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MODELLING OF A CHAOTIC SYSTEM MOTION IN VIDEO WITH ARTIFICIAL NEURAL NETWORKS

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Abstract. In this study a chaotic motion is modelled by artificial neural networks which can be created again. Chaotic signals can occur in many fields like communication, encryption, finance, health, natural affairs. Artificial neural networks, fuzzy models can be used to provide a mathematical form and predict these types of signals as well. In this study, as an example of the motion which was modelled, there might be movement of a planet orbit, movements of balls on a billiard table, inverted pendulum or phase diagrams of such systems. However, for chaotic motion, a modified novel lorenz system's phase diagram in literature was preferred. Object detection for motion which is sequential images of the video was obtained by image processing techniques so this process gives object coordination in the image. Artificial neural networks model which was called NAR structure was constructed and it has trained by these position information with backpropagation algorithm. Subsequently, this NAR model which is artificial neural networks were tested and it was tried to get chaotic motion videos again. As a result, an object, which can be detected with image processing or other techniques, could be detected and traced. So, by using object information, which could be chaotic motion, could be modelled with artificial neural networks, instead of mathematically equations.
Keywords: Chaos, chaotic systems, artificial neural networks, image processing

1. Introduction

Chaos is extremely sensitive to initial conditions and appears to be noise but has a general order. Furthermore, the signals of such systems have been between deterministic and random signals. Since this is promising, studies are carried out to identify such behaviours. In this sense, it first started with the meteorologist Lorenz's modelling of the weather with the data collected for forecasting the weather. After that different scientists have continued to work on this subject for turbulence movements. General characteristics of such systems are nonlinear systems which are very sensitive to the initial state although they have a smooth dynamics. These chaotic behaviours can be encountered in economics, biology, chemistry, informatics, medicine, engineering etc. General characteristics of chaotic signals include hypersensitivity to initial conditions, deterministic type, not random, unlimited number of different periodic oscillations, noise signal or similar power spectrum, complex behaviour of which amplitude and frequency cannot be detected but vary within a limited zone.

Once chaotic signals are obtained, they can be expressed in a mathematical model appropriate to the data. This can be directly in the form of a nonlinear equation, as well as different modelling techniques such as Fuzzy model, Artificial Neural Networks (ANN), Volterra Series or Wiener-Hammerstein model. In this context, this study aims to obtain approximately the same behaviour by using artificial intelligence methods to model this motion by using the data obtained from the motion video of an object that cannot be modelled mathematically.

One of the earliest discoveries in chaos was made in 1963 by Edward Lorenz, who wrote a simple mathematical computer program to study a simplified model of air [1, 2, 3, 4]. This model, proposed by Lorenz, was found to cause very large differences in system output even with very small changes in the initial conditions. When it starts from a different starting point, it exponentially leaves the previous solution at different time intervals. This can be seen more clearly with phase diagrams, bifurcation diagrams or Lyapunov exponentials [5, 6, 7, 8]. For this, firstly a dynamic model suitable for the system must be determined. Determining a suitable model for the system can sometimes be difficult. Recently, with the development of computer systems, systems can be modelled with different types of model types, which can also express the dynamics obtained from the system. Many methods are used to model this type of system with different dynamics [9]. Maguire et al. have shown that a chaotic signal can be expressed by fuzzy models [10].

Kuo and et al. used artificial neural networks to predict a chaotic time series [11]. Gmez-Gil et al studied the modelling of a long-term chaotic signal with artificial neural networks [12]. Frat studied modelling of earthquakes with chaotic behaviour using artificial neural networks [13]. Hanbay modelled the Chua Circuit with artificial neural network [14]. Panahi et al in their study with a proprietary artificial neural network model proposed by them has done modelling of epilepsy disease [15]. On the other hand, Koker et al. Obtained continuous data from the camera to determine the position of the moving object and compared it with the self-determined properties of the image [16]. Karakaya et al. applied HOG algorithm technique on FPGA, they realized object recognition in real-time [17]. Solak et al. used attribute and k-means algorithms for the detection and classification of hazelnut fruit [18]. Varol et al. introduced different face recognition algorithms and applied the PCA algorithm [19]. elik has made recognition for palm with image processing and artificial intelligence in his masters thesis [20]. imen et al. have modelled the movement of a moving object which is chaotic again [21]. In this study, the video was made using the movement of the newly Modified Chaotic Lorenz System in the literature. The moving object is recognized by the template matching technique and the position information of the object is obtained. Using this information, the movement of the object in the phase space is trained in artificial neural networks and it is aimed to reconstruct the object.

In this study, object recognition was first made in order to model the motion of a video subject. In 2nd section, the newly modified chaotic system which was newly proposed in the literature is given. Phase diagrams and Lyapunav exponents of this method are given. In the 3th section, determining Object in Image and obtaining object position are explained. In the 4th section, general information about artificial neural networks was given. Nonlinear Autoregressive Neural Network structure artificial neural networks were trained in 3 different phase portraits of the object's position information. After that, the movement of the object was achieved in 3 different phase portraits with the trained neural network again. In the 5th section, the results are compared and discussed.

2. Construction of Chaotic Motion Video

In this study, the behaviour of a previously proposed modified chaotic system in phase space will be established [22]. This previously modified chaotic system is given in equation 2.1. The parameters of the model used in this system are a=0.12, b=0.115, c=0.5, d=0. In addition, the initial values are set to [0.1 0.1 0]. This system does not have a equilibrium point. But phase portraits are given in figure 1. In addition, Lyapunov exponents are given in figure 2.

Using the two phases of the system obtained by motion, the position information of the moving object in these phase portraits will be determined over the video using image processing techniques. In this section, it is aimed to create the chaotic movement that the object will follow.

$$\begin{aligned} \dot{x} &= ax - yz \\ \dot{y} &= -by + xz \\ \dot{z} &= c - z + xy + dzy \end{aligned} \tag{2.1}$$

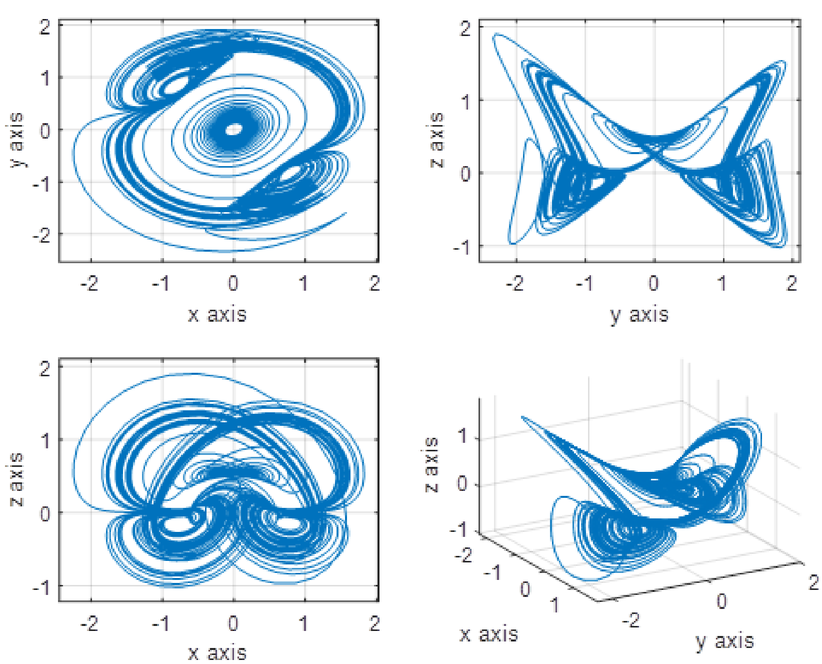


Figure 1. Phase Portraits of Chaotic System

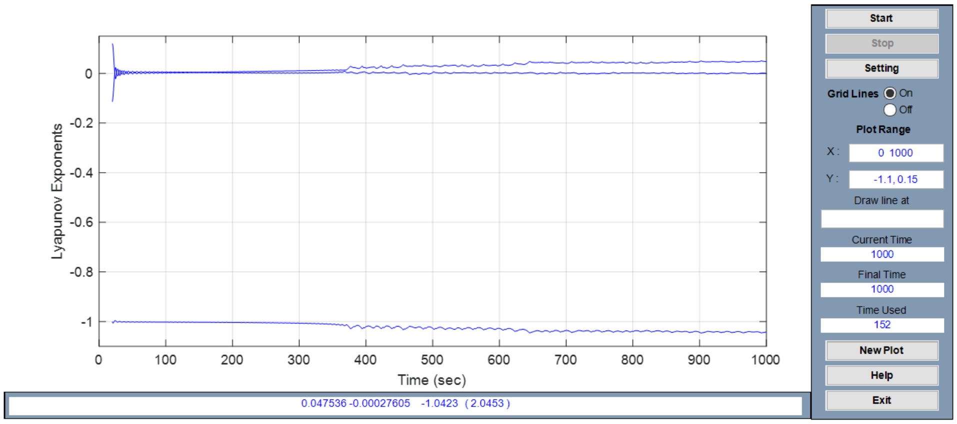


FIGURE 2. Lyapunov exponentials

3. Determining Object in Image and Locate Position

Videos are a combination of many images. Therefore, tracking of any object on the video is provided by determining the position of the object in the image. This is done by searching for the desired image features on the images which was produced from videos. Many techniques are available, such as image matching, template matching, directional gradient histogram, HAAR cascade classifier, principal component analysis, independent component analysis, support vector machines, linear discriminant analysis, elastic beam graph marking, SIRF and SURF. In this study, template matching method is used to recognize the object on the image. In this method, matching can be done in RGB format as well as operations in grey form. In order to reduce the processing burden, the image taken in this study and the image to be matched were converted to binary form which is two level. This makes transactions faster. For this purpose, when the image is taken in the video, firstly the image is converted to binary level. Image was converted from colour to grey form using Equation 3.1 depending on the specified operation. It is then subjected to a thresholding process using Equation 3.2. This allows the image to be quantized to 2 levels. These operations are carried out as shown in Figure 3.

$$f(x,y) = \frac{f(x,y,1)+f(x,y,2)+f(x,y,3)}{3} \tag{3.1}$$

$$f(x) = \begin{cases} 0, & \text{f(x,y)}\leq\text{T}. \\ 0, & \text{otherwise}. \end{cases} \tag{3.2}$$

3.1. **Template Matching.** The template matching algorithm is examined in the literature in two general categories as area-based and feature-based algorithms [23]. The most common field-based algorithms are: Mean Absolute Difference (MAD), Normalized Cross Correlation (NCC), Sequential Similarity Detection Algorithm (SSDA), Sum of Absolute Values (SSDA) Sum of Absolute Differences (SAD) are the Sum of Squared Differences (SSD) algorithms. In feature-based algorithms, edge, corner, shape, texture and contour information of the objects in the template

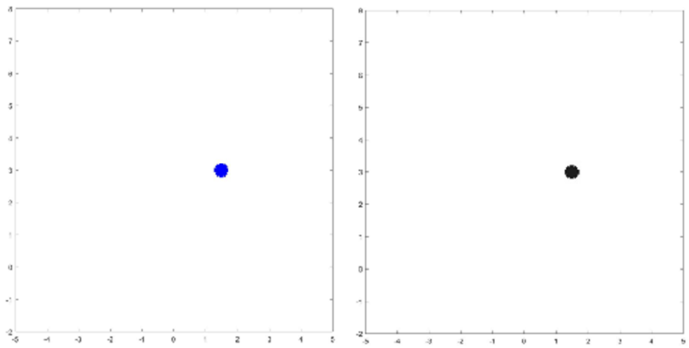


FIGURE 3. Sample Picture and Threshold Picture

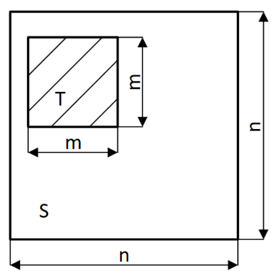


FIGURE 4. S and T Frame

is searched on the next frame [24].
T = mXm and S = nXn as in figure 4; T (i, j) of S, S (i, j) of S, r = (0,1,, n-m) and c = (0,1,, n-m) and the general equations of the SAD, MAD, SDD and NCC Algorithms for progression in the row and column are as in Equations 3.3, 3.4, 3.5 and 3.6 respectively.

According to Equation 3.3, the T (template) pixels are subtracted from the S pixels corresponding to these pixels in each turn. SAD (r, c) value is calculated for each turn by adding the absolute values of the differences that occur. In the round where SAD (r, c) is the smallest, the T template is called matching on the S frame for the values of (r, c). Each method has different application areas, advantages and disadvantages. The SSD method is the most familiar distance measurement algorithm, including template matching, because of its mathematical expression and applicability. However, the SSD method is very sensitive to noise and brightness changes [25]. NCC method is used in high speed industrial applications. A very convenient method to find multiple templates at the same time. However, this method can quickly fail due to brightness changes and object displacement. For example, changes in the sun and cloud effects in the outdoor environment affect the applicability of the NCC method very quickly. However, it is a very effective method to search for and find a template through saved images. The problem of quickly and poorly affecting NCC and SDD due to brightness and complex background is solved by the SAD method [26]. Although the SAD method is widely used in object

FIGURE 5. Target template

tracking and external applications, it requires some optimization and development for exact determination of pixel coordinates.

The T mask is hovered over the image to determine a value according to the algorithm. An example image of the mask to be created for this application is given in figure 5. This applies to the example image given in figure 3. In this way, the image in the template is determined similar to the template. The position information of the object is determined according to the template in the image.

$$SAD(r,c) = \sum_{j=1}^{m}\sum_{i=1}^{m} |S(i+r, j+c) - T(i,j)| \tag{3.3}$$

$$MAD(r,c) = \frac{1}{m^2}\sum_{j=1}^{m}\sum_{i=1}^{m} |S(i+r, j+c) - T(i,j)| \tag{3.4}$$

$$SDD(r,c) = \sum_{j=1}^{m}\sum_{i=1}^{m} \left(S(i+r, j+c) - T(i,j)\right)^2 \tag{3.5}$$

$$NCC(r,c) = \frac{\sum\limits_{j=1}^{m}\sum\limits_{i=1}^{m}\left[S(i+r,j+c)-\bar{S}(i,j)\right]\left[T(i,j)-\bar{T}\right]}{\sqrt{\sum\limits_{j=1}^{m}\sum\limits_{i=1}^{m}\left[S(i+r,j+c)-\bar{S}(i,j)\right]^2\sum\limits_{j=1}^{m}\sum\limits_{i=1}^{m}\left[T(i,j)-\bar{T}\right]^2}} \tag{3.6}$$

4. Modelling of Motion Video with Artificial Neural Networks

Artificial neural network; it is a model of the human brain consisting of nerve cells, which is parallel and stratified, with all the functions of the brain. Nowadays, modelling is used in many different fields for specific purposes. In particular, modelling of nonlinear elements, examination of complex or multivariable systems, examination of parameters that are difficult or impossible to measure, such as industry, medicine, control, etc. modelling is used in areas. ANNs that simply simulate the way the human brain works can be learned from data, generalized, able to work with an unlimited number of variables. has many important features. Therefore, using this model, a model can be produced based on input-output relationships even when it has limited information about the system. This model has the ability to adapt to changing conditions and generate results thanks to its generalization ability when an unknown input is applied. As shown in Figure 6, the simplest artificial nerve cell consists of 5 main components: inputs, weights, coupling function, activation function and output.

$$\begin{aligned} NET &= \sum_{i=1}^{n} w_i x_i + \phi \\ y &= f(NET) \end{aligned} \tag{4.1}$$

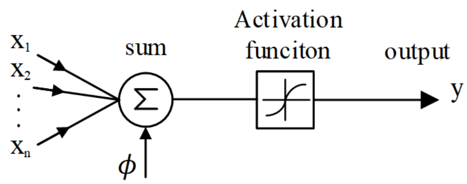


Figure 6. Single Layer Neural Network

The ANN model in Figure 6, given in its simplest form, can be modelled with the equation in Equation 4.1. As used herein, the activation function is generally preferred, the sigmoid function, a derivative that can be derived. Although this single-layer ANN is good, it is not enough to model a chaotic system. Therefore, a multi-layer artificial neural network will be used, which is a structure in which more than one layer is added. This structure is called the perceptron.

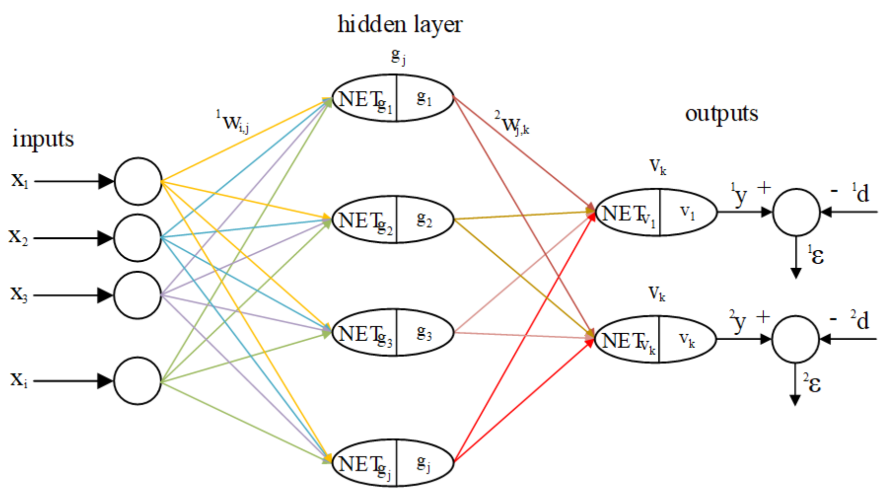


Figure 7. Multi Layer Neural Network

Multi-layer Artificial Neural Networks given in Figure 7 are composed of input layer, hidden layer and output layer. The mathematical logic of this structure is very similar to the perceptron. However, each input value that reaches the input layer can be multiplied by a weight in the hidden layer to reach the neuron in the hidden layer. The value of each neuron reaching here is the input of the next output layer through a specific process. When this process is expressed mathematically, the value of the network coming to the intermediate layer is given in Equation 4.2. The value obtained here can be the input of the output layer with the activation function in Equation 4.3. Likewise, each value reached here is also multiplied by a weight and determines the NET value of the output layer as in Equation 4.4. Then the network output is obtained by the activation function of Equation 4.5 again.

$$NET_{g_j} = \sum_i {}^1w_{i,j}.x_i \tag{4.2}$$

$$g_j = f(NET_{g_j}) \tag{4.3}$$

$$NET_{v_k} = \sum_j w_{j,k}.g_j \tag{4.4}$$

$$^k y = v_k = f(NET_{v_k}) \tag{4.5}$$

Although this is the most basic logic of artificial neural networks, NAR (Nonlinear Autoregressive Neural Network) can be made by adding unit feedback to this structure. Because of the content of this study, this structure is preferred because the inputs are the unit delayed inputs of the outputs directly. The block diagram of this is given in Figure 8.

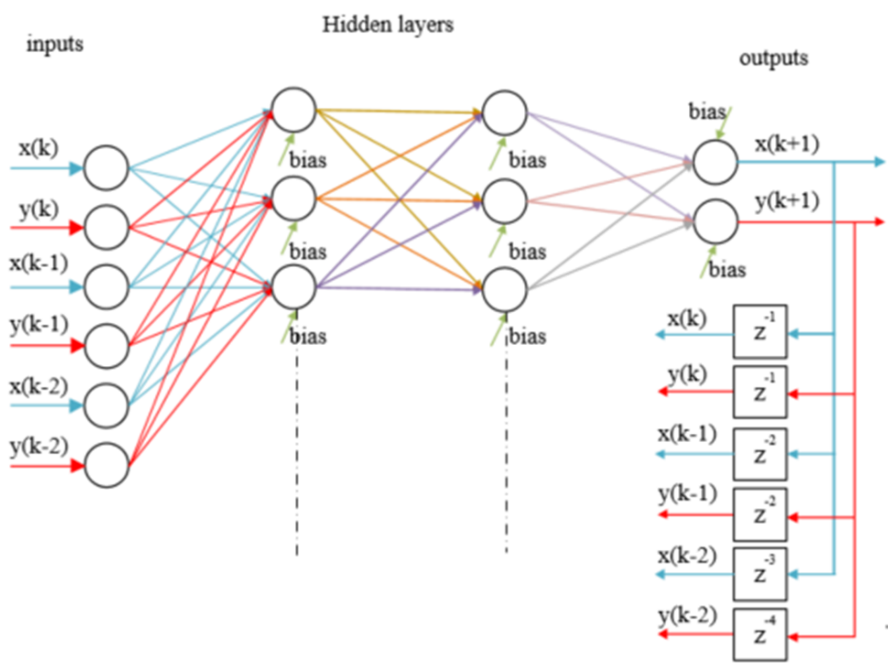
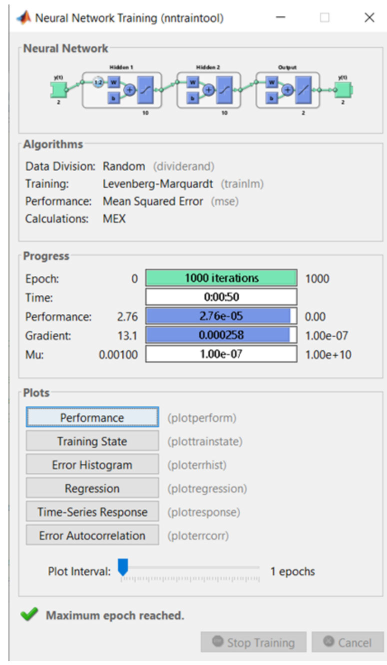


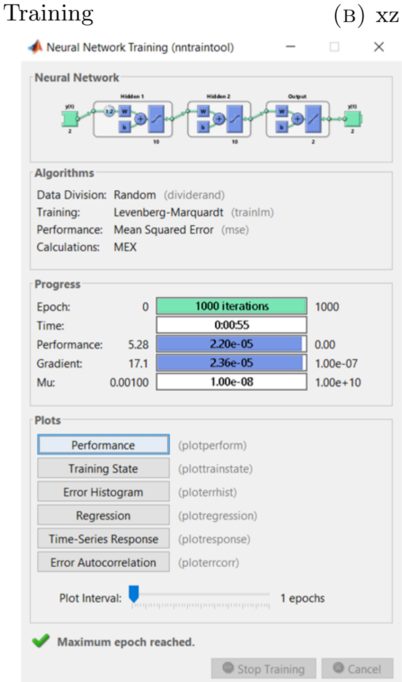
FIGURE 8. Nonlinear Autoregressive Neural Network (NAR) Structure

In order to train the chaotic behaviour of the object on the video, first the position information was taken from the video as described in the second part of the object. This location information was then given to the ANN in the NAR structure. This structure created in Matlab is given in Figure 8. Here, the first layer 10 of ANN, the hidden layer 10 neurons and the output layer is identified as 2 neurons. Nntraintool, which is in the nntool given in Figure 6, was used for the training of ANN. Levenberg-Marquardt was chosen as the back propagation algorithm for training this network. In feedback, each x and y signal with the position signal is selected as the delay of up to 2 units. Training of processes are given in figure 9a, figure 9b and figure 9c. After that, chaotic motion was generated using trained ANN model with respect to phases that were given in figure 10a, figure 10b and figure 10c.

(A) xy Phase Training

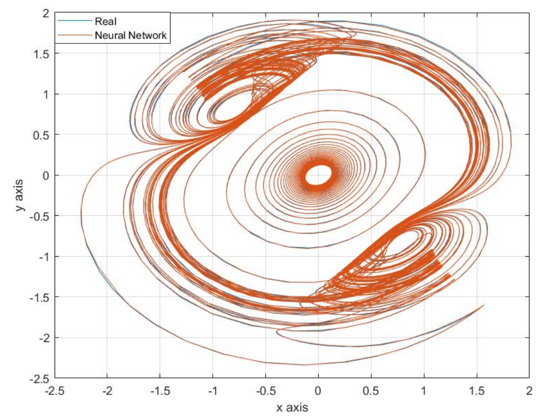


(B) xz Phase Training

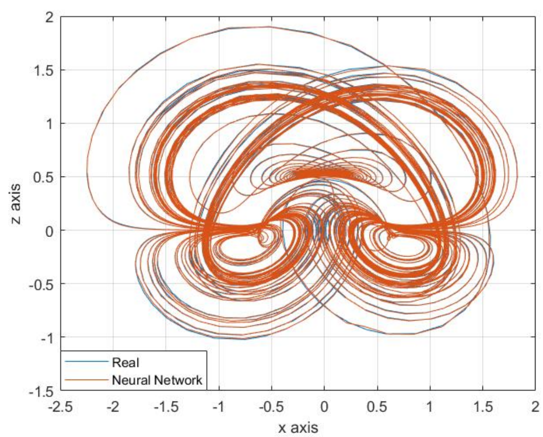


(C) yz Phase Training

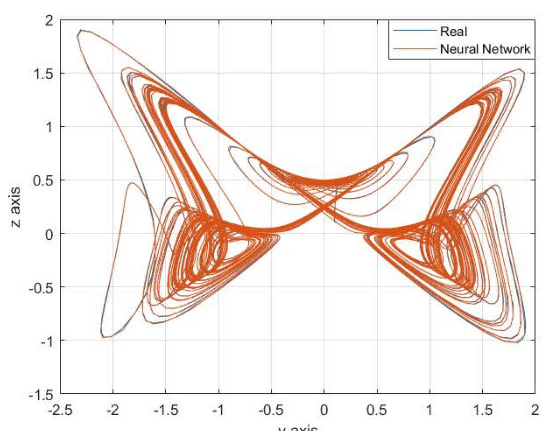
FIGURE 9. Training the data obtained from phase portraits to the artificial neural network



(A) xy Phase Training



(B) xz Phase Training



(C) yz Phase Training

FIGURE 10. Phase Portraits of the Trained Artificial Neural Network Model with the data from real video and chaotic movement of the Real System

5. Conclusions

In this study, the behaviour of the newly proposed chaotic system in the literature was made into motion and a video was created. The object to be followed in the created video was determined by template matching method. Then the position information of this object was obtained. The received position information is then trained in a NAR-structured feedback neural network. On the other hand, a mathematical system of equations could be proposed according to the data obtained. However, in order for the proposed system of equations to be appropriate, it must represent the desired system very well and capture its dynamics well. For this, the designer must know the system well. In particular, it should be a mathematical model that includes many things such as determining / observing, observable / unobservable variables in the system, knowing whether they change over time and estimating them. However, such systems can be modelled by methods such as artificial neural network, fuzzy model, and represent the system and predict the future behaviour of the system. In addition, with this method, the process load was reduced and a mathematical model representing the same dynamic behaviours was studied in a different way. However, since the training of the artificial neural network directly depends on the data, it is necessary to train the artificial neural network by receiving as much data as possible from the system. Otherwise, the artificial neural network may miss the different dynamics of the system and may even produce a different signal from the system and not represent the system and produce incorrect results. As a result, chaotic behaviour modelled by ANN can be used interchangeably as it can display the same characteristics and expected behaviour as the actual chaotic system. Thus, any movement that exhibits this and such chaotic behaviour can also be determined by image processing techniques, modelled by the artificial neural network and reproduced, predicting future outputs or replacing them.

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