

# Identification of Moderate to Acute Diabetic Neuropathic Conditions of Simulated Ulnar Nerve Response using Prony's Method

V. Sajith, A. Sukeshkumar and Jinto Jacob

**Abstract**— Using a portable biopotential amplifier (Electroneurograph), the evoked response of the Ulnar nerve has been recorded from patients with moderate to acute diabetic neuropathic conditions. The ENG signals are again simulated and the features of these signals are extracted using Prony's feature extraction method. The poles and resonance frequencies of ENG signals are used as features. A multilayer feed forward neural network classifier is applied to these features for the classification of Neuropathic Conditions. Identification of moderate to acute diabetic neuropathic conditions at various stages is the primary significance of this technique which helps the doctor for better diagnosis and to go for advanced treatment.

**Index Terms**— Electroneurograph, Ulnar nerve, Diabetic neuropathy, Prony's method, Artificial neural network.

## I. INTRODUCTION

Diabetic neuropathy is the most common and troublesome complication of diabetes mellitus leading to great morbidity and resulting in a huge economic burden for diabetes care. Diabetic patients have a greater risk factor of developing nervous disorders when compared with non-diabetic subjects. The presence of other vascular complications such as peripheral vascular disease in diabetes increases the risk of diabetic foot complications. However, the progression of neuropathy can be reduced by early detection and intervention [1].

Nerve conduction studies, primarily nerve conduction velocities are considered as one of the most sensitive indices of the severity of diabetic neuropathy. Electroneurography is the recording and study of action potential propagation along peripheral nerves. Neurological examination of peripheral nerve function refers to the nerve conduction study which is based on evoked potential. Evoked potentials are obtained when electric pulses are passed through the excitable tissues like nerves and muscles. For nerve conduction studies the parameters of the evoked responses required are the amplitude, latency and area of the responses recorded.

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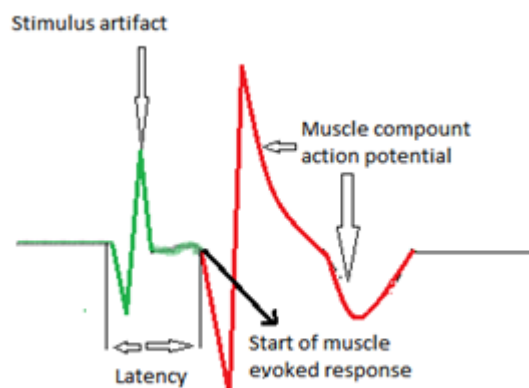


Fig. 1. Typical Normal Ulnar nerve

With this method it is very easy to conduct study of neurological examinations like conduction velocity measurement. An economic, versatile, compact and portable biopotential amplifier has been designed and implemented for measuring the latency to calculate the conduction velocity of ulnar and median nerves of patients with diabetic neuropathic conditions [2]. The specific application is developed according to the requirements of the experimental research practice on the study of compound action potentials of nerves in the field of neurophysiology [3]. Early detection of conduction failure of ulnar nerve in patients with diabetic type 1 and 2 is possible using conduction velocity measurement[4]. For the identification of various neuropathic conditions a mathematical model of the evoked response of diabetic patients using discrete state space modeling is done[5]. This paper establishes the identification of moderate to acute diabetic neuropathic conditions of simulated ulnar nerve response using prony's method.

Many methods and algorithms from signal processing theory have been proposed, described and implemented over the past few years to extract feature from signals such as total least squares based Prony's modeling algorithm[6], autoregressive model[7], wavelet transform[8], multiple signal classification (MUSIC) algorithm[9]. Drawback of these techniques mentioned above is the significant amounts of computation and processing time for extracting the features and the classifications technique employed.

The objective of the present work is to apply Prony's method to represent the ENG signal as a sum of exponentials in order to classify certain ENG identification based on the calculation of the resonance frequencies and the accompanied poles. Resonance complex frequencies of a signal can be used as useful feature for signal discrimination and identification.

The advantage of Prony's method is its simplicity and applicability in real time where a big amount of data may exist. The resonance frequencies computed were classified using multilayer feed forward network classifier models to determine the different classifications of diabetics.

The paper is organized as follows. Section II introduces the method proposed. Section III describes the preprocessing procedure used in this work. Section IV gives a review on the feature extraction method of the proposed work. Section V gives the classifier model used. Section VI discusses implementation procedure. Section VII discusses simulation results.

## II. METHODOLOGY

### A. Normal method

In order to study the function of neurons it is usually the practice to stimulate the nerve and study the action potentials generated by it. The nerve can be stimulated to greater activity by either electrical or chemical stimulation. Here we are interested only in electrical stimulation which is easily controllable. The electrical stimulation can be either constant voltage or constant current. It actually involves passing an appropriate electric current through a region of tissue and thereby causing the neurons in the area to be depolarized.

The nerve stimulation techniques are performed with a variable stimulus generator. The stimulus frequency, stimulus intensity and stimulus duration must be known, adjustable and have an ON / OFF control.

The input portion of the instrumentation amplifier which is named head stage is designed separately and the inputs from the electrodes are given to the head stage by means of shielded coaxial cable. Also the electroneurograph is properly shielded and grounded to minimize the noise effect.

Offset control is provided for base line shift. The stimulating and recording electrodes were placed in appropriate positions and evoked responses were recorded. The block diagram of the recording setup is shown in figure 2.

The normal method adopted for the measurement of conduction velocity is by stimulating at two different points along the nerve and measuring the latency for each electrical response recorded from the muscle. For each stimulation, the time between the start of the stimulus and the onset of the response is measured which is termed as the 'latency'.

The length of nerve segment is obtained by measuring on the surface of the skin the distance between the cathodes when placed for each stimulation. The conduction velocity is obtained by dividing the nerve length between the two stimulating points by difference in latency which is usually expressed in meters per second. It has been observed that a mean conduction velocity of 55.71 m/sec and a standard deviation of 3.01m/sec was measured for the normal Ulnar nerve[3].The electrode positions for the recordings and responses of the Ulnar nerve and are shown in fig.2.

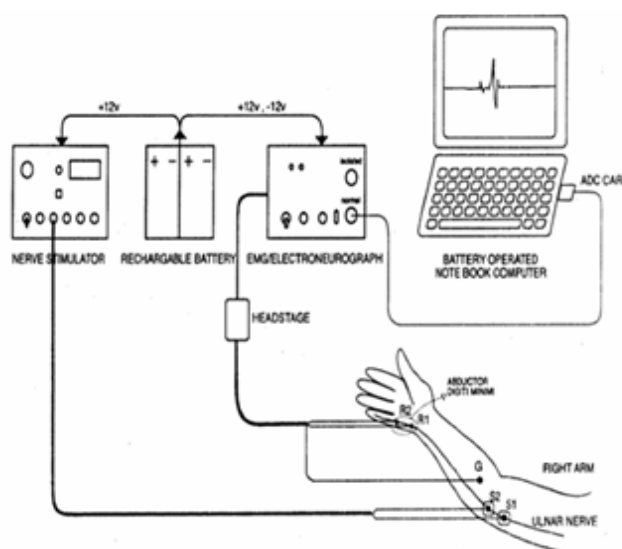


Fig. 2. Recordal setup

Figure 3 shows the Ulnar nerve response of a normal patient. Figure 4 depicts the Ulnar nerve response of a moderate diabetic patient and Figure 5 shows the Ulnar nerve response of an acute diabetic patient.

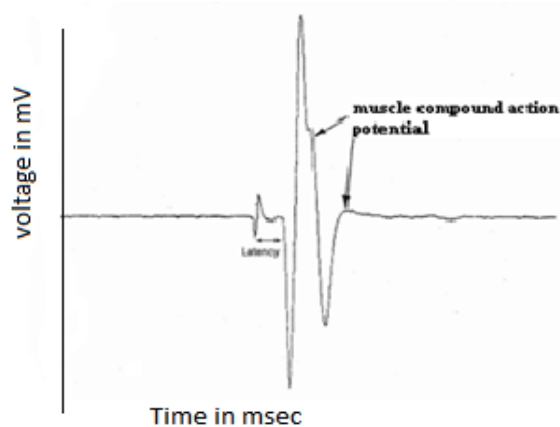


Fig. 3. Nerve action potential-normal

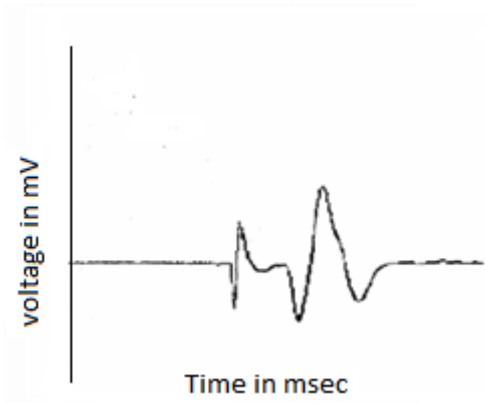


Fig. 4. Nerve action potential-moderate

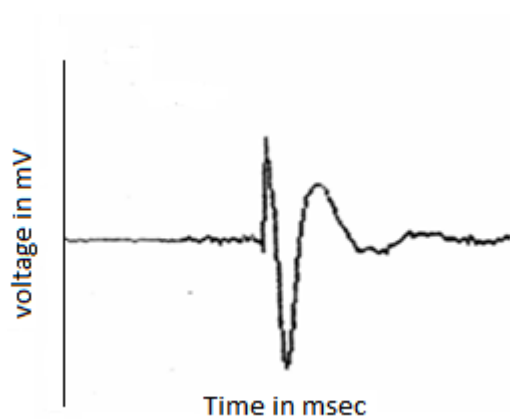


Fig. 5. Nerve action potential-acute

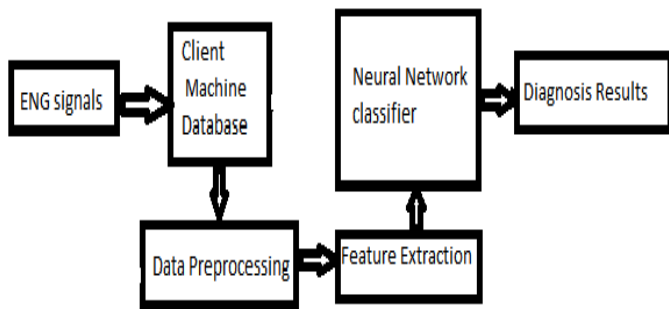


Fig. 6. Proposed system

**B. Proposed method**

The different stages of the proposed methods to identify diabetic neuropathy based on ENG signals are depicted in Fig. 6. It mainly consists of four stages: ENG database, Preprocessing stage, Feature extraction stage, Classification stage. The digital ENG signals are taken using above setup and are stored to form database. These signals are first preprocessed to remove baseline wander, power line interference and high frequency noise. Now Prony's method is applied to extract feature from ENG signals [10]. Finally, neural network classifier models are used to test those features and the diagnosis is made.

**III. PREPROCESSING STAGE**

All ENG data's have been filtered to remove the noise that may influence the signal including, baseline wander, artifact, and power line interference. The presence of these noise sources in the signal may mislead the feature extraction and classification.

Butterworth high pass filter is designed to remove these low bands of frequencies. The cutoff frequencies of the high pass filter is selected as 150 Hz.

**IV. REVIEW ON PRONY'S METHOD**

Prony's method[10] is a technique for modeling sampled data as a linear combination of damped exponentials as given below

$$x(n) = \sum_{k=1}^M h_k z_k^{n-1} \tag{1}$$

Where  $n= 1,2,3,\dots,N$  (N-samples),

$$h_k = A_k e^{j\phi_k}$$

$$z_k = e^{(\alpha_k + j\omega_k)T_s}$$

$T_s$  is the sampling period,  $A_k$  is the amplitude,  $\alpha_k$  is the damping factor,  $\omega_k$  is the angular velocity,  $\phi_k$  is the initial Phase and  $k$  is the exponential code.

The Prony's method evaluates the model parameters by solving two sets of linear equations. To find the first set of linear equations, let us consider the polynomial having the  $z_k$  as its roots:

$$F(z) = \prod_{k=1}^M (z - z_k) = \sum_{m=0}^M a(m) z^{M-m} \tag{2}$$

With  $a(0)=1$ .

Using Eq. (2) and with proper manipulations on relations (1), this results as

$$\sum_{m=0}^M a(m) x(n-m) = \sum_{m=0}^M a(m) \sum_{k=1}^M h_k z_k^{n-m-1} \tag{3}$$

With  $n=M+1, M+2, \dots, N$ .

In (3), using the position  $z_k^{(n-m)} = z_k^{(n-M)} z_k^{(M-m)}$ , the right-hand side contains the polynomial  $F(z)$  evaluated at its root  $z_k$ , then:

$$\sum_{k=1}^M h_k z_k^{(n-M)} \left\{ \sum_{m=0}^M a(m) z_k^{(M-m-1)} \right\} = 0 \tag{4}$$

From (3), using (4), this gives:

$$\sum_{m=0}^M a(m) x(n-m) = 0 \tag{5}$$

With  $n = M + 1, M + 2, \dots, N$ . The  $(N-M)$  relations (5) constitute a linear equation system in  $M$  unknowns, i.e. the  $a(m)$  coefficients.

Using  $N = 2M$  samples the system (5) represents an  $M$  equation system with the same number of unknowns. For practical situations there exists a non-trivial solution due to Nyquist-Shannon digital sampling theorem, the number of data points  $N$  usually exceeds the minimum number needed to fit a model of exponentials, i.e.  $N > 2M$ . In this over determined data case, the linear equation (5) must be modified to:

$$\sum_{m=0}^M a(m) x(n-m) = e(n) \quad (6)$$

The estimation problem bases on the minimization of the total squared error,  $e(n)$ :

$$E = \sum_{n=M+1}^N |e(n)|^2 \quad (7)$$

With the knowledge of the  $a(m)$  coefficients, the roots  $z_k$  of the characteristic polynomial (2) can be calculated. The damping factors and frequencies of each component may be evaluated from these known roots. Finally to calculate the amplitudes and phases of each component it is necessary to solve the second set of linear equations (1) in the unknown's  $h_k$ . The poles and the accompanied resonance complex frequencies,  $f_k$  of the ENG signal can be directly calculated as  $z_k/T_s$ .

### V. CLASSIFICATION STAGE

There is several classification models like Artificial Neural Network- Nearest Neighbor, Linear Discriminate Analysis and Support Vector Machines are used for the diagnosis. In this work we have used ANN for the classification.

Multilayer feed forward network named the multilayer perceptron (MLPs) is employed as a class of neural networks. Usually, MLP is made up of several layers of neurons. Each layer is fully connected to the next one. MLP consists of two phases, the training phase and the testing phase. During the training phase, the features are applied at the input and the corresponding desired classes are at the output of MLP classifier. A training algorithm is executed to adjust the weights and the bias until the actual output of the MLP matches the desired output and performance satisfaction is reached. In the test phase, a set of test features, which are not part of training features, are applied to the trained MLP classifier to test the classification of the unknown features.

### VI. IMPLEMENTATION PROCEDURE

Initially, signals were filtered using a Butterworth high pass filter with cutoff frequency of 150 Hz to reduce the noise. Figure 7, shows a normal signal corrupted with baseline drift and power line interference noise. In Figure 8, shows a noise free signal as a result of applying the Butterworth high pass filter. Similarly figure 9 and figure 11 corresponds to moderate and acute. Figure 10 and figure 12 are their preprocessed waveforms.

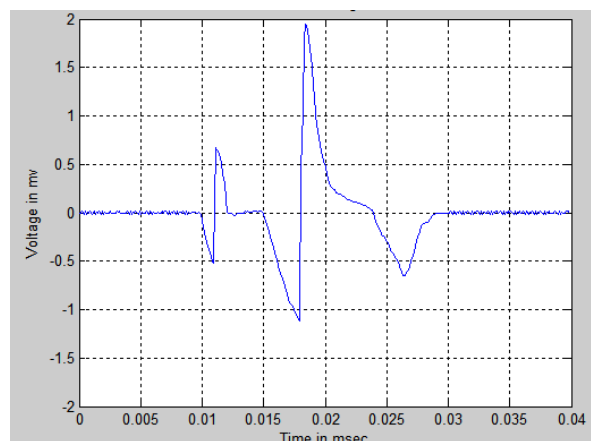


Fig. 7. Unfiltered Normal signal

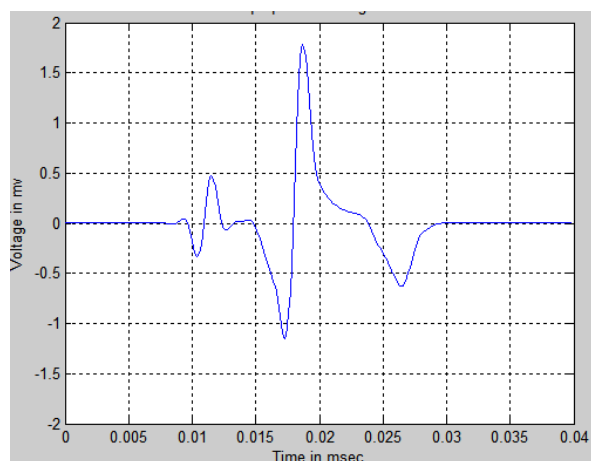


Fig. 8. Pre-processed Normal signal

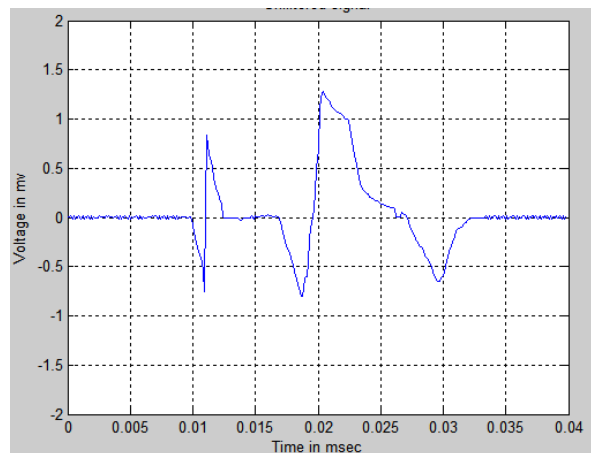


Fig. 9. Unfiltered Moderate signal

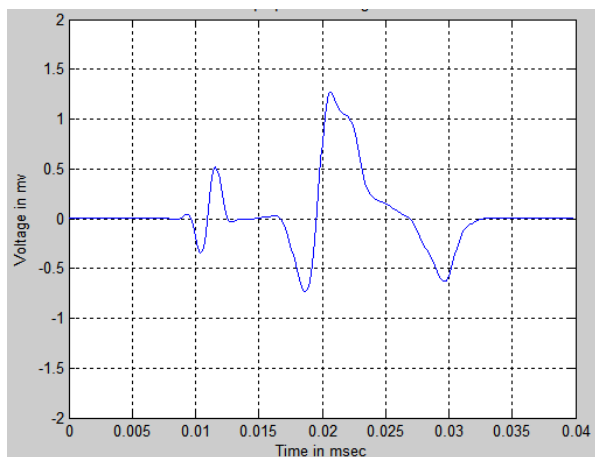


Fig. 10. Pre-processed Moderate signal

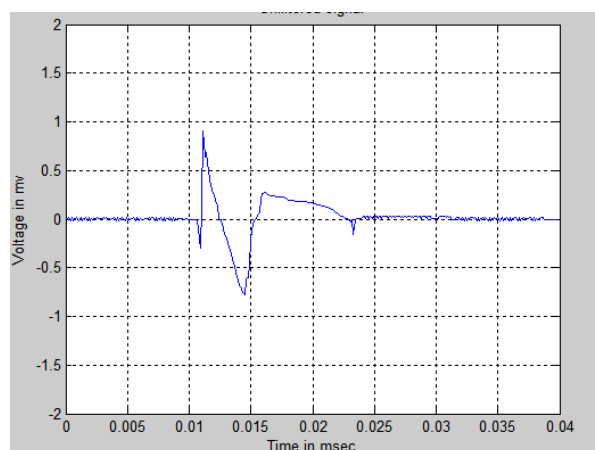


Fig. 11. Unfiltered Acute signal

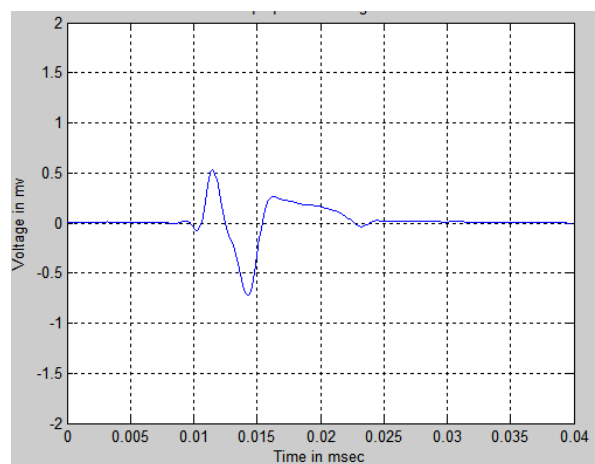


Fig. 12. Pre-processed Acute signal

Testing and training sets are separately formed. The numbers of testing and training samples are shown in Table I. We randomly select the given number of training and testing evoked responses of ulnar nerve from the selected recordings.

TABLE I:- NUMBER OF SAMPLES USED FOR STUDY

Type of signal	Training samples	Testing samples
Normal	10	50
Moderate	10	50
Acute	10	50

In our experiments, we used the multilayer perceptron (MLP) as the pattern classifiers. The original data set was separately divided into training and testing groups. Two factors that might affect the efficiency of MLP are the number of hidden layer neurons and synapses initial weight. Experiments were performed to test the effects of the initial weight and the number of hidden layer neurons parameter.

The performances of the classification are evaluated in terms of sensitivity, specificity, and overall accuracy. Sensitivity and specificity are used to evaluate the ability of the classification system to discriminate one class against the other. The sensitivity is calculated as the proportion of positive samples correctly assigned to the positive class. The specificity is the proportion of negative samples correctly assigned to the negative class. The overall accuracy is the fraction of the total number of simulated responses correctly classified.

## VII. EXPERIMENTAL RESULTS

The classification results using MLP is given in Table II. The diagonal elements in the table are the number of correctly classified response of specific ENG types using the proposed method. In Table 2, MLP neural network generally provides adequate recognition throughout all categories.

TABLE II: - CLASSIFICATION RESULT

Actual/Classified	Normal	Moderate	Acute
Normal	50	0	0
Moderate	0	50	0
Acute	0	0	50

Table III shows the sensitivity, specificity, and overall accuracy of the extracted feature set with MLP classifiers. The results are computed when the number of MLP hidden layer neurons is 55. Average of specificity is 100% for MLP classifier. Also the average of overall accuracy is 100%.

TABLE III: - SENSITIVITY, SPECIFICITY AND OVERALL ACCURACY

	Type	Average (%)
Sensitivity	Normal	100
	Moderate	100
	Acute	100
Specificity	Normal	100
	Moderate	100
	Acute	100
Overall accuracy		100

## VIII. CONCLUSION

The results of this study have significance in diagnosis of diabetic neuropathy at various stages. This also helps the doctor to identify the level of diabetics and take immediate remedial steps.

In future, this work can be extended to any diabetic patients having different stages of diabetic neuropathy.

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