Application of neural network to find the discrete spectrum of the direct Zakharov-Shabat problem

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Optical telecommunications are currently actively developing. However, the constant increase in the amount of traffic transmitted in the near future will exceed the potential of the communication lines based on current developments. Therefore, many scientific groups are actively exploring new promising ways to increase the capacity of communication lines. In particular, it has recently been proposed to use the Nonlinear Fourier Transform (NFT) for data transmission [1]. Direct NFT for the nonlinear Schrödinger (NLS) equation is the computation of the nonlinear spectrum of an optical signal (solving the direct Zakharov-Shabat problem). The nonlinear spectrum consists of discrete and continuous parts. The set of discrete eigenvalues (d.e.) corresponds to the soliton part of the signal. This representation evolves in a trivial way as the signal propagates. At any value of the evolutionary variable, the signal can be fully restored using the inverse NFT. Data transmission using NFT allows taking into account the influence of nonlinear effects in the propagation of an optical signal along the fiber.

The main difficulty in the widespread adoption of NFT is the lack of fast and accurate numerical methods. At the moment, a large number of methods have been proposed for determining the nonlinear spectrum, and significant progress has been made in reducing the complexity of algorithms and increasing their accuracy. However, there are problems with the robustness of computational algorithms when applied to complex signals. It is also difficult to compute NFT in real time for complex waveforms, which limits the possible implementation of the NFT at the hardware level in modern communication lines.

A promising area of research is the application of machine learning, in particular neural networks. In the past decade, great progress has been made in the development of machine learning methods for solving algorithmically complex problems such as, for example, image recognition and classification. The main steps in this are training the model based on a set of some data and applying the model for prediction. The first stage takes a long time to complete. However, the application of the trained model is usually much faster, which makes it possible to implement systems based on machine learning methods on various devices with low performance. Machine learning has also been proposed to be used in NFT-based data transmission systems at the post-processing stage [2]. In our work, we propose to implement a more radical approach and calculate the NFT using neural networks.

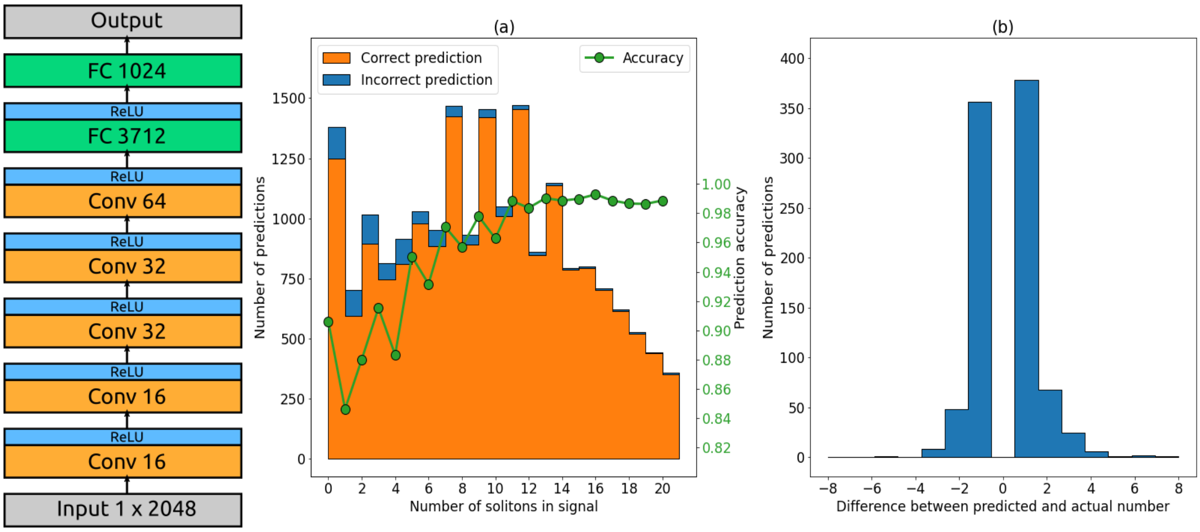

Fig. 1. Neural network architecture and its prediction accuracy.

In this work, we use a neural network to predict the number of d.e. in the nonlinear spectrum of telecommunication signals. Discrete eigenvalues reflect the internal structure of the signal. Knowledge of the internal structure of a signal makes it possible to study its properties and features of propagation in an optical fiber. For our research, we chose the WDM format, which is widely used in optical communication. The signal was generated from a random data set encoded in one of the modulation formats: QPSK, 16-QAM, 64-QAM, 1024-QAM. A simplified version of the VGG-16 network, which is used in image recognition tasks, was chosen as the basis for the network architecture. At the input, the network receives a complex signal consisting of 1024 points. This signal is converted into a vector with 2048 elements, in which the real and imaginary parts of each point of the initial complex signal are sequentially arrayed. Then the signal is processed by several convolutional layers with activation functions and fully connected layers. The network output is the number of solitons in the signal. The number of trained parameters in the network was 3834145.

In total, there were 174847 generated signals in the training set, which contain from 0 to 20 solitons, inclusive. For each signal, this number has been calculated in advance by other methods. The network accuracy was calculated using a validation set of 19427 signals. The network was trained for 300 epochs, the final prediction accuracy for validation was 95.39%. In this case, the maximum error of the network predictions - the difference between the real number of solitons in the signal and the predicted one - was 8. Most of the erroneous results are in the range [-2; 2]. The network works best for signals where the number of solitons is more than 10. For such cases, the accuracy is better than 98%. The worst were the signals with only one soliton - for them the accuracy was 84%. The results obtained show that neural networks have great potential for implementing various stages of NFT.

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References

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