherent and non-coherent demodulators. Moreover, the priori knowledge, such as channel state information (CSI) or channel noise, is usually required. However, in fast-fading scenarios, CSI is usually hard to estimate since the fading coefficients vary quickly within the period of one transmission block. Besides, most of existing works assume that the VLC channel suffers from additive white Gaussian noise (AWGN), and thus the applied demodulators are optimal in terms of the AWGN channel. However, the practical VLC channels are not easy to model since there exist too many factors, including but not limited to: limited modulation bandwidth of LEDs, multi-path dispersion, impulse from additive white Gaussian noise (AWGN), and thus the applied demodulators are optimal in terms of the AWGN channel. However, the practical VLC channels are not easy to model since there exist too many factors, including but not limited to: limited modulation bandwidth of LEDs, multi-path dispersion, impulse noise, spurious or continuous jamming, and low sensitivity of commercial photodetector (PD).

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## II. Proposed Work

### A. System Model -

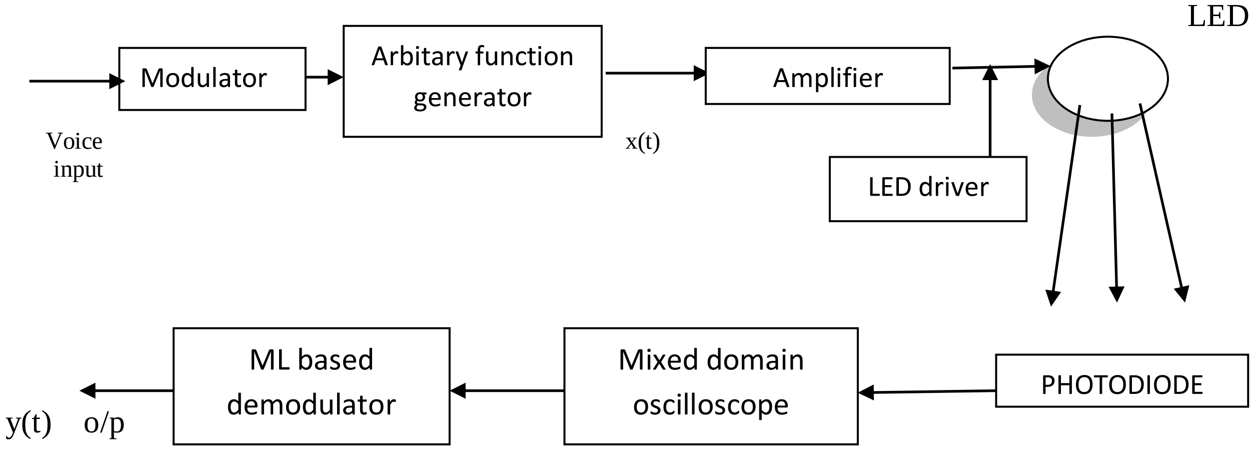


Fig. 1.Basic Block Diagram working of ML based VLC system

### B. *Methodology:*

As illustrated in Fig. 1, we propose a flexible end-to-end VLC prototype, which consists a modulation block, an arbitrary function generator, an amplifier, a bias-T, a LED driver, a single LED, a single PD, a mixed domain oscilloscope, and a ML based demodulation block. According to Fig. 1, the digital signal s(n) is modulated by the M-QAM scheme, converted to the analog signal by the arbitrary function generator, and further amplified by the amplifier. After amplification, the signal adds the direct current (DC) at the Bias-T. Finally, the signal is transformed to the visible light by LED, and sent out to the wireless channels. At the receiver, the optical signal from LED is converted to the analog signal through PD, and then the analog signal is converted to a digital signal at the mixed domain oscilloscope. Afterwards, the digital signal is demodulated by the ML based demodulator.

***Visible Light Communication:***

VLC is an optical communication technology that use visible light rays, these rays locate between [400-800] THz, as optical carrier for data transmission by illumination. It uses fast pulses of light, which cannot be detected by the human eye, to transmit data. It includes any use of the visible light portion of the electromagnetic spectrum to transmit information. The VLC standardization process is conducted within IEEE wireless personal area networks working group (802.15). [One of VLC"s features is providing wide bandwidth as illustrated in Figure 2. We can obviously see that usage the optical portion of spectrum guarantees about 10,000 times greater bandwidth compares to the usage of the RF frequencies.

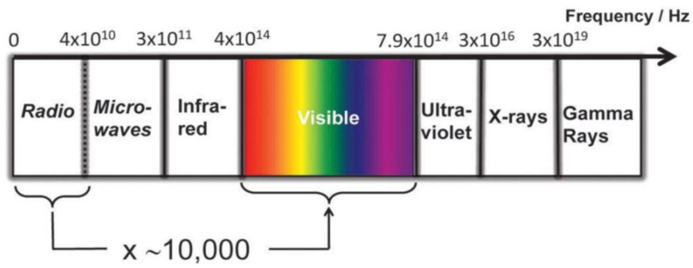


Fig. 2.Visible Light Communication System

***Components:***

As we see in the previous paragraph, VLC is a communication system which consists of a transmitter, a receiver and a communication channel. The main components of VLC systems are:

- High brightness Light-Emitting Diodes (LEDs) or any light sources, which acts as transmitter.
- A silicon photodiode has the roll of a detector and it shows a good response to visible wavelength.
- Communication channel is air or fibre optics.

Usually, we add to these components some necessary circuits like a driving circuit and a receiving circuit. The driving circuit consists of a control circuit and output stage to modify the data and make it ready to be sent and the receiving circuit consists of a filter to select the required band, amplification stage to provide the required Signal to Noise ratio in order to demodulate the signal.

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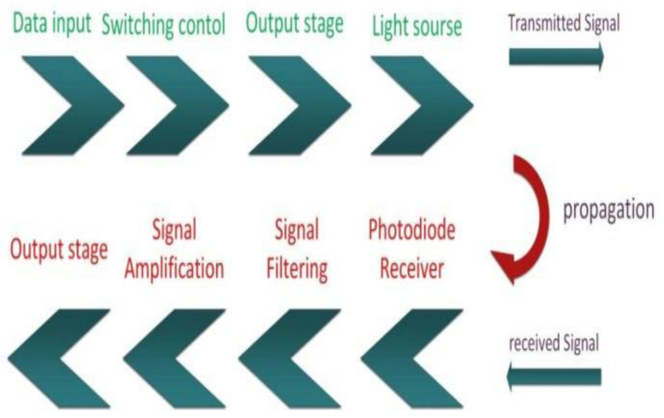
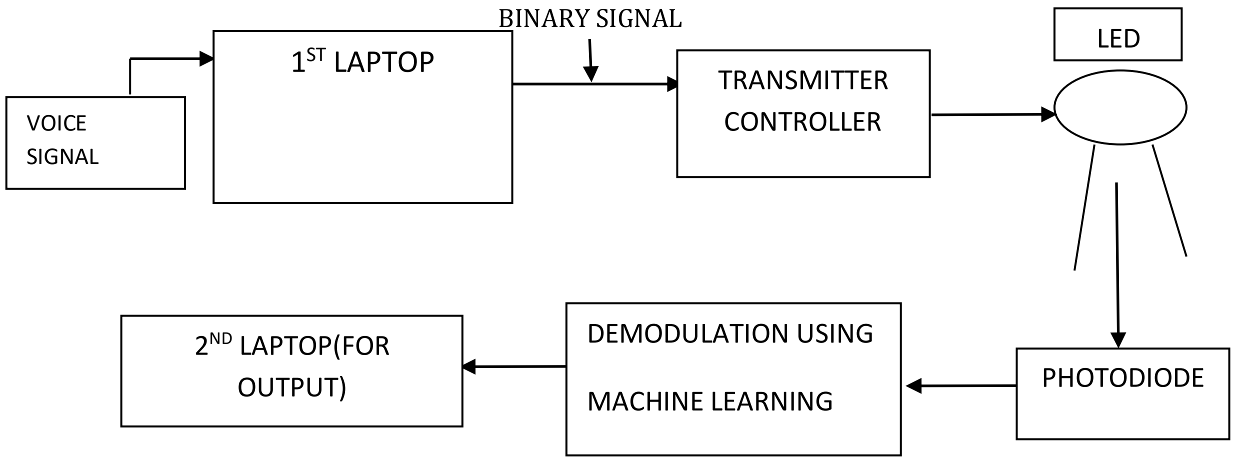



Fig. 3.Transmitted signal and received signal

Fig. 4.Practical block diagram




***HARDWARE:***

- LED
- PHOTODIODE
- PL2303
- LED DRIVER
- TRANSMITTER AND RECIEVER

***Working of LED and PHOTODIODE:***

Li-Fi technology is implemented using white LED light bulbs used for illumination by applying a constant current. However, by fast variations of the current, the light output can be made to vary at extremely high speeds. If the LED is on, it transmits a digital 1otherwise it transmits a digital 0. The LEDs can be switched on and off quickly to transmit data that can′t be detected by a human eye. So what we need at all for sending data are some LEDs and a controller that cods data into those LEDs and for receiving data, we need an Image Sensor, Photodiode which is used as a detector, these components are shown in Figure 3. The LED bulb will hold a micro-chip that will do the job of processing the data. The light intensity can be manipulated to send data by tiny changes in amplitude. the working principle of Li-Fi s/m.

Fig. 5.LED

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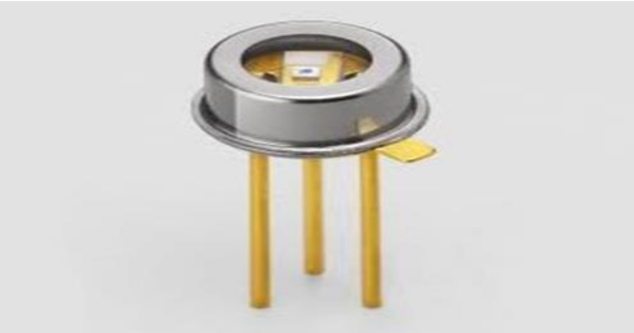

Fig. 6.PHOTODIODE

***Working of PL2303 and Transmitter & Receiver:***

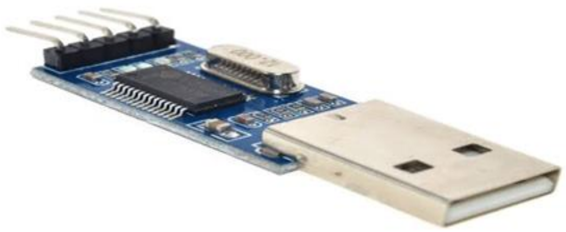

Fig. 7.PL2303 USB PORT

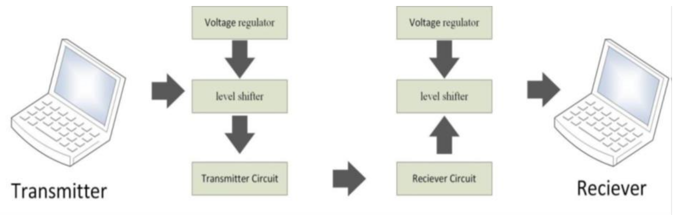


Fig. 8.Transmitter and Receiver

In a PL2303 USB module it is small USB to TTL serial tool, using the PL2303 chip. You can use it to connect some serial device to your PC for data transmission; it can be done by single LED or multi LED. On the receiver side there is a photo detector, which convert this light into electric signals and it will give the electric signals to the device connected to it. Voltage regulator and level shifter circuits are used on both sides to convert or maintain a voltage level between transmitter and receiver.

Fig. 9.Data Transmission using LED

***SOFTWARE:***

MATLAB(GUI)

MACHINE LEARNING(AdaBoost)

***MATLAB (GRAPHICAL USER INTERFACE):***

Matlab is designed to operate efficiency on matrices. (hence MATLAB = “matrix” laboratory). Consequently, MATLAB treats all variables as matrices.

The GUI typically contains control such as menu, toolbars, buttons, and sliders. Many MATLAB product, such as curve fitting toolbox, signal processing toolbox, and control system toolbox include apps with custom user interfaces.

Deliver message by voice is the most important, effective and common method of exchange information for mankind. the voice has large information capacity.so we can use modern method to study voice processing technology, so that people can easily transmit, store, access and apply the voice. we can use MATLAB’s function to remove the noise which has been added to the voice.

***MACHINE LEARNING (AdaBoost):***

Machine learning is an application of artificial intelligence that provide systems the ability to automatically learn and improve from experience without being explicitly programmed. MACHINE LEARNING focus on the development of computer programs that can acess data and use it learn for themselves. The AdaBoost method includes a strong classifier that is constructed by the weak classifiers with the k-nearest neighbour (KNN) algorithm. AdaBoost refers to a particular method of training a Boosted classifier. For example in the two vclass problem, the sign of the weak learner output identifies the predicted object class and the absolute value gives the confidence in that classification.

***ADABOOST BASED DEMODULATOR:***

AdaBoost algorithm is a powerful tool that can integrate multiple independent weakly classifiers into a high-performance stronger classifier. In this paper, we exploit the AdaBoost method to demodulate signals, where the generation process of strong classifier is shown in. Here, KNN is employed as the weak classifier.

Suppose that the strong classifier is composed of Q KNNs . For the qth KNN, the weight of samples in T is represented by

dq = [dq,1, dq,2, . . . , dq,K ]^T, q =1, 2, . . . , Q, and dq,i stands for the weight of the ith sample in T . When q = 1, dq,i = 1/K, i = 1, 2, . . . ,K. The training set of the qth KNN is represented by Tq, which is generated by re-sampling of T according to dq .

## III. EXPERIMENT RESULTS AND DISCUSSIONS

The proposed end-to-end VLC system prototype includes a source computer, an arbitrary function generator, an amplifier, a bias-T, a LED, a sliding rail, a PD, and a mixed domain oscilloscope. We use this prototype to generate the real VLC modulation dataset and verify the proposed data-driven demodulation methods. The parameters of the devices used in the end-to-end VLC system prototype are listed in Table 2. In the experiments, a serial binary bit stream is randomly generated and modulated in 8 different types of signals on computer with MATLAB. We sample N points in one period to generate modulated digital signals for each scheme, which is transferred to analog waveforms by the arbitrary function generator. The modulated current after amplification is super□imposed on LED. At the receiver, the sampled digital signals are monitored and shown by the mixed domain oscilloscope. After normalization, we treat the signal in one period as input of DBN for training and testing. In CNN, we transfer the vector into image as demonstrated in Section III. The vector is considered as the feature of transmitted symbol and processed by AdaBoost so that it can be demodulated. Our open dataset2 contains eight modulation types, i.e., OOK, QPSK, 4-PPM, 16-QAM, 32-QAM, 64-QAM,128-QAM and 256-QAM. For each type of modulation, there are four different numbers of sample points in each period, i.e., N = 10, 20, 40, 80. The number of periods in each case is listed in Table 3. Specially, N = 8, 16, 32, 64 for 4-PPM. Let d denote the distance between LED and PD. The data is collected for every 5cm from d = 0cm to d = 140cm and normalized. The illuminance of the ambient light is about 85 Lux. At the distance of d = 100cm, the illuminance of the LED is 492 Lux. Our database is available at https://pan.baidu.com/s/1rS143bEDaOTEiCneXE67dg.Eight modulation schemes are tested in experiments, where the numbers of signal periods for training and testing are listed in . For the DBN demodulator, we adopt the gradient descent method in pre-training stage. Then, the parameters are fine-tuned by the BP algorithm. For the CNN demodulator, the BP algorithm is also used to train parameters.

Table -1 Devices and Parameters of the VLC system prototype.

| Device/Parameter | Value |
|---|---|
| Arbitrary function generator | Tektronix AFG3152C |
| Sampling Rate | 2500000 samples/second |
| Amplifier | Mini-Circuits ZHL-6A-S+ |
| Gain of Amplifier | 25dB |
| Bias-T | SHWBT-006000-SFFF |
| PD | PDA10A-EC |
| Field of View (FOV) of PD | 90º |
| Responsivity of PD | 0.44A/W at 750nm |
| Mixed Domain Oscilloscope | Tektronix MDO3012 |
| Power Of LED | 7.35W¹ |
| Half-Intensity Radiation Angle | 60º |

Table -2 The Structure and size of the Dataset.

| Modulation | N | | | |
|---|---|---|---|---|
| | 10 | 20 | 40 | 80 |
| OOK | 72000 | 36000 | 18000 | 18000 |
| QPSK | 72000 | 36000 | 18000 | 18000 |
| 4-PPM | 90000 | 45000 | 22500 | 11250 |
| 16-QAM | 67500 | 33750 | 18000 | 18000 |
| 32-QAM | 81000 | 36000 | 36000 | 36000 |
| 64-QAM | 81000 | 72000 | 72000 | 72000 |
| 128-QAM | 81000 | 72000 | 72000 | 72000 |
| 256-QAM | 81000 | 72000 | 72000 | 72000 |

## IV. CONCLUSION

In this paper, three data-driven demodulators (CNN, DBN,and AdaBoost) based demodulators are designed for the physical layer of VLC systems. A flexible end-to-end VLC system prototype is constructed for real data collection. By using the proposed prototype, an open online real modulated dataset is created, which consists eight types of modulated signals, i.e., OOK, QPSK, 4-PPM, 16-QAM, 32-QAM, 64-QAM, 128-QAM and 256-QAM. Based on this real dataset, we investigate the demodulation performance of the proposed three demodulators. Experimental results show that for a given transmission distance, the demodulation accuracy decreases as the modulation order increases. Moreover, that the demodulation accuracy of the AdaBoost based demodulators is higher than other demodulators. For the short distance or high SNR scenario, a high-order modulation is preferred. In the future, we will further investigate dedicated ML base demodulators for VLC systems. There are many applications that can be realized using Visible Light Communication.

Careful consideration will be needed to introduce it into a market.

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