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Predicting suitable modulation type using Machine Learning Algorithms in FSO system

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Abstract: Free space optical communications (FSO) offers many and varied advantages, including high data transfer speed, ease of installation and deployment compared to fiber-optic communications, in addition to not requiring a license. However, this technology suffers from some obstacles, which are represented by weather conditions that obstruct the laser during the transmission process. In addition, in recent years, artificial intelligence technologies have been introduced into free-space communications systems. This research presents work in two stages. The first is to implement a simulation of the FSO system using Optisystem program with two types of modulation, Non Return to Zero (NRZ) and Return to Zero (RZ), in different weather conditions (Clear - Rain - Fog). In the second stage, machine learning algorithms have been used to predict the best type of modulation depending on the weather condition. The results showed that the Random Forest (RF) algorithm gave better results in prediction accuracy compared to the Support Vector Regression (SVR) and K-Nearest Neighbors (KNN) algorithms.

Keywords: FSO, Optisystem, Machine Learning Algorithms, RZ, NRZ

1 Introduction

FSO technology has received great attention due to the many advantages it offers. This technology is similar to fiber-optic communications except that the laser is transmitted in free space from the sender to the receiver instead of using optical fibers [1-3]. An important condition in FSO technology is to achieve line of sight (LOS) between sender and receiver to ensure that data arrives correctly [4][5]. One of the advantages offered by FSO is that it meets the greatly increasing demands of users for high data rates. The speed it provides varies depends on the distance and weather conditions from the sender and the receiver. FSO does not require a license worldwide [6][7]. FSO technology is implemented on the ground between satellites or even between the ground and the satellites using a low-power laser beam carrying the data to be transmitted that does not harm eyes between the sender and the receiver [8]. This technology is used in military applications and all fields that require high confidentiality because of its advantage in providing security and high confidentiality of transmitted data. However, there are some drawbacks and limitations to this technology. There are many parameters that affect the system performance. These parameters include transmission frequency bandwidth of laser, transmission power of the laser. Besides these conditions, there are the atmospheric conditions and turbulence that impede the passage of laser during its transmission. These factors deteriorate the system performance [4][6]. Rain, fog, and snow particles present in the atmosphere scatter and absorb the laser. This in turn leads to a weakening and attenuation of the signal [9] [10]. Dispersion results in the phenomenon of multipath. As a result of this phenomenon, the signal is distorted at the receiving device and the value of bit error rate (BER) increases. BER is an important and major factor in determining system performance and thus it has been adopted in this work. There are several techniques to overcome these drawbacks and improve system performance, including modulation, encoding, and many other methods [11] [12].

Recently, machine learning algorithms (MLAs) have been introduced into optical telecommunications networks, bringing intelligence to these networks by predicting important network parameters. In addition, in some studies, the FSO channel was predicted through the use of neural networks expanded for the repetitive unit (GRU) after they obtained the signal strength information at the receiving side (RSSI). The present research relied on an experimental room in which the climate changed. The obtained results showed that FSO channel fading is predicted with high accuracy [13]. Also Machine learning algorithms are used to monitor the type of distortion in the optical channel, in a hybrid fiber optical/ FSO system. Gaussian process regression (GPR) was used to predict optical channel defects, and the performance was evaluated using root mean square error (RMSE) and R2 histograms. The results show that the model is able to predict with high accuracy channel defects except for strong amplified spontaneous emission (ASE) noise [14], and in [15] the researchers used machine learning techniques to estimate the signal quality at the receiving end in terms of BER values, in a RO-FSO system that uses orthogonal frequency division multiplexing (OFDM) modulation technology. The results showed that the artificial neural network (ANN) algorithm gave better results than the KNN and DT algorithms in terms of R2 and RMSE coefficient values.

In this research, FSO connection has been implemented using NRZ and RZ modulation techniques. The purpose is conducting comparison between the performance of NRZ and RZ in different weather conditions (rain - fog - clear) using Optisystem software. After that, machine learning algorithms (RF - KNN – SVR) were used to predict the proper modulation depending on the weather condition during the transmission process. RMSE coefficient is the main parameter for calculating the accuracy of each algorithm and finding out which algorithm is the best in prediction.

The rest of this research is organized as follows: in the second section, material and methods have been presented. In the third section, the different weather conditions have been discussed. In the fourth section, the used machine learning algorithms have been presented. In the fifth section, the design of the FSO system using Optisystem software is presented. In the sixth section the results have been discussed and finally the research has been concluded.

2 Materials and Methods

Optisystem simulator has been used in the first phase of the research to implement the proposed system. Optisystem is dedicated to simulate wired and wireless optical communications systems. The second stage of the research involved using Python language to implement MLAs for the required prediction process.

The research methodology included introducing the FSO system with its advantages and disadvantages by studying fog and rain weather conditions and their effect on the transmitted signal and thus the system's performance. Finally, MLAs were applied experimentally in order to predict the appropriate type of modulation of the proposed system in different weather conditions.

3 Impact of weather conditions on the FSO channel

Weather conditions such as fog, rain or snow that obstruct the laser while it is transmitting in free space are among the influences that degrade the performance of the FSO communications system. Attenuations, resulting from each weather condition, affect the signal sent through the atmosphere and are as follows.

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- Attenuation of Fog: The Beer-Lambert law states that attenuation due to fog in the transmitted optical signal and at a distance R between the transmitter and receiver is given by equation (1) [16].

$$A_{foff} = \frac{3.912}{V(km)}\left(\frac{\lambda}{\lambda_0}\right)^{-q} \qquad (1)$$

Where: V is the visibility, λ: is wavelength of transmitting laser in nm, $\lambda 0$: is the reference of visibility at wavelength $\lambda 0$, q: determines scattering size distribution factor [16].

- Attenuation of Rain: Rain is less effective compared to fog and the attenuation value in rain is lower than in fog since the attenuation increases with the increase in rain rainfall intensity. Equation [2] describes the attenuation resulting from rain according to equation (2) [17]:

$$\alpha_{\text{rain}} = 1.076\ R^{0.67} \qquad (2)$$

4 Machine Learning Algorithms used in this work

Supervised learning algorithms have been used to predict a specific variable by finding a function that combines a set of input variables called features. Supervised learning algorithms are divided into two types: regression algorithms and classification algorithms. In this work, regression algorithms have been used.

a. Support Vector Regression (SVR)

SVR is an implementation of the SVM algorithm in the regression and not classification section, [18] [19], as it was applied in many problems related to regression, including signal processing and data mining, and gave good results in them. The primary goal of the SVR algorithm is to minimize the prediction error values of the target values after finding a function relating the input features and the continuous target variable. This is done by finding the best fitting line, where the best fitting line in SVR is the hyperplane with the largest number of samples [20].

b. Random Forest (RF):

RF is a supervised machine learning algorithm. It is of great importance in giving accurate results especially when compared to a decision tree algorithm. The random forest is a group of decision trees that work in parallel for the prediction process. Each decision tree consists of a partial set of the total data and produces its own prediction result. Finally, the arithmetic mean of the prediction values for all trees is calculated. This algorithm gives good results in addition to reducing over-fitting and the process of interpreting the results is simple [21].

c. K-Nearest Neighbors (KNN)

KNN algorithm is used to solve classification and regression problems. The basic idea of its working principle is that it groups similar samples together. During the training process, this algorithm collects a set of training samples and stores them as a reference. The KNN then predicts the values of the new data based on the amount of similarity to the previously stored data. This algorithm is easy to implement.

However, its main disadvantages are the difficulties in finding the correct value of K which often depends on experience [22].

After applying the MLAs to the database, the models performance was evaluated by measuring the Root Mean Square Error (RMSE). The smaller the value of this measure is, better the prediction value is. The season is that it expresses the amount of difference between the true value and the expected value and shown in equation (3) [23]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{N}} \qquad (3)$$

5 The Proposed System

In the first stage, Optisystem simulator was used to build the FSO system in different weather conditions. BER values were calculated according to each weather condition and different distances in two cases. The first case is using the NRZ modulation and the second case is using the RZ modulation.

In the second stage, machine learning algorithms were used in order to predict the appropriate type of modulation depending on the weather condition during the transmission process. Applying theses algorithms has been done on the database collected from the first phase of the Optisystem simulator. The database contains attenuation values depending on the weather condition, the type of modulation used, and the distances the signal reaches in each case in addition to BER values. The dataset collected from the first stage is 350 lines long. Before machine learning algorithms were applied to it, we performed some processing operations on the data. After that, the dataset was divided into two groups: a group for training the model, which constitutes 80 percent of the total data, and a group for testing the model, which constitutes 20 percent of the total data. The model is trained and then tested to determine its ability to predict if new data is entered into it.

Figure 1, shows the design of the system using the Optisystem simulator. Bits are generated in the form of a sequence of zeros and ones through the Pseudo Random Binary Sequence (PRBS) block at a rate of 2.5 Gbps. These bits are then transmitted to the generator used, NRZ or RZ. After that they pass through the laser rate which allows us to determine different parameters. The laser then travels into free space.

In this research, attenuation values have been discussed depending on the weather condition in addition to the distance between the transmitter and the receiver. The attenuation values were set as shown in Table 1.

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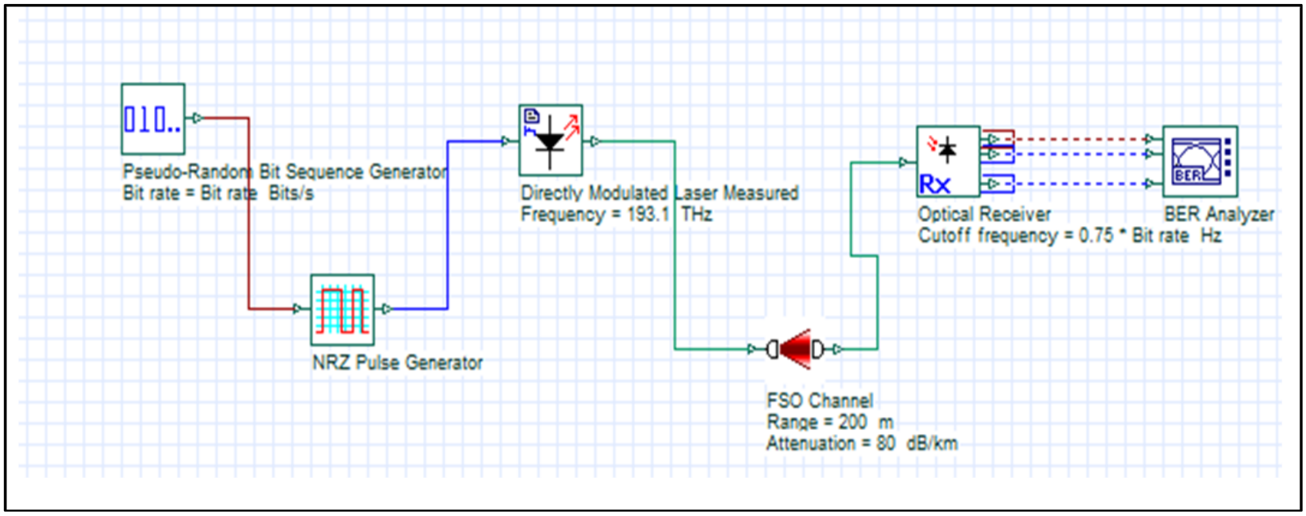

Figure 1: FSO system

Table 1: Parameters of Simulation

Parameters		Values
The attenuation Value in (dB/km)	Dense Fog	80.904
	Mild Fog	33.961
	Low Fog	15.55
	Dense Rain	10.115
	Mild Rain	4.285
	Low Rain	1.537
	Clear	0.155
Wave Length (nm)		1550

6 Experimental Results

As mentioned previously, the Optisystem simulator has been used to obtain all the results and form the database where the results were presented in two stages. In the first stage, the results of the study were presented for attenuation versus distance for the two types of modulation (NRZ and RZ) under different weather conditions (clear - rain - fog). In the second stage, the RF, SVR, and KNN algorithms were applied to the database collected from Optisystem in this work. Figure 2, shows the distance the signal reaches under the effects of weather conditions, Clear, Rain and Fog. In clear weather, it is noticed that when using the NRZ modulation, the signal reaches a distance of 1300m with acceptable BER values. When using the RZ modulation, the signal reaches a distance of 1500m. When the weather conditions change and the attenuation value increases, the signal reaches a shorter distance. In rainy weather, when attenuation value increases, the signal reaches a distance of 410m in the case of NRZ modulation and a distance of 600m in the case of RZ modulation. In the case of foggy weather, which is the condition that most hinders the passage of the laser compared to rain, the signal, when using NRZ modulation, reaches 275m, while in the case of RZ, the signal reaches only 150m.

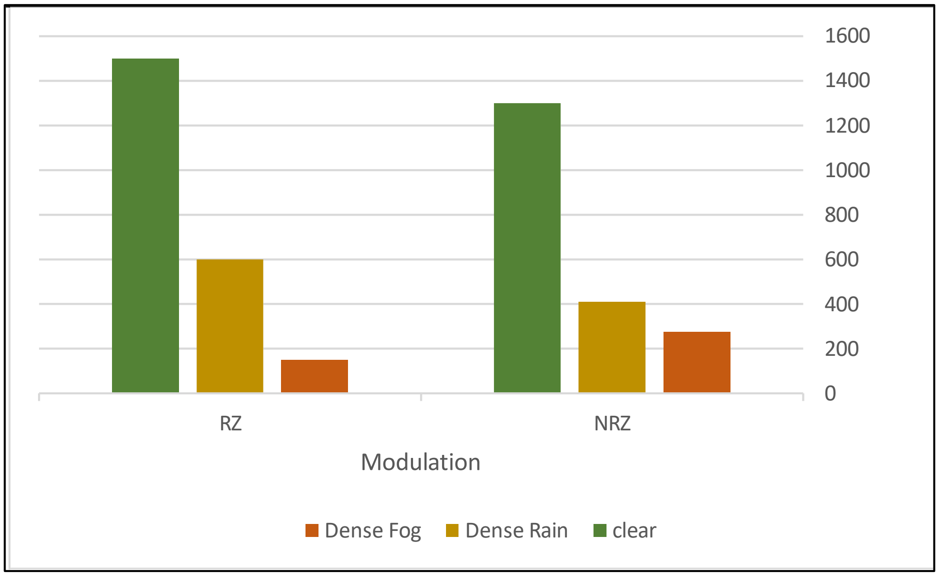

Figure 2: Modulation vs distance under different weather condition

From these results, it is noticed that the NRZ modulation gives better results than the RZ modulation in the case of foggy weather where the signal reaches a greater distance. However, in the case of clear and rainy weather, that is, at lower attenuation values, the RZ modulation shows lower BER values than the NRZ at the same distance, that is, the

signal reached in this case to a greater distance. Figure 3 shows the prediction accuracy of machine learning algorithms based on the RMSE criterion. From the Figure 3, it is noticed that the random forest algorithm gives RMSE=0.028. The KNN algorithm gives RMSE = 0.058, and the SVR algorithm give RMSE = 0.080.
From the results obtained, it is noticed that the RF algorithm gives better accuracy than the remaining two algorithms because it gives the lowest RMSE value.

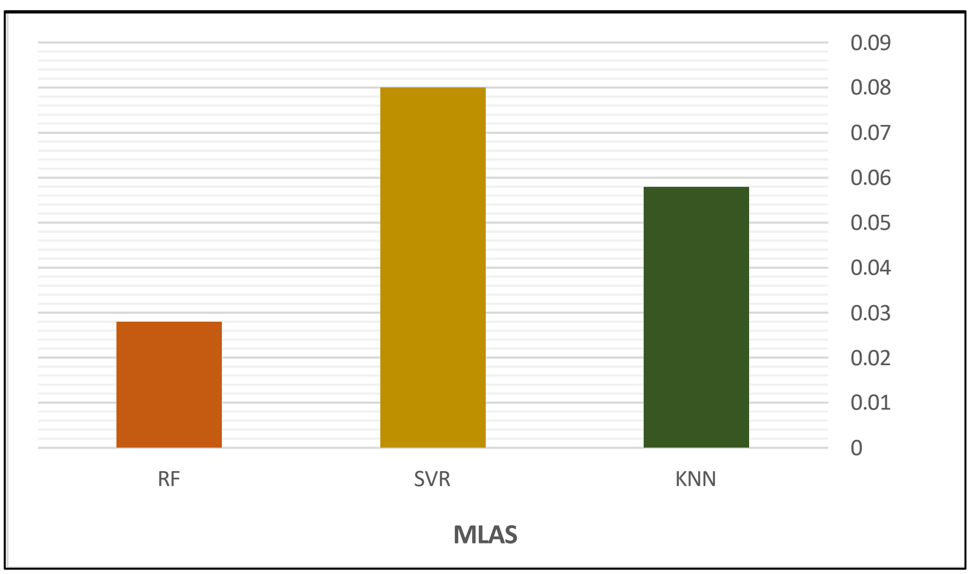

Figure 3: Predicting accuracy of MLAs depending on RMSE

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Table 2 shows summary of prediction results of MLAs that obtained from simulation.

Table 2: summary of prediction results of MLAs

	RF	DT	SVR
RMSE	0.03	0.1	0.9

7 Conclusions

In this research, the best modulation type, RZ or NRZ, has been predicted depending on the weather conditions during the transmission process, using MLAs in the FSO system. It should be noticed that this research was carried out with only two modulation techniques. It is possible to use other modulation types that give better results in different weather conditions. Based on the results obtained, the SVR algorithm is not suitable for use in FSO systems to predict the best modulation type. The RF algorithm gives results with better accuracy than the other two algorithms.

Machine learning techniques can be used to predict other parameters such as quality factor, BER or other channel-related parameters. In addition, deep learning techniques can also be used to introduce intelligence after adding techniques to the FSO system to mitigate the effects of weather conditions and turbulence, such as coding techniques that detect and correct errors.

Conflicts of Interest Statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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