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Oleg V. Kryuchin, Alexander A. Arzamastsev, Klaus G. Troitzsch

Abstract

This paper describes the analysis of a neural network used to predict currency exchange rates in comparison to technical analysis. The neural network structures used are a multilayer perceptron and a Volterra network.

Keywords: artificial neural networks, currency exchange rates, time series.

1 Introduction

The prediction of financial time series is a topical problem of economics because changing prices of shares and changing currency exchange rates influence different economic parameters. For a long time it has been assumed that financial time series are random but in the 1980s the theory of deterministic chaos appeared. This theory predicts that there are many hidden conformities in financial time series [1].

The theory of deterministic chaos suggests that a financial time series is a dynamic system. There is a group of parameters for such a system which characterizes the system condition and allows to calculate system values at every point of time from initial values by some special convention (see eq. 1) [2]. This convention is defined by the following function of system evolution:

$$x(t_m) = \Theta(x(t_{m-1}), x(t_{m-2}), \ldots, x(t_{m-L}), \vec{u}) \quad (1)$$

where $\vec{x}$ describes the system state and its immediate past, L is the size of the lag space (number of previous series values used to calculate the value of the current value), $\vec{u}$ are control parameters, and Θ is the system evolution function. The state of the currency exchange rates is characterized by the time series (2).

$$\vec{x}(t) = (x(t_0), x(t_1), \ldots, x(t_m)) \quad (2)$$

where $x(t_i)$ is the currency exchange rate at time t_i. For simulating the time series it is necessary to discover the function Θ and the parameter $\vec{u}$ from equation (1). The flavor of function Θ is unknown so in the simulation this function is replaced by the approximate function F witch is defined for the minimum difference between the empirical exchange rate x_m and the forecast exchange rate y_m in equation (3).

$$y(t_m) = F(x(t_{m-c}), x(t_{m-2c}), \ldots, x(t_{m-Lc}), \vec{u}) \quad (3)$$

where c is called the discharging coefficient which defines the length of the forecasting period. So the target of forecasting currency exchange rates is to detect the parameters F, L and c by minimizing the value ε.

$$\varepsilon = \sum_{m} |x(t_m) - y(t_m)| \tag{4}$$

One of the most often used strategies is direction detecting. So at the current time t_m this approach detects the next direction of change and calculates the value at time t_{m+c}. This calculated value is $y(t_{m+c})$. Then the difference of the values at points t_m and t_{m+c} is compared to swap value s_x. The swap value is the radius around point $x(t_m)$ within which all selling or buying operations are unprofitable. If the constraint $|y(t_{m+c}) - x(t_m)| > s_x$ holds then an operation is recommendable. If the new value $y(t_{m+c})$ is greater then the current value $x(t_m)$ then a buying operation is recommended otherwise a selling operation. So it is necessary to define one of three conditions:

$$\theta_y = \begin{cases} 1, & y(t_{m+c}) > x(t_m) + s_x; \\ 0, & |y(t_{m+c}) - x(t_m)| \leq s_x; \\ -1, & y(t_{m+c}) < x(t_m) - s_x; \end{cases} \tag{5}$$

To solve this task it is possible to use different methods, for example a technical analysis or a neural network analysis. The latter analysis is not limited by the character of the input information, which may be a time series or information about the behavior of other market factors. For example, artificial neural networks (ANN) are actively used by institutional investors (such as large pension funds etc.) which work with a large amount of information and where the development one one particular exchange rate depends on many other currency pair quotations. The difference to technical analysis (based on general recommendations) is the possibility to find optimal factors (for forecasting currency pair quotations) and to use them in forecasting [3, 4].

The aim of this paper is to predict exchange rates between Euro and US dollar using an artificial neural network. To achieve this aim, several tasks have to be solved. These tasks are

- training an ANN structure which considers at ime series of €/$ exchange rates;
- checking the adequacy of the ANN-model based on this structure;
- comparing the forecasting results of a technical analysis and the neural networks analysis;
- formulating a corollary about the possibility to use ANN for prediction.

2 Time series

Figure 1 shows the time series of currency pair quotations €/$, whose values were determined every 15 minutes during March 15 and 16, 2010 (quotations values were downloaded from the Forex market using the trade terminal IBC Trader `http://ibcapitalgroup.com/ru/instruments/`). It is possible to use different standard methods for forecasting future values. There are two kinds of time series forecasting methods.

These assume either stationary time series or unstationary time series. Methods of the first group speculate that the process is stationary with respect to the mean. The most popular of these methods are models of autoregression and moving average (ARIMA) [5, 6].

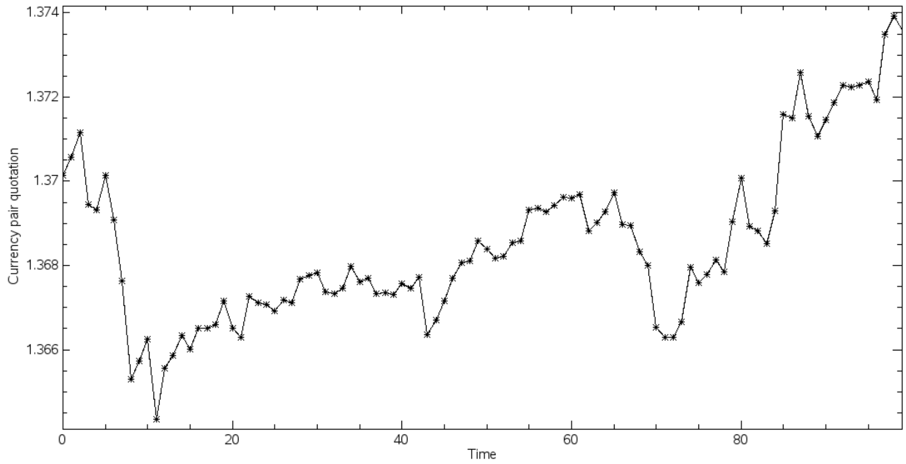

Figure 1: Quotations of currency pair €/$ from March 15 to 16, 2010.

3 The technical analysis

If technical analysis is used, then the time series of quotations $\vec{x}(t)$ usually is broken into intervals. First and last values of each interval are the opening price (x^o) and the closing price (x^c), and the highest (x^h) and the lowest (x^l) prices within each interval are also defined.

The most popular tool of technical analysis is the moving average (MA) which calculates the mean value of prices in a given time interval. So this tool is a method of smoothing price factors which are cumulated over several periods. The MA can be calculated for each serial data array, such as opening and closing prices, maximum and minimum quotations, the trade size or values of other indicators (for example the MA itself).

There are several kinds of MA:

- simple MA (equation (6));
- exponential MA (equation (7));
- smoothed MA (equation (8));

$$\hat{x}_i = \frac{1}{m}\sum_{j=i-1}^{i-m} x_j^o \quad (6)$$

$$\hat{x}_i = c_p x_i^c + \hat{x}_{i-1}(100 - c_p) \quad (7)$$

$$\hat{x}_i = \frac{1}{m}\sum_{j=i-1}^{i-m} x_j^c - \hat{x}_{i-1} + x_i^c \quad (8)$$

Here x_i^o, x_i^c are opening and closing prices at time t_i, m is the length of the smoothing period, c_p is a discounting or depreciation coefficient.

Another tool used is a stochastic oscillator which builds two series. The first series values are calculated by formula (9) and the second is the MA of the first. Often a third series is added which is the MA of the second. The crossing of smoothed and non-smoothed means changes the direction of the moment of the quotations. If the smoothed curve crosses the non-smoothed curve from below this means that the exchange rate is expected to increase, otherwise it is expected to decrease.

$$\tilde{x}_i = \frac{x_i^{cl} - \min(x_i, x_{i-1}, \ldots, x_{i-m-1})}{\max(x_i, x_{i-1}, \ldots, x_{i-m-1}) - \min(x_i, x_{i-1}, \ldots, x_{i-m-1})} \times 100 \tag{9}$$

There are different strategies of using the MA and the stochastic oscillator approach.

The best results of forecasting of €/\$ (Euro and US dollar) exchange rates were achieved using a stochastic oscillator with periods 5, 3 and 3. Quotation values were calculated correctly with a probability of 0.65.

4 The neural network formation

ANNs are mathematical instruments which are computer models of biological neural networks, which can be trained using lognormal observations and can be used with scarce or noisy information. This instrument is very flexible and this property allows to consider different lognormal observations using the change of structure and of control parameters of the model [7].

Training ANNs is reduced to minimizing the inaccuracy function:

$$\varepsilon = \sum_{i=L}^{N-1} (x_i - y_i)^2 = \sum_{i=L}^{N-1} (x_i - F(x_{i-1}, x_{i-2}, \ldots, x_{i-L}, \vec{w}))^2 \tag{10}$$

where $\vec{w}$ is a vector of weight coefficients.

The ANN which simulates exchange rate time series is formulated using the algorithm defined in [8]:

1. The lag space size L is searched. This value defines the number of input neurons in the ANN. Usually this value lies in the band (8; 16) [9].

2. The type of structure of ANN is selected. The numbers of neurons in hidden layers and the number of hidden layers are defined by the configuration of the structure.

3. The value of c which determines the length of the forecasting period (see eq. 3) is searched.

4. The optimal number of pattern rows is calculated. This value is defined by the structure size and the number of weights. If there are N quotations then the number of pattern rows is $N - L$ [10].

5. For pattern building the quotation values at time points $\vec{t}$ (equation (11)) are calculated. These values are $\vec{x}$ (equation (12)).

$$\vec{t} = (t_c, t_{2c}, t_{3c}, \dots, t_{Nc}) \quad (11)$$
$$\vec{x} = (x_0, x_1, x_2, \dots, x_{N-1}) \quad (12)$$

6. The input pattern (X) and output pattern (D) are formulated (values of patterns are formulated in formula (13)).

$$X = \begin{pmatrix} x_{N-L-1} & x_{N-L} & \dots & x_{N-3} & x_{N-2} \\ x_{N-L-2} & x_{N-L-1} & \dots & x_{N-4} & x_{N-3} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ x_1 & x_2 & \dots & x_{L-1} & x_L \\ x_0 & x_1 & \dots & x_{L-2} & x_{L-1} \end{pmatrix}, D = \begin{pmatrix} x_{N-1} \\ x_{N-2} \\ \vdots \\ x_{L+1} \\ x_L \end{pmatrix} \quad (13)$$

7. Weight coefficients are changed using a gradient algorithm of the steepest descent [11].

There is no unique method of searching for the lag space and for the discharging coefficient as each method has advantages and disadvantages. For the €/\$ exchange rates used in this paper whose series are shown in Figure 1 the parameter L is set to 100, and c takes as values 15, 30, 60 and 120 minutes (standard periods used in trade strategies).

5 Multilayer perceptron

A multilayer perceptron (MLP) is a structure in which each neuron in each layer (except output layer) is connected to all neurons of the next layer. Weight coefficients is are calculated by formula (14):

$$l_w = \sum_{i=1}^{N_L-1} \hat{N}_i \hat{N}_{i-1} \quad (14)$$

where N_L is the number of layers and $\hat{N}_i$ is the number of neurons in i-th layer. Figure 2 shows the general multilayer perceptrone structure.

The MLP structure is universal so it can be used for most of all problems.

6 The Volterra Network

The Volterra network is a dynamic network for the nonlinear adaptation of an array of delayed signals. The vector $\vec{x}$ from equation (2) activates the network at time m. According to the defintion of a Volterra series the output signal y is calculated by

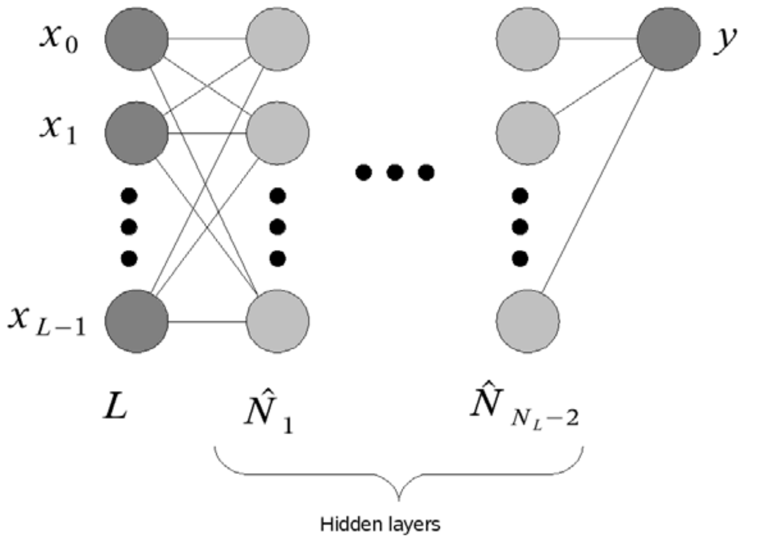

Figure 2: MLP structure.

formula (15).

$$\begin{aligned} y(\iota) &= \sum_{i_1=1}^{L}(w_{i_1}x_{\iota-i_1}) \ + \\ &+ \sum_{i_1=1}^{L}\left(\sum_{i_2=1}^{L}(w_{i_1,i_2}x_{\iota-i_1}x_{\iota-i_2})\right) \ + \ \ldots \ + \\ &+ \sum_{i_1=1}^{L}\left(\sum_{i_2=1}^{L}\left(\sum_{i_3=1}^{L}\cdots\sum_{i_K=1}^{L}(w_{i_1,i_2,\ldots,i_K}x_{\iota-i_1}x_{\iota-i_2}\ldots x_{\iota-i_K})\right)\right) \end{aligned} \tag{15}$$

where $\vec{x}$ is input vector and weights w_i, $w_{i,j}$, $\ldots$, $w_{i,j,\ldots,k}$ and etc. are called Volterra kernels and correspond to the reaction of the highest factors. This polynomial degree K is called the Volterra series degree [11].

The signal with index $i \ mod \ L$ is set to i-th neuron. Here values of the output neurons are calculated by formula (16).

$$y_{i,j} = x_\iota\left(f\left(\sum_{k=0}^{L} y_{i-1,ik}\right) + w_{i,j,\iota}\right), \quad \iota = j \ mod \ L \tag{16}$$

where $y_{i,j}$ is the output value of the neuron located at the j-th position of the i-th layer, x_ι is ι-th input value and f is the neuron activation function (usually it is a linear function).

The number of neurons at the i-th layer can be calculated by formula (17) and the number of weight coefficients (Volterra kernels) can be calculated by formula (18). It is recommended to use a Volterra series of degree 3. This degree corresponds to an ANN with four layers.

$$\hat{N}_i = L^{N_L - i - 1} \tag{17}$$

$$l_w = \sum_{i=1}^{N_L - 1} \hat{N}_i \tag{18}$$

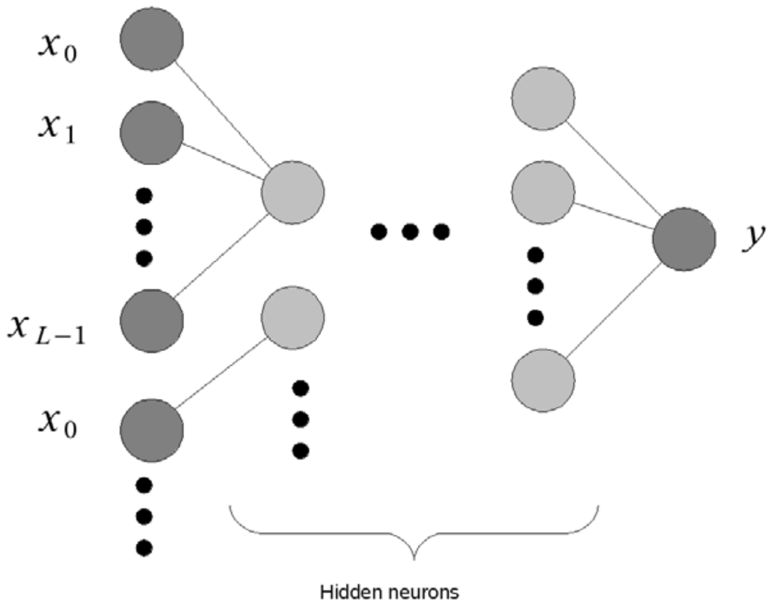

Figure 3: The Volterra network structure.

7 Testing results

The algorithm of testing consists of several steps:

1. The algorithm starts at time $t = t_0$, and sets the test index to $k = 0$.
2. The pattern is formed by a convention written in section 4 (by formula (13)).

$$\chi_k = \begin{cases} 1, & \theta_x = \theta_y; \\ 0, & \theta_x \neq \theta_y; \end{cases} \tag{19}$$

where

$$\theta_y = \begin{cases} 1, & y_{N+1} > x_N + s_x; \\ 0, & |y_{N+1} - x_N| \leq s_x; \\ -1, & y_{N+1} < x_N - s_x; \end{cases}, \quad \theta_x = \begin{cases} 1, & x_{N+1} > x_N + s_x; \\ 0, & |x_{N+1} - x_N| \leq s_x; \\ -1, & x_{N+1} < x_N - s_x; \end{cases}$$

3. Weight coefficients are trained by a gradient algorithm of steepest descent [11].

4. The input vector $(x_{N-L+1}, x_{N-L+2}, \dots, x_N)$ is formed. The ANN calculates the output output value y_{N+1}.

5. The quotation change $\Delta y_{N+1} = y_{N+1} - x_N$ is calculated and used for calculation of value χ_k by formula (19).

6. The time t is changed $(t = t + c)$ and the test index is incremented $(k = k + 1)$.

7. The algorithm goes to step 2.

These tests estimate the probability of obtaining the correct direction of the quotation change. For the multilayer perceptron it is 72 % and for a Volterra network it is 76 %. The technical analysis allows to forecast the correct direction of change with a probability of about 65 %. So the neural network analysis using a Volterra network is efficient.

Table 1 shows the values of the sufficiency coefficient for ANN-models (calculated by formula (20)) using a multilayer perceptron (β_M) and a Volterra network (β_V).

$$\beta = \frac{1}{I_T} \sum_{i=0}^{I_T - 1} \chi_i \tag{20}$$

where I_T is the number of experiments.

Figure 4 shows a series of currency pair quotations, both empirical and forecast by the multilayer perceptron and the Volterra network, respectively.

Table 1: Values of sufficiency of ANN-model.

	ANN-model sufficiency							
Coefficient of discharging c	15 min.		30 min.		60 min.		120 min.	
Prediction rating L	β_M	β_V	β_M	β_V	β_M	β_V	β_M	β_V
8	69	73	69	71	67	70	65	65
9	70	73	70	72	69	71	65	67
10	71	73	71	73	71	72	65	69
11	72	75	72	73	69	73	66	69
12	72	76	72	75	70	73	66	70
13	72	75	72	75	70	71	67	72
14	72	75	71	74	70	70	67	73
15	70	75	70	73	70	72	66	72
16	69	74	69	73	70	72	67	70

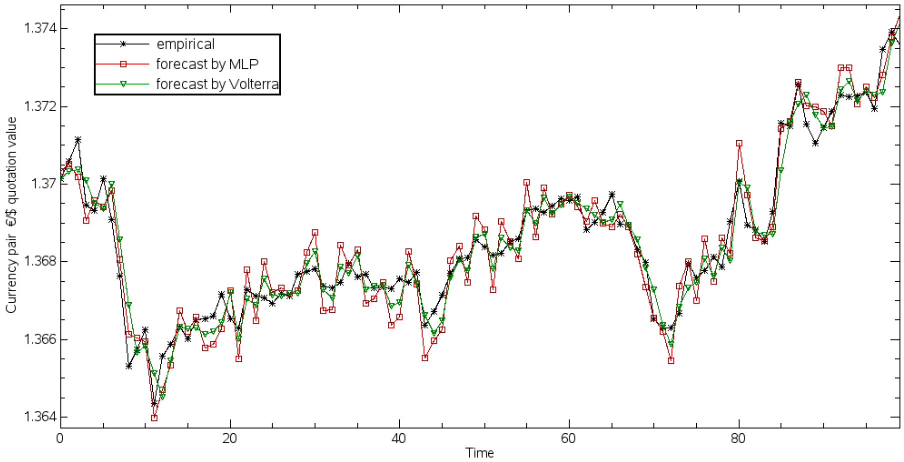

Figure 4: Empirical exchange rates, exchange rates forecast by the multilayer perceptron and by the Volterra network.

8 Conclusion

It follows from the experimental results that a Volterra ANN with four layers and twelve inputs allows to predict the correct direction of the quotation change with a probability of 76%. So such a structure can be used for forecasting exchange rates.

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