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Automatic determination of digital modulation types with different noises using Convolutional Neural Network based on time–frequency information

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ABSTRACT

In this study, a novel digital modulation classification model has been proposed for automatically recognizing six different modulation types including amplitude shift keying (ASK), frequency shift keying (FSK), phase-shift keying (PSK), quadrate amplitude shift keying (QASK), quadrate frequency shift keying (QFSK), and quadrate phase-shift keying (QPSK). The determination of modulation type is significant in military communication, satellite communication systems, and submarine communication. To classify the modulation types, we have proposed a two-stage hybrid method combining short-time Fourier transform (STFT) and convolutional neural network (CNN). In the first stage, as the data source, the time–frequency information from these modulation signals have been extracted with STFT. This information has been obtained as 2D images to feed the input of the CNN deep learning method. In the second stage, the obtained 2D time–frequency information has been given to the input of the CNN algorithm to classify the modulation types. In this work, noises at various SNR values from 0 dB to 25 dB were created and added to the modulated signals. Even in the presence of noise, the proposed hybrid deep learning model achieved excellent results in the noised-modulation signals.

1. Introduction

Based on the characteristics of the communication channel used in data communication, basic band signal transmission, or band-passing signal communication can be performed [1,2]. If the communication channel is a short-range conductor cable, it can be expressed using pulses corresponding to data logic 1 and logic 0 without any modulation process [3]. However, if the communication channel is in the air environment or if it is in the case of very long-distance wired communication, the data encoded in pulse code modulation (PCM) format must be modulated using carriers in a specific frequency range to make it suitable for transmission throughout the channel [4]. Automatic modulation classification (AMC) has been an important part of many militaries, security, and civil telecommunications applications for many years [5]. In military and security applications, modulation is used as another level of cryptography. In civil applications, multiple modulation types are implemented with a signal transmitter to control data rate and line security. By automatically classifying the modulation type on the receiver side, the receiver will not need to be warned about the modulation type, and the demodulation process is successfully performed without any changes [6].

As a result, since the transmitted signal does not require modulation information in the frame, the spectrum efficiency will increase. AMC has been part of intelligent radio systems, including conceptual radio and software-defined radio [7].

In the literature, there are many machine learning methods and studies related to AMC [8–10]. Zhechen Zhu and Asoke K. Nandi have written a book on AMC and have made applications in various fields. In this book, many attribute extraction methods and classification algorithms are described and applied to various modulation signals, and different applications are given [11]. In Afan Ali and Fan Yangyu studies, principal component analysis (PCA) and two different class-based hybrid methods have been proposed to classify three different modulations including phase-shift keying (PSK), frequency-shift keying (FSK) and quadrate amplitude modulation (QAM) [12]. First, the size reduction by PCA algorithm has been performed and then there are three different types of modulation with classification algorithms including *k*-nearest neighbor (KNN) and Support Vector Machine (SVM) [12]. In the study of M. Bouchou, H. Wang and M. E. H. Lakhdari et al. a new method based on the Stacked Sparse Auto-Encoder (SSAE) has been proposed to recognize the modulations containing BPSK, QPSK, 8PSK, 16QAM, 64QAM, 16APSK,

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and 32APSK. They have achieved 100% accuracy by adding 5 dB noise [13]. F. O. Akyön et al. in their studies, they proposed a new method based on deep learning that automatically recognizes intra-pulse modulation types in radar signals. The study also used a reallocated short-term Fourier Transform (STFT) of the measured signals [14]. K. Zhang et al. on the other hand, the data-driven dictionary-learning-based automated modulation classification platform has been proposed [15]. In the work of Xiaoyu Liu, Diyu Yang, and Aly El Gamal [16], they proposed a novel framework combining of CNN and LSTM to classify the modulation signals including BPSK, QPSK, 8PSK, QAM16, QAM64, BFSK, CPFSK, and PAM4 with the noises. And then, they achieved 88.5% at high SNR [16]. In the study of Sharan Ramjee, Shengtai Ju, Diyu Yang, Xiaoyu Liu, Aly El Gamal, Yonina C. Eldar [17], they proposed a hybrid model based on PCA and deep learning for modulation signals classification and then obtained 90% even with the high SNR noises in the classification of the digital modulations. Yuan Zeng and et al. proposed a method to classify the 11 different modulation signals including BPSK, QPSK, 8PSK, 16QAM, 64QAM, BFSK, CPFSK, PAM4, WB-FM, AM-SSB, and AM. In their method, they used the STFT for feature extraction and then used the CNN for classification algorithm [18]. Daldal et al. proposed a novel deep learning based model for digital modulations signal classification and obtained the high classification performance in the classification of six different digital modulation signals including Amplitude Shift Keying, Frequency Shift Keying, Phase Shift Keying, Quadrature Amplitude Shift Keying, Quadrature Frequency Shift Keying, and Quadrature Phase Shift Keying [19]. Daldal et al. proposed a novel data pre-processing named as Neutrosophic c-means (NCM) based feature weighting (NCMBFW) for weighting the modulation signals dataset and then combined it with the classifier algorithms for classification of four digital modulation signals including the multi-carrier amplitude shift keying (MC-ASK), frequency shift keying (MC-FSK), and phase shift keying (MC-PSK) modulation types. They achieved the superior results compared to the other conducted works in the literature in the recognition of MC-digital modulation signals [20].

When the literature is examined, it can be seen that the several combinations of the hand-craft feature extraction and selection methods and machine learning models have been utilized for the AMC task. Considering the high generalization abilities as well as the advantageous of the end-to-end learning schema of the CNNs in various fields, we adopt this approach to AMC. More specifically, a hybrid model based on the combination of STFT and convolutional neural network (CNN) is proposed in AMC. We have realized the application of this hybrid method to the solution of AMC problem for the first time. In the proposed study, the 2-dimensional data source has been obtained from the modulated signals using STFT method and the spectrogram images obtained have been given as an input to the CNN deep learning algorithm, and modulation types have been determined automatically.

This article consists of six sections. Section 2 provides material and method. The proposed model is explained in Section 3. The experimental results are given in Section 4. Section 5 gives a discussion about the results. Lastly, Section 6 concludes the results and also shed light on future works.

2. Material and method

2.1. The formations of basic modulation types (ASK, FSK, and PSK) and demonstrations of these modulation signals on MATLAB

This digital transmission is referred to as digital passband modulation because the digital baseband signal in the carrier modulation is converted into a band-limited high-frequency passband signal. Transition band modulations are three kinds, including Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK).

Table 1
The basic modulation equations explaining ASK, FSK, and PSK.

$X_{ASK} = A_1 x Cos\omega_c t - Logic\ 0$	$X_{ASK} = A_2 x Cos\omega_c t - Logic\ 1$
$X_{FSK} = AxCos\omega_{c1} t - Logic\ 0$	$X_{FSK} = AxCos\omega_{c2} t - Logic\ 1$
$X_{PSK} = AxCos(\omega_c t) - Logic\ 0$	$X_{PSK} = AxCos(\omega_c t + \theta) - Logic\ 1$

a. **ASK Modulation**: For the bits 0 and 1 in the baseband signal, A_1 and A_2 use the same frequency carriers.
b. **FSK Modulation**: In FSK modulation, two separate frequencies of the same amplitude are used for bits 0 and 1 in the baseband signal.
c. **PSK Modulation**: In PSK modulation, carriers with phase differences of the same amplitude and frequencies are used for bits 0 and 1 in the baseband signal.

The basic modulation equations explaining ASK, FSK, and PSK are given in Table 1.

Fig. 1 shows the flow diagram of the MATLAB program for obtaining the data from the 8 bit 1–255 of the FSK signal and plotting the graphs. Here, two different frequencies are used for the carrier signals. For ASK modulation, the frequency is defined as a single frequency, and 2 separate amplitudes are defined whereas a constant value of frequency and amplitude is defined for PSK modulation, and a separate phase value (0, 180) is added to both equations [21]. These fields are the equations defined for logic1 and logic0 in the program.

For example, the basic modulation charts for binary=10110100, i.e., decimal = 180 data obtained for each digital modulation are shown in Fig. 2, and the data is distorted according to the 5 dB SNR ratio are shown in Fig. 3.

2.2. The formations of Multi-Carrier Digital Modulation Types (QASK, QFSK, and QPSK) and demonstrations of these modulation signals

Multi-level transmission can be performed by switching the amplitude, frequency, or phase of the carrier between more than two different values. In this way, it is possible to transmit more information through the transmission of a single carrier. In multilevel switching tape marking, the transmission is performed by using the different amplitude (MASK), frequency (MFSK) or phase (MPSK) value in the carrier for the M piece symbol according to the modulation type [22]. For multi-level transmission, the bits of the binary information signal is typically grouped, and a different carrier is assigned to each group of bits. The transmission of the information represented by the bit group as a result of the transmission of this carrier is provided. In multilevel modulations, QASK, QFSK and QPSK modulations are generally used. In these modulations, the speed is doubled as 2 bits are transmitted at the same time. Table 2 shows the symbol ratios according to the multi-carrier modulation type. Table 3 shows the equations for quadrate modulation. In addition, using 8, 16, 32 carrier modulations according to four carrier modulations, a large increase in data transfer rate occurs, as shown in Table 3. However, the increase in the number of carriers requires that demodulator circuits be more complex.

Table 3 shows an equation expression for quadrate type modulations. The values obtained by 4 different carriers according to the modulation type are shown. The amplitude of QASK modulation, frequency of QFSK modulation, and phase changes of QPSK modulation are available in determining the carriers.