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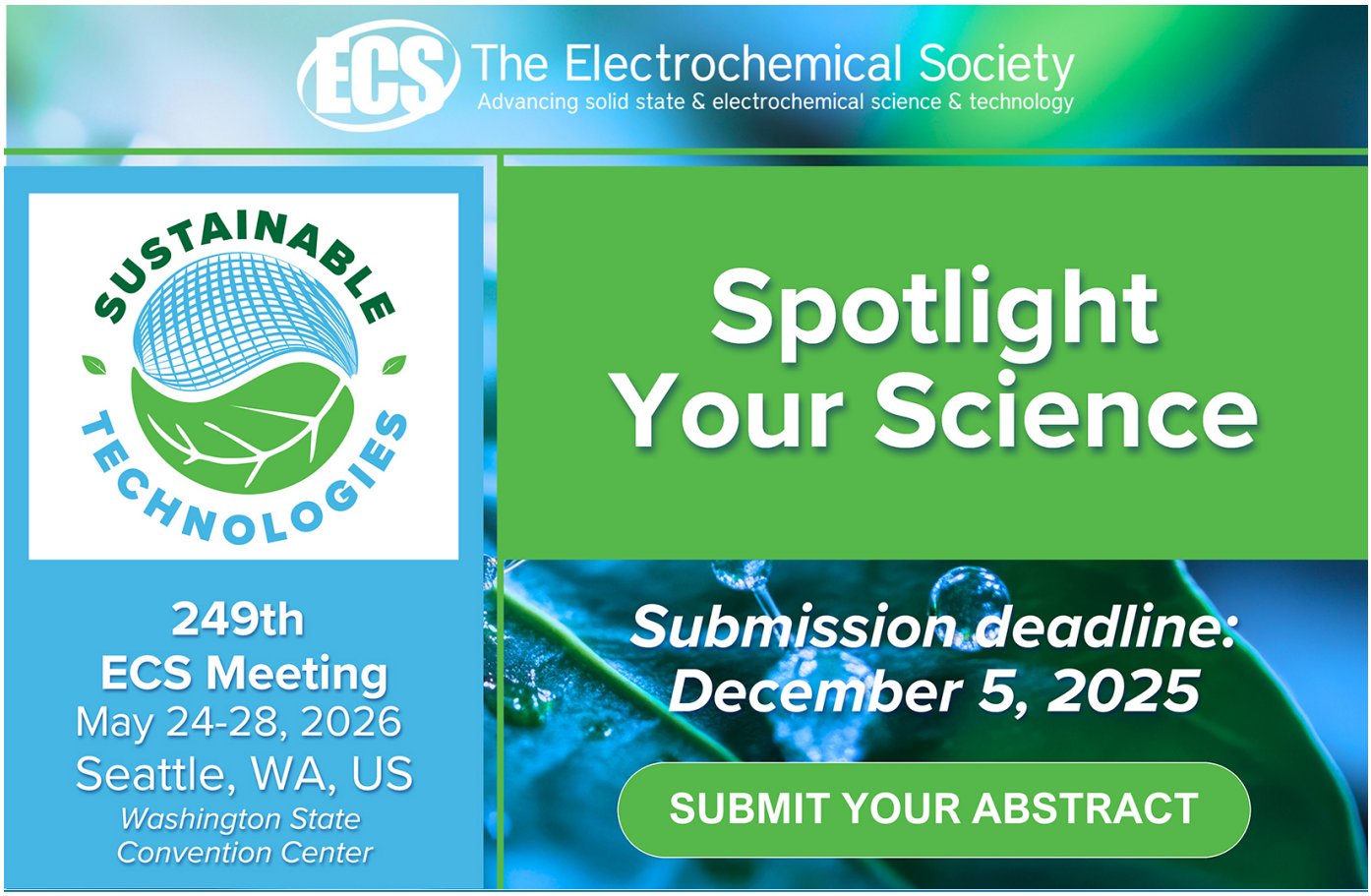
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# Heart rate variability analyzed by computer science

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**Abstract.** Computer science is being used in medical applications with very good results. In this work, artificial neural networks are used as intelligent techniques that allow analyzing the heart rate variable to anticipate changes in the autonomic nervous system, which seeks to maintain the homeostasis of the organism and the execution of adaptive responses to environmental changes. This clinical examination has been little explored, and we want to contribute with this work to correct ectopic beats and artifacts detected in an electrocardiographic signal for the precise calculation of heart rate variability. The reverse propagation algorithm is used. The ectopic beat detection and correction program is validated based on the calculation of the sensitivity, specificity, and accuracy of ectopias and artifacts detection. A sample of 40 electrocardiogram signals is taken using for training and testing. With the proposed method, an accuracy of 82.34%, a sensitivity of 89.22% and a specificity of 95.78%.

## 1. Introduction

The autonomous nervous system (ANS) is an important component of the nervous system made up of neurons and nerve pathways that allow the body to maintain homeostasis and carry out adaptive responses to environmental changes. Innervates the heart muscle, regulates respiration, circulation, metabolism, among others [1]. The clinical examination of ANS diseases has been little explored due, among other things, to the difficulty in performing assessment tests and the low sensitivity and specificity of each of them in isolation [2]. However, some recent research reveals that the measurement of heart rate variability (HRV) is very important to anticipate changes in the ANS [3].

When calculating HRV, the correct determination of the normal RR segments (the RR interval distance between two successive R waves. In sinus rhythm, this interval should be constant) is very important to construct a tachogram that models the behavior patterns of the heartbeat, but ectopic beats and artifacts that could cause that valid the graphical representation of the depolarization of the heart's ventricles forming a spike structure in the electrocardiogram (QRS) complexes of little amplitude are not detected must be eliminated or that there are false detections, therefore generating series of RR intervals that do not reveal useful information from the ANS. The heart rate depends on the sympathetic and parasympathetic activation, which is an important indicator to understand the behavior of the ANS, as the ectopic beats do not provide relevant information about the ANS, the HRV should be calculated considering only normal beats [4].

The program previously used to calculate the tachogram was vulnerable to the appearance of ectopic beats and artifacts. To solve this, it is proposed to implement a computational tool based on RNA that detects and suppresses ectopic beats and artifacts that induce error in HRV calculation. Therefore, the

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present project proposes implementing an algorithm for the correction of ectopic beats and artifacts detected in an electrocardiographic signal to calculate heart rate variability and establish the most efficient methods. Through the development of an algorithm that classifies and corrects the signal, an algorithm was designed in MATLAB® using artificial neural networks (ANN) to correct Ectopic beats and artifacts detected in an EKG signal for accurate HRV calculation. Hopfield suggested a close relationship between physical systems and neural networks. The physicist John Hopfield, considered one of the most important promoters of the new connectionism, considered that each combination of weights of the network connections has an associated energy, which results from evaluating the restrictions determined by the input data and the result produced through the net. According to Hopfield, a state of energy equilibrium is reached when the input and output of each unit are equal [5].

## 2. Background

In 1936 with Alan Turing, it was considered the father of modern computing, the first to speak of the brain as a computational system; and he showed that the "Turing machine" could solve any mathematical problem that could be represented by an algorithm. In 1943, Warren McCulloch, a neurophysiologist, and Walter Pitts, a mathematician, wrote a theory about how neurons work and modeled a simple neural network using electrical circuits [6]. In 1949, Donald Hebb contributed to the utmost importance in which he establishes a relationship between the psychology and physiology of the nervous system. It describes that human learning occurs when certain changes in a neuron are activated, which formed the basis of the neural network theory [7]; the Dartmouth conference, held in 1956, is considered the event that gave rise to artificial intelligence as a field of action, its fundamental statement established that “every aspect of learning or any other characteristic of intelligence can, in principle, be described so precisely that a machine can be made to simulate it” [8].

In 1974, Paul Werbos developed the backpropagation learning algorithm used in artificial neural networks, which was reinvented by David Rumelhart and G. Hinton in 1986 [9]. Today, work continues with networks. neurons to classify biological patterns and recognized authors such as Mateo J, *et al.*, publish the results of their research year after year [10]. As a background, there is Detection and classification of non-proliferative diabetic retinopathy using a backpropagation neural network [11], in [12] a method is proposed to cancel ectopic beats by classifying between normal and abnormal beats. The system is based on a radial base function neural network.

The heart's work to push blood into the arteries is known as a heartbeat, which occurs when the myocardium forms its walls contracts. This contraction occurs due to the displacement of proteins present in myocardial cells, this displacement is triggered by a change in electrical potential in the myocardial cell membrane, which is known as action potential and originates and spreads in the cells that form the electrical conduction system [13]. The cardiac impulse conduction system is formed by: Sinoatrial or sinus node: it is located at the mouth of the superior vena cava. It is also known as the pacemaker of the heart since it is the place where the cardiac impulse begins, which extends through the two atria until it reaches the atrioventricular node [14]. Atrioventricular node: It is located in the right atrium below the fossa ovale and its function is to conduct the impulse to the atrioventricular bundle.

## 3. Methodology

Taking as a reference [14-16] for the elaboration of a program for the correction of ectopic beats and artifacts in electrocardiographic signals, a review of the state of the art of implementation of artificial intelligence techniques for signal processing was carried out. Neural networks of the backpropagation type were selected as the technique to be used to classify the beats. The algorithm was programmed to extract temporal and frequency attributes of the twenty signals used for the network's training. An algorithm was developed whose purpose is to create the test attributes of the network. The RNA was built, and a program designed to determine the number of hidden layer neurons required for optimal network performance. Finally, the program for the detection and correction of ectopic beats was validated from the calculation of the sensitivity, specificity, and accuracy of detection of ectopias and artifacts. A sample is taken of 40 ECG signals extracted from the database of 100 ECG signals from the

"Ciencias Biomédicas" laboratory of the Universidad Industrial de Santander, Colombia, taken with the Biopac MP35, with a sampling frequency of 1000 Hz, DII lead and duration of 5 minutes, 20 signals were used for RNA training, the other 20 were used in the validation of the program.

## 4. Results and discussion

To create a neural network capable of classifying ectopic beats and normal beats, four stages of development were followed. Heartbeat segmentation. From the function "complexQRS" [15] the coordinates in time and amplitude of each beat R are identified, the output variables will be "mrf" which is a vector formed by the coordinates on the y axis (amplitude) of each wave R identified, and "trf" is a vector formed by the coordinates on the x-axis (time) which will allow me to locate at what time a beat occurred. These two coordinate vectors "mrf" and "trf" allow to locate the maximum point, also known as the R wave, to subsequently manually select the beats to be used to train the neural network. For the calculation of attributes, two command files were created: "training.m" and "testeo.m", for training and testing the network vector set is created for ectopias and one for normal beats Equation (1) and Equation (2).

$$\mathrm{ec} = \begin{bmatrix} \mathrm{Lat.\,ectopico}_{(1,1)} & \cdots & \mathrm{Lat.\,ectopico}_{(1,\mathrm{m})} \\ \vdots & \ddots & \vdots \\ \mathrm{Latido.\,ectopico}_{(20,1)} & \cdots & \mathrm{Lat.\,ectopico}_{(20,\mathrm{n})} \end{bmatrix}, \tag{1}$$

$$\mathrm{not} = \begin{bmatrix} \mathrm{Lat.\,normal}_{(1,1)} & \cdots & \mathrm{Lat.\,normal}_{(1,\mathrm{i})} \\ \vdots & \ddots & \vdots \\ \mathrm{Lat.\,normal}_{(20,1)} & \cdots & \mathrm{Lat.\,normal}_{(20,\mathrm{j})} \end{bmatrix}, \tag{2}$$

The main structure of the algorithm is an iterative cycle. The first block of this cycle allows loading the twenty signals to be analyzed from the library, in the second block the pre-processing of the signal is carried out. Each sign is trimmed to a width of five minutes so that all signs being used have the same dimensions. Each signal is then filtered using the 6.8 biorthogonal wavelet transform (TW) [15]. In the third block, the R peaks are detected and marked from the coordinates provided by the "complex QRS" function, each complete electrocardiographic signal is plotted, and the points formed by the coordinates (trf, mrf) that correspond to the maximums of each window.

The fifth block is that of attribute extraction. Once each of the QRS intervals of the signal has been correctly detected and defined, we proceed to extract characteristics of each one of them to define whether these are normal beats (which will later be identified with 0) or ectopic/artifacts (identified with 1). It was decided to make use of six different attributes that correspond to temporal measurements and frequencies of the signal. Some of these attributes are direct measures of the interval X; however, others are comparative measures with respect to a Y pattern beat of the same signal, which for obvious reasons must be normal Figure 1(a) and Figure 1(b). To calculate the correlation, the "corr" function of MATLAB® is used, with which the linear correlation coefficient is obtained Equation (3).

$$\mathrm{correxs} = \mathrm{corr}(\mathrm{X}, \mathrm{xs}\{\mathrm{i}\}), \tag{3}$$

Analyzing the temporal behavior of the ectopic signals, it was possible to conclude that in these usually the maximum peak, which normally occurs in R, is much lower, and therefore the minimum, which normally occurs in S, is much larger than that of a normal complex. For this reason, the relationship between R and S is used as an attribute. This attribute is obtained by calculating the maximum value and the minimum value of each beat that is being analyzed and dividing them by each other [17], Equation (4).

$$\mathrm{ratio(x)} = \frac{\max(\mathrm{x})}{\min(\mathrm{x})}, \tag{4}$$

The calculation of this attribute is performed using the MATLAB® function “max” and “min” and dividing the results obtained Equation (5).

$$\text{ratioxs} = \frac{\max(\text{xs\{i\}})}{\min(\text{xs\{i\}})}. \tag{5}$$

Standard deviation (SD) is a measure of dispersion that gives an idea of how far the data deviates from its mean. The standard deviation of the beat function being analyzed was used. It is denoted by $\text{std}(X)$ and is defined as the positive square root of the variance [17] (See Equation (6)).

$$std(X) = \sqrt{\sum_{i=1}^{N}(X_i - \bar{X})^2}. \tag{6}$$

Effective value (RMS) in alternating current, is the value that, when taken to direct current, produces the same calorific effects. Mathematically, the rms value of a continuous signal, X, [17] is defined as Equation (7).

$$X_{rms} = \sqrt{\frac{1}{T}\int_{t_o}^{t_o+T} i^2(t)dt}, \tag{7}$$

for a discrete signal, it is calculated like this [17] Equation (8).

$$X_{rms} = \sqrt{\sum_{i=0}^{N}\|X_i\|^2}. \tag{8}$$

Using this parameter in the neural network is convenient whenever, as can be seen in Figure 2, the Fourier transform of the ectopic beat (Figure 2(a)) presents a greater amplitude in the direct current (DC) component, compared to the normal beat (Figure 2(b)).

Total harmonic distortion (THD) it is the relationship between the harmonics of the signal and the fundamental tone. It allows knowing the power of the signal that is lost due to harmonics [16]. The total harmonic distortion of a signal is mathematically defined as the relationship between the total powers of the harmonics over the power of the fundamental tone So [17] Equation (9).

$$\text{THD} = \frac{\sum P_i}{P_0}\%. \tag{9}$$

The transform of ectopic beats sometimes reaches very different amplitudes than normal beats, which handle very similar amplitude values to each other (quotient of maximum absolute values). The maximums reached by the transform of the beat being analyzed X and the transform of the pattern are compared Y in Equation (10) [17].

$$\text{fr} = \frac{\max(|\text{fft}(X)|)}{\max(|\text{fft}(Y)|)}, \tag{10}$$

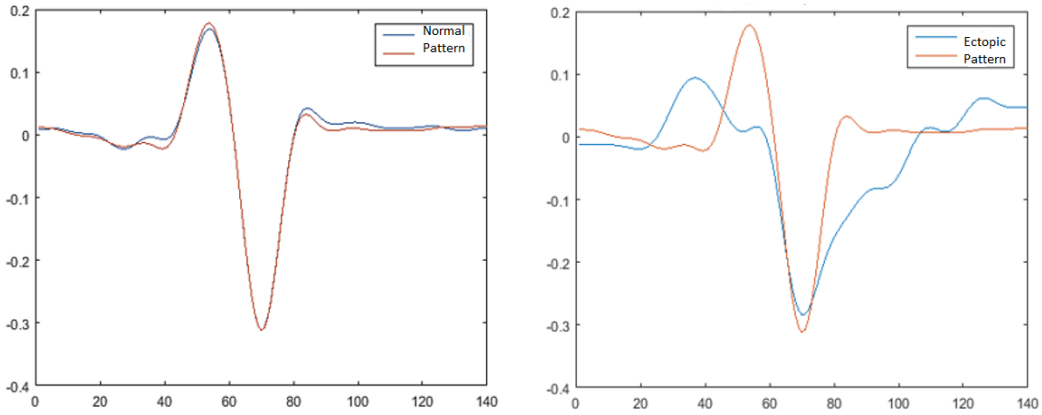
When calculating the attributes, the "innoto" matrix is constructed that contains six rows corresponding to the attributes and a single column that corresponds to the beat that is being analyzed in the current iteration. Then the sets of vectors "innot" and "inec" are constructed, which contain the attributes of all the selected beats to train the network of the signal corresponding to the current iteration. The "innot" and "inec" vector sets have as many columns as there are beats selected from the iterated signal. The matrices that are going to train the network are created, grouping “inec” and “innot” in a single matrix called “innero”, which contains the attributes of both the ectopies and the normal beats of each signal [17] (see Equation (11)).

$$\text{innero} = \big(\text{inec}(\text{innot})\big). \tag{11}$$

The "inner" matrix is constructed, which includes the total attributes of both the ectopic and normal beats, for all the twenty signals used. This matrix will be the input of the neural network Equation (12).

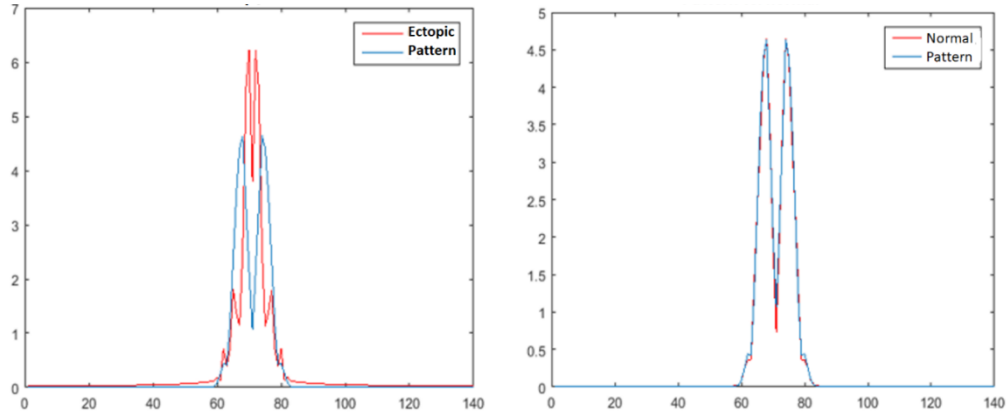
$$\text{inner} = (\text{inero}_1 \quad \text{innero}_2 \quad \ldots \quad \text{innero}_{20}). \tag{12}$$

The target vector is constructed by creating a vector of ones and zeros; this single-row vector has as many 1s as there are "inner" ectopies and as many zeros as normal beats. This vector is called "outo". Once the input data have been selected and processed, they must be normalized before supplying them to the neural network, since in this way a better generalization of the network is obtained in the learning process; said normalization process consists of dividing each one of the interior values of the inner matrix, in such a way that the highest value of the input to the network will be one. The normalization is done column by column until all the values of the matrix oscillate between 0 and 1.




(a) (b)

**Figure 1.** Tracing of a normal signal vs. pattern (a), ectopic signal vs. pattern (b).




(a) (b)

**Figure 2.** FFT ectopic beat vs. pattern (a). FFT normal beat vs. pattern (b).

To train the neural network, a minimum of 4 elements is required: an input matrix, a target vector, a training function, and a performance function; of which the first two were calculated in the second stage. The neural network is created using the Neural Pattern Recognition tool of the MATLAB® "nnstart" toolbox, from the elements mentioned above. An iterative cycle is implemented that tests the network from 80 neurons to 200 neurons, calculating the performance of each of the resulting networks. The best performance is obtained with 86 neurons, so this RNA is saved as the definitive one.

Correction of ectopic beats and artifacts. So far, a tool has already been created that classifies beats into normal or ectopic, this network is saved as an object in Matlab® and can be called from any command file, as long as it is stored on the computer. The RNA output vector is called zt and is made up of ones where the network classified a beat as ectopic and zeros in the positions where the network classified a beat as normal. The positions of the zt vector are compared with those of trf (which contains the times at which an R peak was detected). A new vector called trf2 is constructed that contains only the elements of trf whose homologous element in zt was a zero (normal beat), in this way, ectopic beats are no longer taken into account in the calculation of the tachogram since it is constructed with the trf2 as abscissa.

According to studies carried out by other authors [14], several designs allow the construction of algorithms for the classification of ectopic and non-ectopic beats. For example, Mateo J, *et al.*, implemented various artificial intelligence techniques for this purpose, obtaining an accuracy of 92.77%, the sensitivity of 92.78%, and 92.49% specificity with neural network trained by backpropagation; With the proposed method, an accuracy of 82.34%, the sensitivity of 89.22% and specificity of 95.78% were obtained. The foregoing allows us to interpret that the proposed method has an accuracy that, although it is lower than those developed in other studies, is good and useful; that the program developed is less sensitive to the detection of ectopias but more specific because very precise QRS complex segmentation techniques are used, which greatly reduce the occurrence of false positives.

## 5. Conclusions

This work presents how to obtain an algorithm for the correction of ectopic beats and artifacts detected in an electrocardiographic signal, with a sensitivity of 89.22% and a specificity of 95.78%, using artificial neural networks of the backpropagation type in the programming tool. MATLAB. The determination of the Ectopia and Artifact Detection Accuracy index was calculated at 82.34%. Which projects that out of every hundred real ectopies the software will correctly identify approximately 82 of them. Better characterization of the beats was observed from the frequency attributes.

Although temporal attributes are very useful for the differentiation of ectopic beats due to their amplitude, they are also very vulnerable to variations that occur during signal acquisition. For example, in some signals where the R peaks of normal beats had low amplitude, the maximum / minimum ratio was very similar to that obtained with noise signals. The threshold value used to binarize the output of the neural network in the correction algorithm was determined as of great importance. Achieving a better definition of this value will allow greater accuracy in the classification of beats. To optimize the classification algorithm, it is recommended to use more homogeneous signals in terms of amplitude and lead used for the acquisition, with this you will obtain better differentiation of the beats based on their attributes and therefore greater accuracy. The delta rule, the mathematical basis of the backpropagation algorithm is the decreasing gradient technique, based on modifying the weights in the opposite direction to the gradient, which contributes to the results obtained. This research aims to establish methods for eliminating ectopic beats to calculate the heart rate variability and thereby study the autonomic nervous system.

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