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A Study on Unsupervised Learning-Based Autoencoder Model for Leakage Detection in Plant Piping Systems

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1. Introduction

This study introduces a leak detection method using deep learning technology to solve the corrosion problem of pipes due to the increase in the operating life of plant facilities.

Existing leak detection methods encounter difficulties in accurately identifying micro-leaks in the presence of noise in the data collection environment. Furthermore, there is a limitation in early-stage leak detection due to the unfeasibility of remote always-on monitoring [1].

Currently, with the advancement of deep learning technology, it is being applied across various industries to enhance competitiveness and boost production efficiency. Therefore, in this paper, we propose a micro-leak detection method by implementing an autoencoder model based on the fully connected neural network structure, utilizing the principles of unsupervised learning and harnessing the power of deep learning technology.

The structure of this paper is as follows: Chapter 2 addresses data preprocessing and the configuration of training data. Additionally, in Chapter 2, we implement an autoencoder model based on the structure of a fully connected neural network to assess the signal restoration ability for an input signal. Subsequently, the leakage state is determined based on the threshold value using the implemented autoencoder model. Finally, Section 3 presents the conclusion.

2. Methods and Results

This section describes an autoencoder-based model for leak detection, which includes a fully connected neural network architecture.

2.1 Data preprocessing and training data configuration

In this paper, steady-state and leak time-series data were collected from four microphone acoustic sensors, and fast Fourier transform [2] was applied to extract frequency domain information. In addition, 100 data samples were obtained using a method of extracting the average value for each section from the transformed data samples to optimize the model training time and computational efficiency, as shown in Figure 1.

Finally, to organize the training data, we grouped the collected data into mini-batch units as depicted in Figure 2 below.

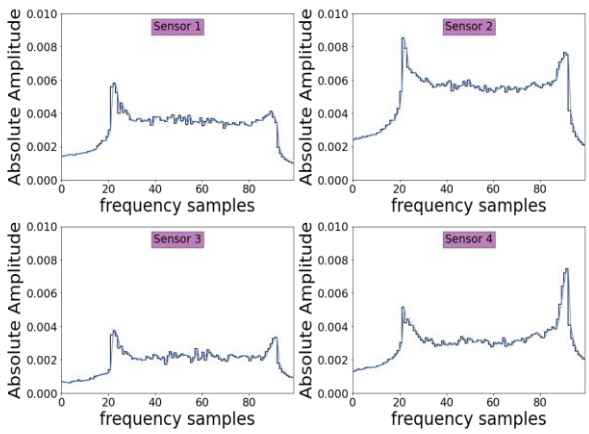

Fig. 1. Four sensor signals preprocessed in the frequency domain

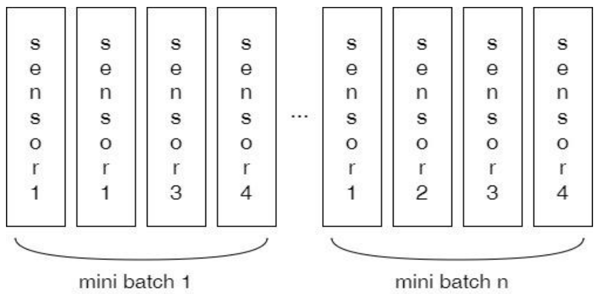

Fig. 2. Sensor data arrangement for model training

2.2 Autoencoder model based on fully connected neural network structure.

An autoencoder consists of an encoder that compresses input data into a low-dimensional representation and a decoder that restores compressed data and is an unsupervised learning-based technique that learns pattern features of data [3]. As shown in Figure 3, this study implemented an autoencoder model based on the structure of a fully connected neural network.

The restoration performance for the input signal was evaluated using the average absolute error (MAE) [4]. The evaluation for the input signal was conducted five times, and by averaging the three highest performances, a value of 1.2638e-4 MAE was achieved.

Figure 4 depicts the actual input signal alongside the decoder's resilience to it, illustrating the model's proficient restoration of the input signal.

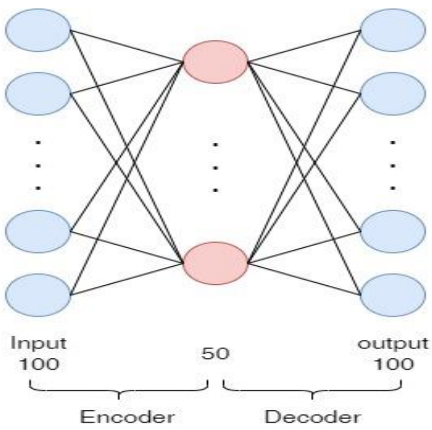

Fig. 3. Autoencoder model based on fully connected neural network structure.

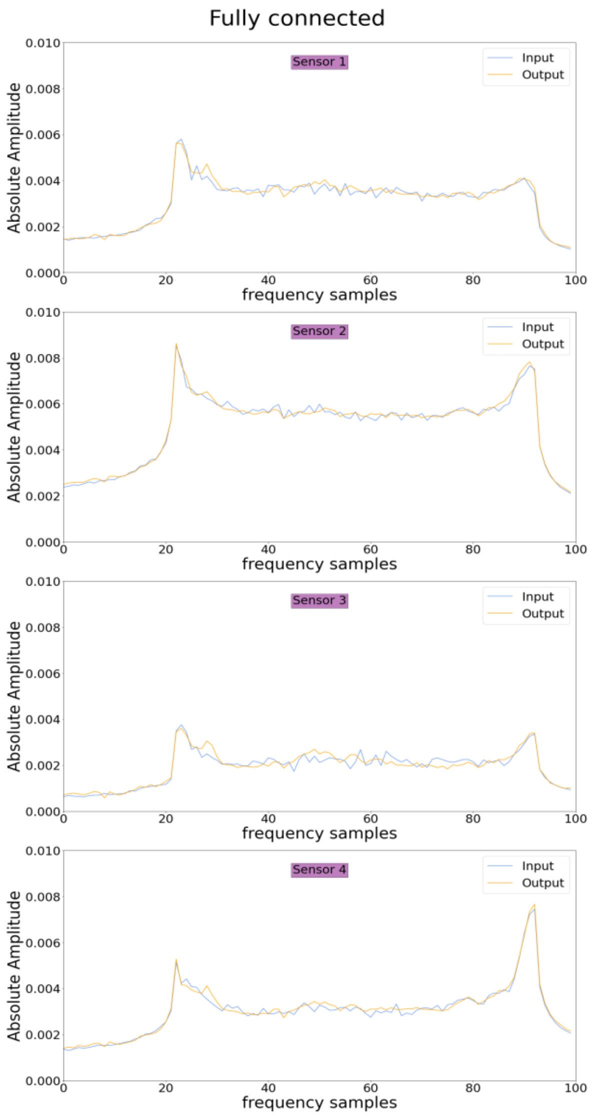

Fig. 4. Signal restoration results for four sensors using the autoencoder model implemented with a fully connected neural network structure.

2.3 Autoencoder model to determine leakage based on threshold.

In this paper, following the training of the autoencoder model using only steady-state data, the normal and leaky states were determined based on the threshold by specifying the range in which the steady-state data would be distributed [5]. The threshold was defined as the sum of the mean and standard deviation of the reconstruction errors obtained from the steady-state data.

Applying the threshold methodology described in this paper, the leak detection performance of the fully connected neural network-based model yielded a classification accuracy of 0.99 when evaluating the model performance.

3. Conclusions

In this paper, an autoencoder model based on an unsupervised learning-based fully connected neural network structure for leak detection in plant pipelines was examined. The restoration performance of the input signal and the accuracy of leak discrimination using the threshold were quantitatively evaluated. The evaluation yielded a MAE restoration performance of 1.2638e-4 and a leak discrimination accuracy performance of 0.99. These results demonstrate high signal restoration and leak detection performance.

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