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Time Series Classification of Vibration Data Using Attractors Made from Multidimensional Space by Convolutional Neural Network

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1. Introduction

The researches on time series data analysis have been actively conducted in recent years. This data has various characteristics, such as oscillating regularly and irregularly. Chaos theory mainly handles irregularly oscillating data. The theory deals with a phenomenon that appears in a part of a dynamical system. It shows a complicated state that cannot be predicted due to numerical errors. Unpredictability is not random and follows deterministic rules. However, because it cannot be obtained by the integration method, the methods for observing other phenomena are required. One of them is the time delay coordinate system which is a kind of chaos theory [1]. By using this method, 1-dimensional data (1d-data) can be converted into multidimensional data such as 2-dimensional data (2d-data) and three-dimensional data. It is applied in various fields such as cranial nerve system and engineering system.

In recent years, the researches on time series data analysis using Neural Networks (NN) such as 1-dimensional Convolutional Neural Network (1d-CNN) and Recurrent Neural Network (RNN) has been actively performed [2]. The reason why NN attract attention is that NN can learn and recognize input information by itself. However, even if these models are used, it is difficult to analyze time series data with very irregular vibrations. It is impossible for NN to learn the numerical and time series characteristics of the data. Therefore, it is necessary for NN to preprocess this data. In order to solve this problem, this study extends the data to multidimensional data using the time delay coordinate system. The objective is to find regularity that NN can easily learn from time series data with irregular vibrations.

2. Convolutional Neural Network

CNN is one of the NN and is mainly used in image recognition [3]. It is established in 1956 as an academic field, and it has received a lot of attention since winning the image recognition competition in 2012. Recently, various networks such as VGGNet and ResNet have been devised, and the misrecognition rate has been greatly improved [4], [5]. CNN is used in various fields such as medicine and automobiles, and its application range is expanding. It already puts into practical use in automated driving, robots, surveillance cameras and so on. Besides images such as object detection and segmentation, it has achieved tremendous performance in many tasks such as natural language processing and speech processing. CNN is inspired by the biological processes and mimics the arrangement of the visual cortex of animals. It consists of an input layer, an output layer, and a number of hidden layers between them. It is usually composed of the convolutional layers, the pooling layers, and the fully connected layers. The convolution layers and the pooling layers are feature amount extraction parts that read the image and create the feature map. In the convolution layer, some of the filters with different resolutions are applied to each learning image, and the output of each convolution images is used as an input to the next layer. The filter starts from the detection of very simple features such as brightness and edges, and extracts even complex features unique to the object. Furthermore, filters increase the level of complexity of features that uniquely define objects. The pooling layer reduces the size of the original image while leaving important information as a feature. By performing this process, it is possible to prevent difficulty in learning and over learning due to an increase in the amount of data. Even if the image moves and rotates, the same value as the original image can be also output. In the last fully connected layer, the output is converted into a 1-dimensional array, and the probability of classification is calculated.

3. Proposed Method

In this study, 1d-data is converted into multidimensional data using the time delay coordinate system. First, let the value of data at a specific time be $x(n)$. Furthermore, if the time delay value is τ, this system can be expressed by Eq. (1).

$$f(x) = x(n), x(n+\tau), x(x+2\tau), \ldots \tag{1}$$

Thereupon, we propose to extract 2d-data as image made from the multidimensional space (Fig. 1). In this study, the number of the dimensions is set to 5. The objective is to successfully extract the amount of information in the multidimensional space as image features. Figure 2 shows the flow of this study. First, 1d-data is converted into multidimensional data using the time delay coordinate system. Next, 2d-data is extracted from the multidimensional data. Finally, CNN is used to extract image features and perform binary classification.

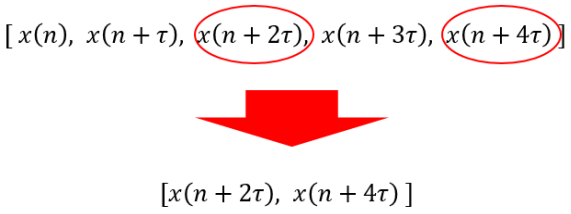

Fig.1 Method how to make image

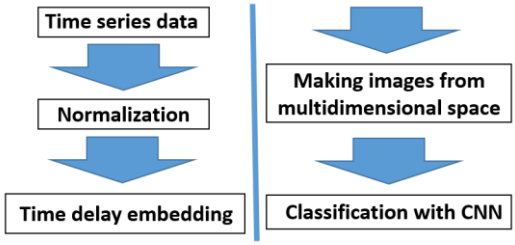

Fig.2 Flowchart of this study

4. Simulation Method

The data used in this study are the surface shapes of two fabrics that change in 1 $[ms]$ acquired by a tactile nanosensor [6]. This surface shapes indicate the vibrations when any loads are applied to the fabrics. Table 1 shows the number of data for each fabric used in this study. Time series data of 2000 $[ms]$ are used. There are CNN are used for attractor images and 1d-CNN and RNN are used for original time series data.

Table 1 The number of the dataset

	Train Data	Test Data
Original Data	100	20
Image Data	100	20

Figure 3 shows the structure of the CNN used in this study. CNN is the network that extracts features in the convolutional layer and classifies inputs based on the features. Figure 4 shows the structure of the RNN used in this study. RNN has recursion in which the output of a certain layer is input retrospectively.

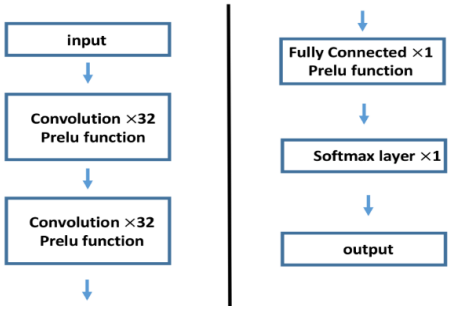

Fig.3 CNN structure

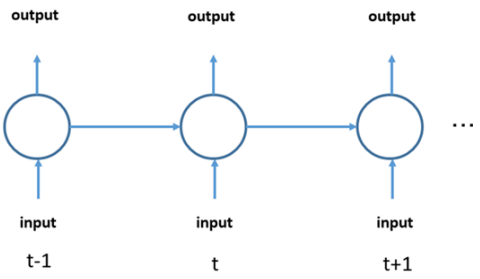

Fig.4 RNN structure

5. Simulation Result

We investigate the average of 10 times of train and test accuracies. Table 2 shows the accuracies when the number of dimensions is set to 5. For example, attractor 1-3 is generated in the first and third dimensions. The test accuracy of the attractor 1-5 is the best. However, the test accuracies of most of the attractors are lower than those of the RNN and 1D-CNN. It can be seen that a specific attractor is effective in the CNN feature.

Table 2 Train and test accuracies

This study	Train accuracy(%)	Test accuracy(%)
1D-CNN	100	67.5
RNN	100	72.0
attractor1-2	100	43.6
attractor1-3	100	48.5
attractor1-4	100	57.6
attractor1-5	100	75.2
attractor2-3	100	46.8
attractor2-4	100	58.9
attractor2-5	100	69.0
attractor3-4	100	49.0
attractor3-5	100	55.5
attractor4-5	100	62.8

6. Conclusion

In this study, we proposed a method that uses time delay coordinate system to expand time series data into multidimensional space and converted the data into images. It was confirmed that how the accuracy of the time series classification changes using CNN by extending 1d-data to multidimensional data. As a result, some of the test accuracies using the proposed method were superior to those using the conventional method.

However, most of the test accuracies of the proposed method were lower than those of RNN and 1D-CNN. In the future, we will explore how to extract and utilize multidimensional features and clarify how to obtain sufficient classification accuracy. In order to clarify the characteristics of the time series data, it is also examined which part of the image the NN focus on.

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