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(REVIEW ARTICLE)

Prediction of failures in fiber-optic information transmission systems

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Abstract

The article discusses a method for predicting failures in fiber-optic data transmission systems using a self-analysis mechanism. The proposed method is based on the use of machine learning algorithms that can adapt to changing operating conditions by automatically selecting or retraining models. The method includes the stages of data collection and preprocessing, feature extraction, construction of predictive models and their dynamic optimization. The self-analysis mechanism provides continuous assessment of the accuracy of forecasts and allows timely adjustment of model parameters. Testing on actual data showed high forecast accuracy and the superiority of the proposed method over traditional approaches. The results are visualized using error and deviation graphs, confirming the effectiveness of the proposed method.

Keywords: Fiber-optic data transmission systems; Machine learning algorithms; Reliability; Failure prediction

1. Introduction

In the context of the rapid development of modern technologies, as well as the continuous growth of the volume of transmitted and processed information, the issue of ensuring the reliability of communication systems is becoming increasingly important. Fiber-optic data transmission systems (FODTS) play a particularly important role in this, due to their high throughput, resistance to external interference and the ability to transmit a signal over long distances without significant losses, which are the basis of modern telecommunications infrastructure. System malfunctions, in particular failures that are a random event that consists in disrupting the system's operability, can lead to significant economic losses and disruption of critical services that require continuous data transmission. Therefore, predicting failures in telecommunication networks is necessary to ensure stable operation and maintain a high level of service.

Currently, scientific research is being conducted and methods for predicting failures in FODTS are being applied based on statistical analysis, machine learning methods, monitoring and diagnostics of the system in real time [1,2,3].

2. Literature review

Failure prediction is classified into two main types depending on the differences in the analytical objects: based on failure logs and based on the state of the system. In the first case, the main idea is to collect fault logs and then analyze their possible relationships using data mining or machine learning methods. These identified relationships are then used to predict failures. In [4], a method for predicting network failures based on alarm logs was investigated to build an adaptive failure prediction model.

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A method for monitoring performance and predicting failures in optical networks based on machine learning was proposed in [5]. In [6], deep neural networks (DNN) were used for monitoring and diagnostic methods for optical networks. In [7], a method based on long short-term memory (LSTM) for detecting, localizing, and evaluating reflective fiber defects, including connectors and mechanical splices, is presented. In [8], a scheme for identifying potential causes of failures for optical networks is proposed.

An automatic hardware failure prediction system developed in [9] describes a method for predicting hardware failures using machine learning. The method and system for predicting failures based on machine learning with retraining of machine learning models are given in [10]. All the studies and methods provided provide useful solutions for predicting failures in various systems, but they have limitations associated with the lack of dynamic adaptation and the use of self-learning models that can automatically adjust their parameters in real time. Therefore, the development of a method for predicting failures with self-analysis is one of the important tasks for improving the reliability of the FODTS. The essence of the developed method is the automatic selection of machine learning algorithms or changing the parameters of the selected algorithm for the best result of predicting failures in communication networks.

3. Research method and results

The method is based on the principles of Big Data analysis, which involves processing and interpreting large amounts of information with a high data update rate. The method is aimed at solving the problem of minimizing the loss function L, which is expressed through the difference between the predicted values of the model $\hat{y}$ and the actual data y:

$$L(y,\hat{y})=\frac{1}{n}\sum_{i=1}^{n}(y_i-\hat{y}_i)^2$$

where n - number of data points, y_i - true value, $\hat{y}$ - predicted value.

The scheme of the method for predicting failures in the FODTS with self-analysis is shown in Fig. 1. Collection of failure data serves as the basis for analysis, representing multidimensional time series. Data preprocessing significantly improves data quality, facilitates the modeling process and increases the accuracy of predicting failures in fiber-optic systems. Features (characteristics) are extracted from the filtered data, which will be used to build a prediction model.

Model training is the most significant stage, where a predictive model is built based on the selected features using machine learning algorithms. At the prediction stage, the model is used to estimate the probability of failures in the system based on current and historical data.

The self-analysis system continuously evaluates the performance of the model in real time, adjusting its parameters in case of deviations from the expected results. Visualization plays an important role in interpreting the results, providing graphs and charts that demonstrate the relationships in the data and the effectiveness of the model.

The system periodically (at a specified time) updates the models and revises the failure data coming from the communication networks. This allows for a prompt response to new data and ensures forecast accuracy.

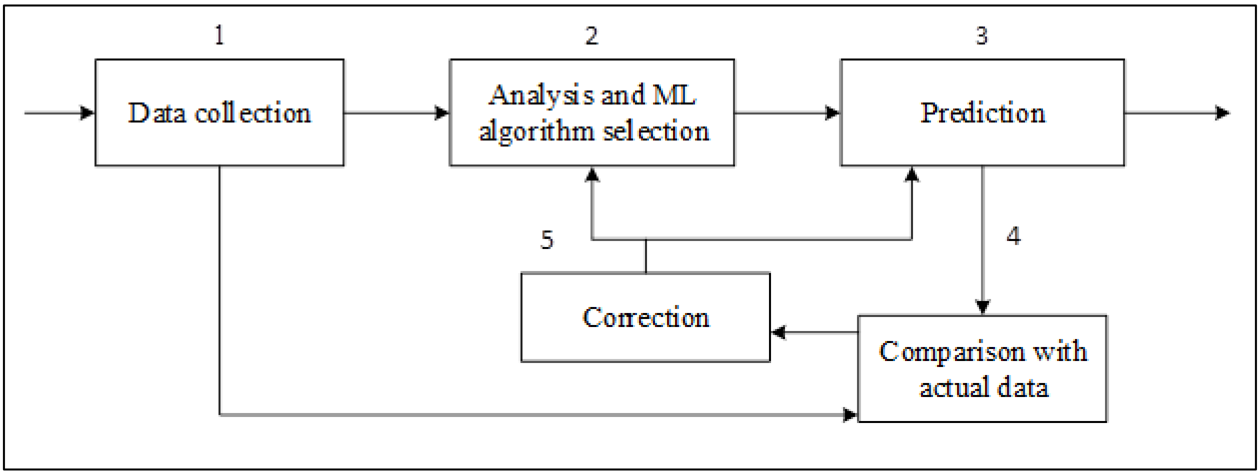

Figure 1 Failure prediction method scheme in FODTS with self-analysis

The method was tested on real data and showed high failure prediction accuracy. As part of the testing, experiments were conducted to compare the proposed method with existing approaches, which allowed for identifying its advantages and disadvantages.

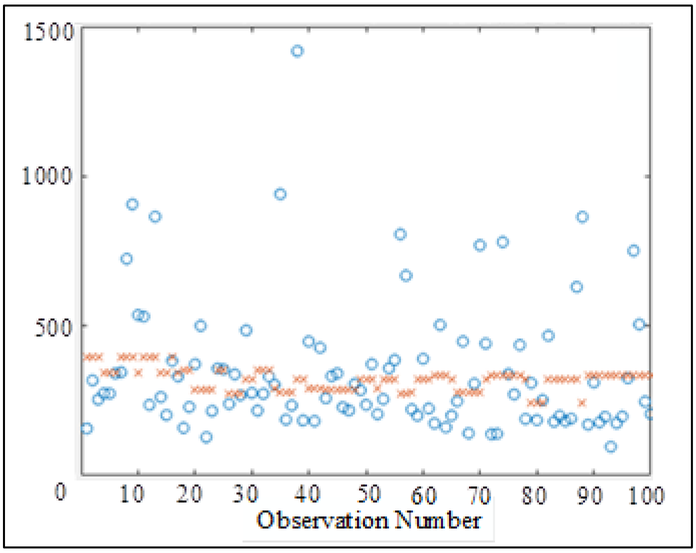

Figure 2 Comparison of real and predicted data. Real data are marked with blue circles, and predicted data are marked with red crosses

The graph in Figure 2 compares real failure data with predicted data, which allows us to evaluate how accurately the machine learning model predicts failure times based on the provided data. The graph shows that most of the predicted values are grouped along a certain line between failure times of 200 to 600 minutes. The real data has a larger spread. Most of the predictions are close to the real data, which indicates that the machine learning model is able to make fairly accurate predictions in most cases. However, there are a few outliers on observations with large failure times, which shows that the model can be improved to better account for these outliers and extreme cases.

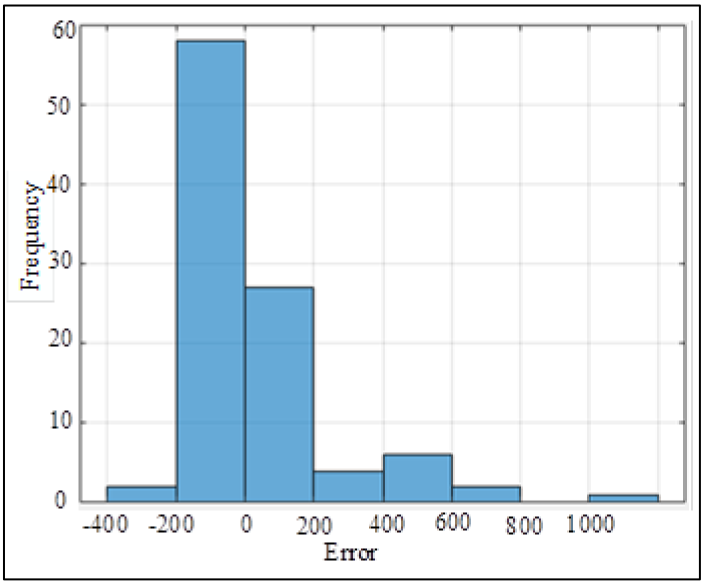

Figure 3 Histogram of errors (residuals)

The histogram of residuals (Fig. 3) shows how accurately the model predicts and identifies potential problems in individual forecasts that require improvement. The graph shows that the model is stable, since most errors are near 0, which means that the forecast results are close to the actual values.

When a discrepancy between the predicted and actual data is detected, the system automatically adjusts the algorithm parameters or selects another algorithm to improve accuracy. This allows the system to adapt to changes in failure data that arrive at certain intervals.

4. Conclusion

The proposed method for automatically improving machine learning forecasting models implements a mechanism for self-analysis of failure data in communication networks and selecting the best model for forecasting. Forecasting is carried out using several models, and the system automatically selects the best one, and regular data updates and self-analysis of models allow the system to adapt to changes. Modeling and testing on real data showed that the proposed method outperforms existing approaches in accuracy and adaptability. The use of self-analysis mechanisms allows the system to identify discrepancies between forecasts and actual data in real time, optimize model parameters and ensure stable operation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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