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USING ARTIFICIAL NEURAL NETWORKS FOR ECG SIGNALS PREDICTION

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ABSTRACT

The authors have investigated some potential applications of artificial neural networks in electrocardiografic (ECG) signal prediction. For this, the authors used an adaptive multi-layer perceptron structure to predict the signal. The proposed procedure uses an artificial neural network based learning structure to estimate the (n+1)th sample from n previous samples To train and adjust the network weights, the backpropagation (BP) algorithm was used. In this paper, prediction of ECG signals (as time series) using multi-layer feed-forward neural networks will be described. The results are evaluated through approximation error which is defined as the difference between the predicted and the original signal. The prediction procedure is carried out (simulated) in MATLAB environment, using signals from MIT-BIH arrhythmia database. Preliminary results are encouraging enough to extend the proposed method for other types of data signals.

Keywords: artificial neural network, ECG signal, prediction, backpropagation, prediction error

I. Introduction

The Electrocardiogram (ECG) is a time-varying signal which reflects the electrical activity of the heart. The ECG signal is obtained by recording the potential difference between two electrodes placed on the body surface. A single normal cycle of the electrocardiogram represents the succesive atrial and ventricular depolarization/repolarization. Each heartbeat is a complex of distinct cardiological events, represented by distinct features in the ECG waveform. These features represent either depolarization (electrical discharging) or repolarization (electrical recharging) of the muscle cells in particular regions of the heart and they can be observed as a series of deflections away from the baseline on the ECG. It is important to have a clean record in order to extract the most important parameters for accurate clinical investigations. In this work we assume that a normal ECG record consists of periodically repeated intervals.

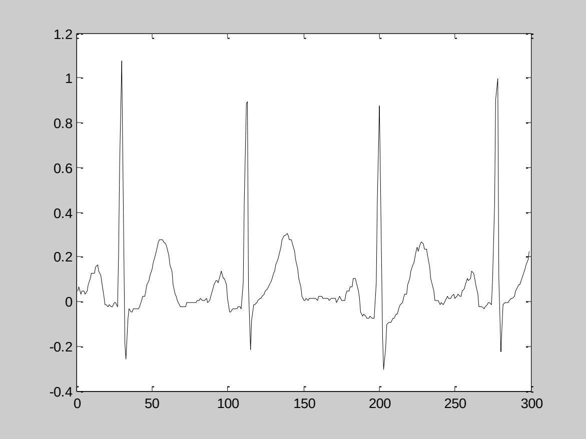


Figure 1. The ECG signal

Then it is possible to predict the following sample of the digitalized ECG record when a few previous samples are known. To estimate next time sample is possible to use a neural network based structure.

The prediction of time series using neural network consists of teaching the net the history of the variable in a selected limited time and applying the taught information to the future. Data from past are provided to the inputs of neural network and we expect data from future from the outputs of the network. Artificial Neural Networks are being increasingly used in medical applications such as ECG signal detection, classification and automated diagnosis. In this applications backpropagation neural network has been used because of its good pattern recognition capabilities in supervised training mode [2]. In this work the authors have investigated potential applications of artificial neural networks in electrocardiografic (ECG) signals filtering carried out by a good approximation of this signal. Usually, denoising methods should have to improve signal-to-noise ratio for obtaining clean recordings and to preserve the original shape of signal, especially the peaks, without distortioning the waves and segments.

II. Artificial neural networks

Artificial neural networks (ANNs) recently has received great attention in many research fields. The ANN's are biologically inspired computer programs designed to simulate the way in which the human brain processes information. They can be defined as mathematical algorithms that approach the functionality of small neural clusters in a very fundamental manner. Artificial neural networks are relatively crude electronic networks of "neurons" based on the neural structure of the brain. They process records one at a time, and "learn" by comparing their prediction of the record (which, at the outset, is largely arbitrary) with the known actual record. The errors from the initial prediction of the first record is fed back into the network, and used to modify the networks algorithm the second time around, and so on for many iterations. The artificial neural networks ANNs gather their knowledge by detecting the patterns and relationships in data and learn (or are trained) through experience, not from programming. ANN represents a promising modeling technique, especially for data sets having non-linear relationships which are frequently encountered in RCG signal processing. In terms of model specification, artificial neural networks require no knowledge of the data source but, since they often contain many weights that must be estimated, they require large training sets [4]. An ANN is formed from hundreds of single units, artificial neurons or processing elements (PE), connected with coefficients (weights), which constitute the neural structure and are organised in layers. Figure 2 presents the general structure of an artificial neural network [1].

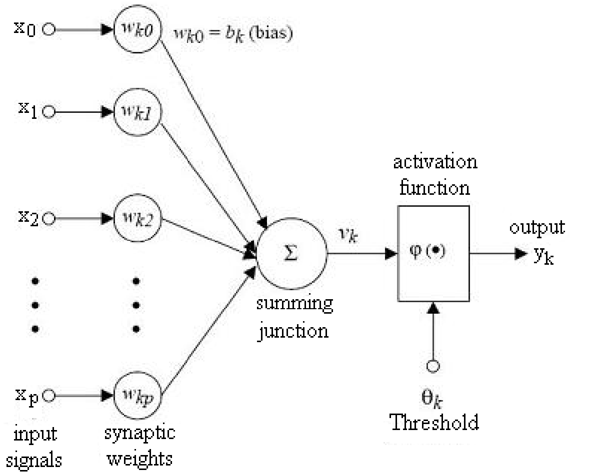


Fig. 2. Structure of an artificial neural network.

The input layer is composed not of full neurons, but rather consists simply of the values in a data record, that constitute inputs to the next layer of neurons. The next layer is called a hidden layer; there may be several hidden layers. The final layer is the output layer, where there is one node for each class. A single sweep forward through the network results in the assignment of a value to each output node, and the record is assigned to whichever class's node had the highest value. To obtain what we need from an ANN, there are two phases in neural information processing, the learning phase and the retrieving phase. In the training phase, a training data set is used to determine the weight parameters that define the neural model. This trained neural model will be used later in the retrieving phase to process real test patterns and yield classification results. The power of neural computations comes from connecting neurons in a network. The behavior of a neural network is determined by the transfer functions of its neurons, by the learning rule, and by the architecture itself. The weights are the adjustable parameters and, in that sense, a neural network is a parameterized system. The weighed sum of the inputs constitutes the activation of the neuron. The activation signal is passed through transfer function to produce a single output of the neuron. Transfer function introduces non-linearity to the network. During training, the inter-unit connections are optimized until the error in predictions is minimized and the network reaches the specified level of accuracy. New ANNs can be synthesized by describing the transfer functions of their neurons, by the learning rule and by the connection formula. The various applications of ANNs can be summarised into classification or pattern recognition, prediction and modeling. Unsupervised feature-extracting networks represent an alternative to principal component analysis [3]. Non-adaptive unsupervised networks are able to reconstruct their patterns when presented with noisy samples and can be used for signal approximation based nonlinear filtering.

Feed-forward ANNs allow signals to travel one way only; from input to output. There is no feedback (loops) i.e. the output of any layer does not affect that same layer. Feed-forward ANNs tend to be straight forward networks that associate inputs with outputs[5].

III. The proposed algorithm

The general form of the used structure is shown on figure 3. This neural network is formed in three layers, called the input layer, hidden layer, and output layer. Each layer consists of one or more nodes, represented in this diagram by the small circles. The lines between the nodes indicate the flow of information from one node to the next.

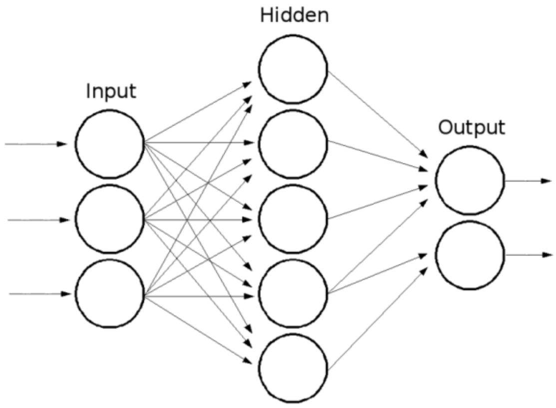


Figure 3 The proposed ANNs structure

The objective of any prediction method is making claims about something that will happen, often based on information from past and from current state. For this an artificial neural network based learning structure was created, as presented on figure 4. Certain number of measured values is used as inputs and the value to be predicted is used as required output.

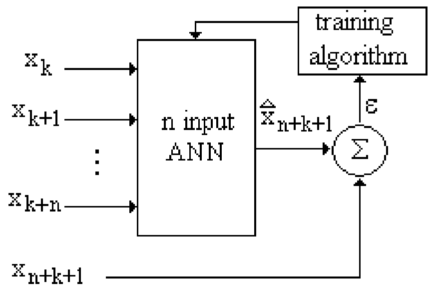


Fig.4 The estimation structure

The trained neuronal network output is the estimated value of $\tilde{x}(k+N+1)$.The estimation of the $x(k+N+1)$th sample is carried out with the help of previously N samples. The procedure is presented on figure 5. Input part of the time series is called window, the output part is the predicted value. By shifting the window over time series the items of training set are made

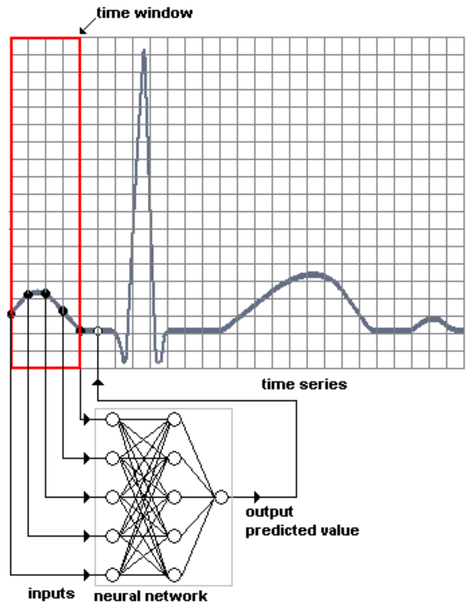


Figure 5. The principle of estimation

Various types of neural networks can be used for prediction, but in this work we use backpropagation network. The training process gives the estimated output, so the estimated error (the difference between the original and the estimated signal) is a white noise-like signal. The error at the output layer in the proposed model propagates backward to the input layer through the hidden layer in the network to obtain the final desired output. The gradient descent method is utilized to calculate the weight of the network and adjusts the weight of interconnections to minimize the output error[2].

IV. Results

We measured the filtering quality of the current implementation for different types of feed-forward ANN's . The original signal is presented on figure 6.

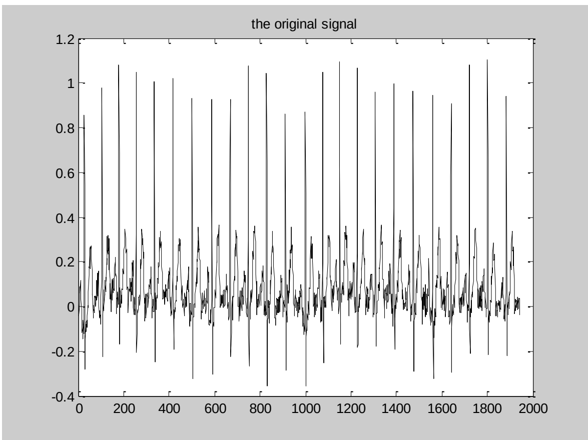


Figure 6. The original ECG signal

A number of 20 samples from the original signal was chosen as input in the artificial neural network based learning structure. Figure 7 presents the learning efficiency of the ANN. The learning error, as we can see on figure 8 has relatively great values around the local maxima (R peaks on ECG) due to the backpropagation algorithm. The training performace is illustrated on figure 9, the proposed goal (training error for the learned sequence under 10^{-6}) was reached after 124 iterations (20 inputs, 1 hidden layer with 9 neurons and training length of 800).

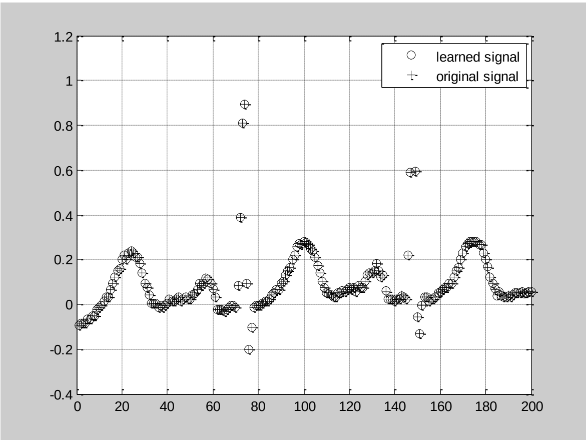


Figure 7. The learning and learned sequences

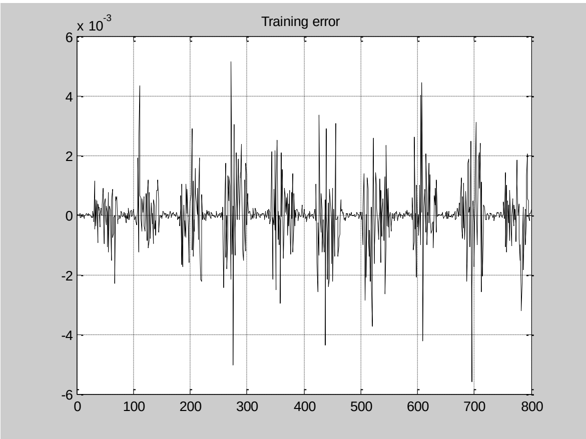


Figure 8 The training error

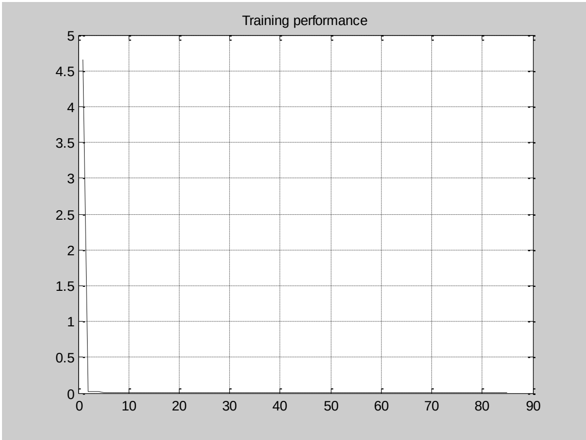


Figure 9. The training performance

Figure 10 presents the learning results and the output of ANN for the learned and the remained signal parts. Finally the original signal and the filtered version (just parts of them for a good representation), are compared on figure 11. The different errors obtained with the used network structure (radial basis function as activation function, 1 hidden layer with 9 neurons, linear output) are compared in table 1. As we can see, the training sequence and the number of inputs are strongly correlated. This can be an advantage in approximation, assuming that the ECG signal is almost periodical, but its nostationarity properties can have bad influence in learning process.

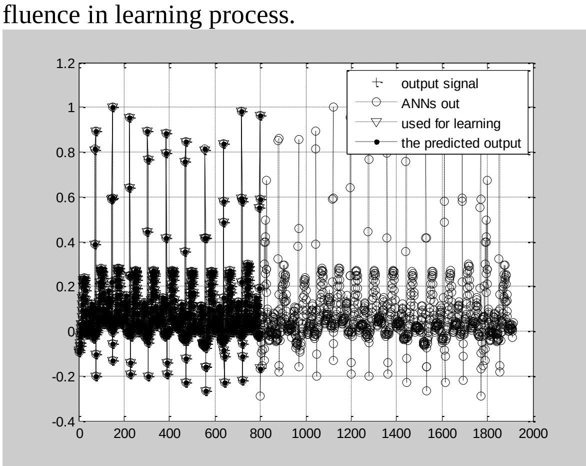
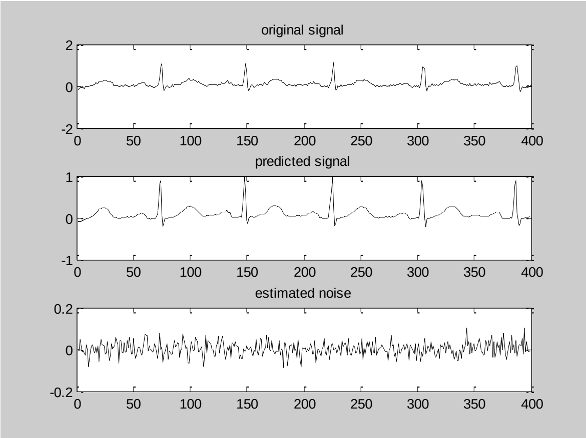


Figure 10. The learning results



Figurre 11 The results of prediction

Mean average error comparison for different training lengths and different input sizes is presented in table 1, they are represented on figure 12.

Table nr. 1

Number of input neurons	Training sequence length 600	Training sequence length 700	Training sequence length 800
10	0.0111	0.0404	0.0640
15	0.0444	0.0054	0.0100
20	0.0126	0.0049	0.0134
25	0.0232	0.0104	0.0093
30	0.0100	0.0098	0.0070

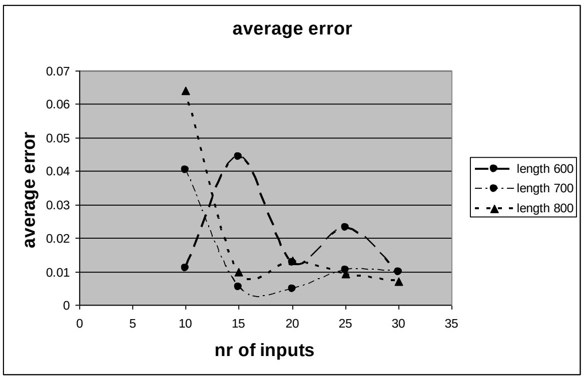


Figure 12 The obtained average error

V. Conclusions

Neural networks can be used for prediction with various levels of success. The obtained results are promising, as further work, other types of ANNS can be used in order to find the most appropriate structure for an optimal denoising. The advantage of the usage of neural networks for prediction is that they are able to learn from examples only and that after their learning is finished, they are able to catch hidden and strongly non-linear dependencies, even when there is a significant noise in the training set. The disadvantage is that NNs can learn the dependency valid in a certain period only and the error of prediction cannot be generally estimated.

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