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Time Series Classification with Time Delay Coordinate System Using Convolutional Neural Network

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Abstract
Time series data are often classified by using Recurrent Neural Network and 1-Dimensional Convolutional Neural Network. In this study, we used 2-Dimensional Convolutional Neural Network for 1-Dimensional data using the chaos theory. We used the time delay coordinate system for inputs of Convolutional Neural Network. By constructing a figure called an attractor and analyzing it with 2-Dimensional Convolutional Neural Network, we could improve some of the test accuracy compared with conventional methods.

1. Introduction

Time series data are used everywhere in society. Classification of time series data has been actively conducted in recent years. Its characteristics are varied and those with regularity and those with irregular chaotic properties can be mentioned. Chaos is a phenomenon showing a complicated appearance. The appearance is considered to be unpredictable due to numerical error and found in a part of a dynamical system. Chaos is unlike any unpredictable random. Although its behavior follows the deterministic rule, it cannot obtain the solution by the integral method. Therefore, we need to find other methods. The one of methods is converting 1-Dimensional data into 2-Dimensional data (2D-data). By using this method, we can observe the behavior [1]. Furthermore, we can classify time series data to analyze this 2D-data. Thereupon, we are required to discover how to analyze it.

In recent years, the method which analyze 2D-data by Convolutional Neural Networks (CNN) attracts attention. CNN is one of Neural Networks and a mathematical model similar to some properties found in brain functions. In this study, we expect to improve test accuracy of classification by combining chaos theory and CNN.

2. Convolutional Neural Network

The research on CNN was established as an academic field in 1956. Since then, it has repeated the ice ages and booms many times and now reaches the present. Currently, CNN is diverse in medical field, car field, home electronics field and so on. The beginning of these booms was image recognition. CNN is inspired from the biological process and conceived from the arrangement of the visual cortex of animals. In the field of image recognition, CNN has achieved tremendous performance with many tasks. In addtion, CNN is attracting attention. In particular, the intermediate layer of CNN extracts high versatility and splendid feature quantities.

The network structure of CNN is divided into an input layer, an intermediate layer and an output layer. The intermediate layer includes convolution layers, pooling layers and fully connected layers. Features of inputs are extracted in the convolution layer, and position invariance is acquired in the pooling layer. Next, it becomes the 1-Dimensional array in fully connected layers and it changes to probability. Finally, CNN outputs classification results by the probability.

In recent years, Recurrent Neural Network (RNN) which has time series structure and 1-Dimensional CNN (1D-CNN) which perform feature extraction of 1-Dimensional data (1D data) are often used. However, in this study, we convert the 1D data to graphics and try to extract features of 2-Dimensional data (2D data).

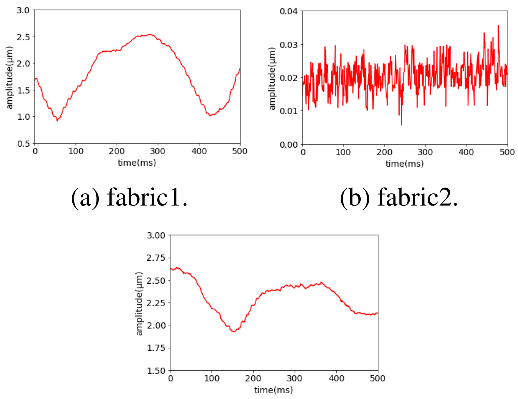
3. Dataset

We carry out time series classification of the surface shape of fabrics. We prepare three types of fabrics. In this study, we call them fabric1, 2 and 3. Table 1 shows the number of the time series data each length.

Table 1: The number of the time series data.

	train data	test data
length of 500 (ms)	100	20
length of 2000 (ms)	25	5

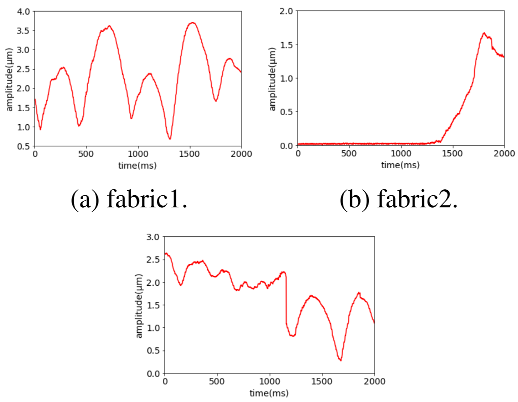
Figures 1 shows the examples of the time series data about the amplitude of the surface shape with the time series data with the length of 500 (ms). Figures 2 shows the examples of the time series data about the amplitude of the surface shape with the time series data with the length of 2000 (ms).



(a) fabric1. (b) fabric2.

(c) fabric3.

Figure 1: The amplitude of the surface shape of each fabric when we use time series data with the length of 500 (ms).



(a) fabric1. (b) fabric2.

(c) fabric3.

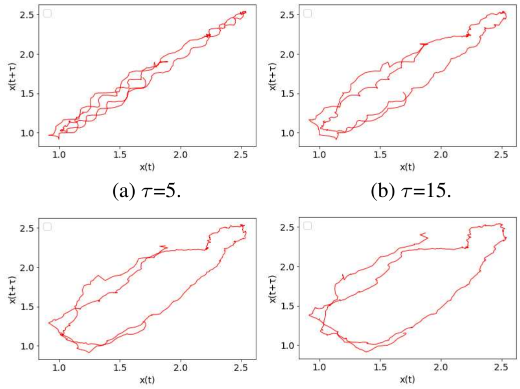
Figure 2: The amplitude of the surface shape of each fabric when we use time series data with the length of 2000 (ms).

4. Proposed Method

We convert the 1D data into 2D data using time delay coordinate system. Let the value of data at a certain time be $x(n)$. Furthermore, if the time delay value is τ, this system is represented by Eq. (1).

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

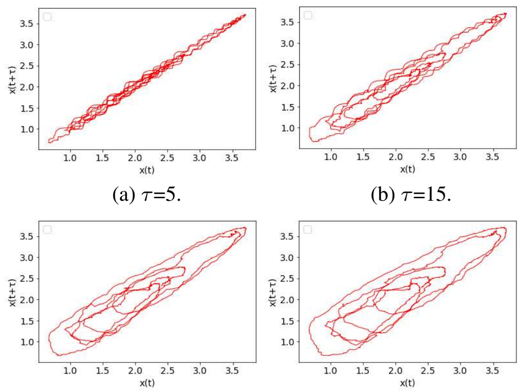
In this study, we set the number of the dimension to 2 to use 2D-CNN. Let the horizontal axis be $x(n)$ and the vertical axis be $x(n + \tau)$. We analyze the image made by this operation with 2-Dimensional CNN. Figures 3 and 4 show the examples of the structure of the delay coordinate system each length of the fabric1. Figures 5 and 6 show the examples of the structure of the delay coordinate system each length of the fabric2. Figures 7 and 8 show the examples of the structure of the delay coordinate system each length of the fabric3.



(a) τ=5. (b) τ=15.

(c) τ=25. (d) τ=35.

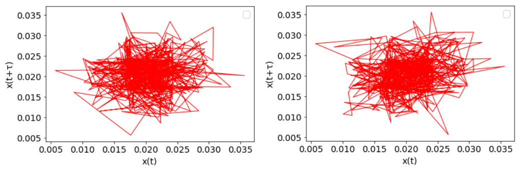
Figure 3: Structure of the delay coordinate system when we use time series data with the length of 500(ms) of fabric1.



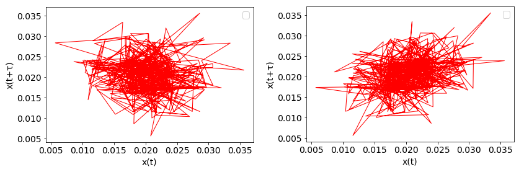
(a) τ=5. (b) τ=15.

(c) τ=25. (d) τ=35.

Figure 4: Structure of the delay coordinate system when we use time series data with the length of 2000(ms) of fabric1.

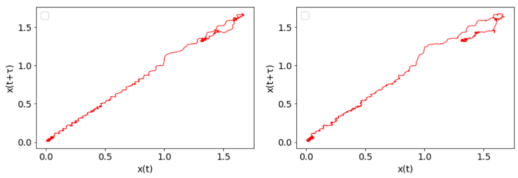


(a) τ=5. (b) τ=15.

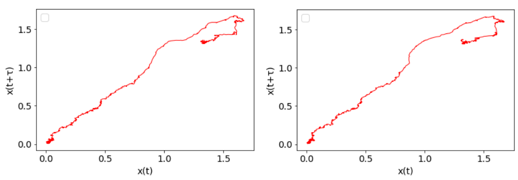


(c) τ=25. (d) τ=35.

Figure 5: Structure of the delay coordinate system when we use time series data with the length of 500(ms) of fabric2.

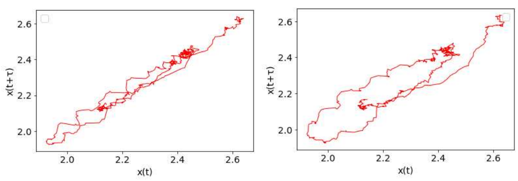


(a) τ=5. (b) τ=15.

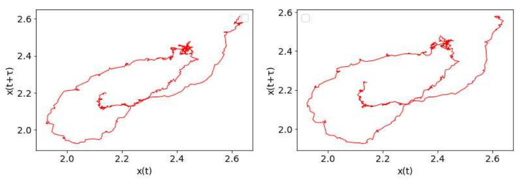


(c) τ=25. (d) τ=35.

Figure 6: Structure of the delay coordinate system when we use time series data with the length of 2000(ms) of fabric2.

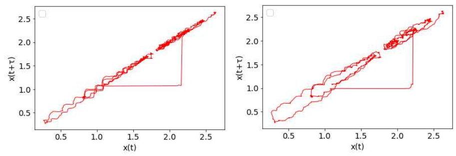


(a) τ=5. (b) τ=15.

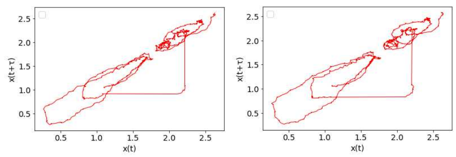


(c) τ=25. (d) τ=35.

Figure 7: Structure of the delay coordinate system when we use time series data with the length of 500(ms) of fabric3.



(a) τ=5. (b) τ=15.



(c) τ=25. (d) τ=35.

Figure 8: Structure of the delay coordinate system when we use time series data with the length of 2000(ms) of fabric3.

5. Architecture

We used 1D-CNN and RNN for convention architecture. The structures of 1D-CNN and 2D-CNN were the same. Figure 9 shows structure of CNN which we used in this study.

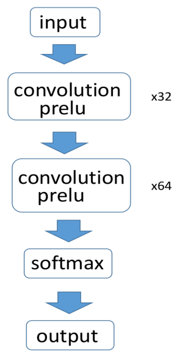


Figure 9: Structure of CNN.

We used 2 convolutional layers. The pooling layers take time to process. Therefore, we did not use the pooling layers and we could reduce the time to process. We used the activation function after convolution called prelu [3]. The equation of prelu is expressed as follows.

$$f(x) = \begin{cases} x & (x \geq 0) \\ ax & (x < 0) \end{cases} \tag{2}$$

The negative slope a ($0 < a < 1$) is adjusted by network learning. We derive the probability to calculate classification results by the softmax activation function.

$$\rho(x) = \frac{exp(x_j)}{\sum_{i=0}^{n} exp(x_i)} \tag{3}$$

$\rho(x)$ is the probability of being classified as j. n is the total number of classes.

RNN is one of Neural Networks where connections between nodes form a directed graph along a sequence. This allows it to exhibit temporal dynamic behavior for a time sequence. Figure 10 shows structure of RNN we used in this study.

In this study, we set the weight collection to 0.001 and set epochs to 150. In every dataset, train accuracy reached maximum value 1.

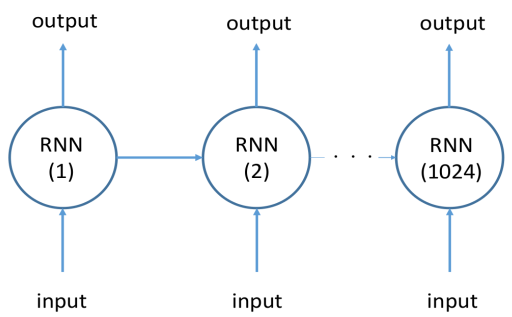


Figure 10: Structure of RNN.

6. Simulation results

We show the effect of classification by time delay coordinate system. At first, we show the classification results when we use time series data with lengths of 500 (ms) and 2000 (ms) changing τ. At second, we compared the results with the highest test accuracy using 2D-CNN with 1D-CNN and RNN.

Table 2: Test accuracy with 2D-CNN changing τ when we use 500 length of time series data.

	$\tau = 5$	$\tau = 15$	$\tau = 25$	$\tau = 35$
fabric1,2	0.95	0.93	0.93	0.95
fabric2,3	0.95	0.75	0.93	0.9
fabric3,1	0.6	0.78	0.55	0.45
fabric1,2,3	0.65	0.61	0.65	0.62

Table 3: Comparison of test accuracy using 2D-CNN with 1D-CNN and RNN.

	RNN	1D-CNN	2D-CNN
fabric1,2	0.85	0.84	0.95
fabric2,3	0.85	0.83	0.93
fabric3,1	0.78	0.78	0.78
fabric1,2,3	0.72	0.73	0.65

7. Conclusion

In this study, we used the time delay coordinate system. This method showed any of test accuracy was improved compared with the conventional method. Sufficient accuracy was obtained with binary classification. However, sufficient accuracy was not obtained with multiple classification.

Table 4: Test accuracy with 2D-CNN changing τ when we use 2000 length of time series data.

	$\tau = 5$	$\tau = 15$	$\tau = 25$	$\tau = 35$
fabric1,2	0.5	1.0	0.8	1.0
fabric2,3	0.4	0.5	0.78	0.92
fabric3,1	0.65	0.8	0.56	0.9
fabric1,2,3	0.34	0.43	0.53	0.67

Table 5: Comparison of test accuracy using 2D-CNN with 1D-CNN and RNN.

	RNN	1D-CNN	2D-CNN
fabric1,2	0.96	1.0	1.0
fabric2,3	1.0	1.0	0.92
fabric3,1	0.7	0.3	0.9
fabric1,2,3	0.8	0.67	0.67

In the future, we will construct the time delay coordinate system with changing parameter τ. In addition, we will adjust the width of dividing the time series data.

Acknowledgment

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