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Research Article

ANALYSIS OF CARDIOVASCULAR (CVD)/CORONARY HEART DISEASES(CHD) USING ARTIFICIAL NEURAL NETWORK (ANN)

JyotismitaTalukdar and Sanjib Kr. Kalita

Gauhati University

A R T I C L E I N F O

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A B S T R A C T

Neural Network (ANN) is a very important research domain now a days. Artificial Neural Network , coupled with Data mining , is a very exciting field .In the health sector, Neural Network /Artificial neural networks, plays a very important roles,particularly, in the early prediction of diseases . In this paper, we are developing an ANN model for early detection of any kinds of Cardiovascular Disease(CVD) and Coronary Heart Disease(CHD). The results so obtaind, with respect to any heart patients, compared with the Doctors diagnosis and found satisfactory results. In some cases, up to even 90 % accuracy in predicting the diseases have been obtained. Heart diseases like RHD & MS, DCM, CAD, SSS, RBBB+LAFB, the average predicting accuracy is found more than 80%.

INTRODUCTION

One of major challenge facing the healthcare organization today is the provision of quality services at affordable costs**.** The quality of serviceof service implies diagnosing and administering the patients correctly. A majority of areas of health services such as prediction of heart attack, effectiveness of surgical procedures, medical tests, medication, effectiveness of medical treatments can be estimated by the application of ANN. Artificial Neural Network (ANN) has extensive application to biomedical systems. Neural networks learn by example, so the details of how to identify diseases are not needed. It requires only set of examples representative of all the variations of the diseases. Of course, the examples are to be selected very carefully if the system needs to identify or predict the disease reliably and efficiently.

Experimentally, the neural networks are used to model the human cardiovascular system. By building a model of the cardiovascular system of an individual and then comparing with the real time physiological measurements, such as : Heart rate, Blood pressure, Blood sugar, Cholesterol etc.,taking from the patients, we can make an early prediction of the disease . If the model is found to be adapted to an individual, then it becomes a model of that individual.

Diagnosis of heart disease is a difficult and tedious task in medical field. In general, all the doctors are predicting heart disease by learning and experience.

Corresponding author:* **JyotismitaTalukdar
Gauhati University

The diagnosis of heart disease is a multi-layered issue which sometimes may lead to false unpredictable effects. Some of major issues related to correct diagnosis of heart disease are:

- Less accurate results,
- Less experience,
- Time dependent performance,
- Knowledge up gradation,
- Complex and multiplexed symptoms etc.

HianChye and Gerald Tan[12] proposed that if the clinical decision support and the computer-based modelling on patient records work in an integrated way then the it could reduce the medical errors, enhance patient safety, decrease unwanted practice variation. This would certainly improve the patient outcome. In view of this the ANN have the potential to generate a knowledge-rich environment which can have significant effect on increasing the quality of clinical decisions.

Objective

It is the objective of this paper to develop a system or simulated environment for early prediction or diagnosis of Heart disease, for example-Cardiovascular Disease (CVD) and Coronary Heart Disease (CHD) using ANN technique. It is expected that the proposed environment would discover and extract hidden knowledge associated with heart disease from the historical heart disease database. It would certainly assists the healthcare practitioners to make correct clinical decisions which is not possible following the traditional and conventional decision support system.

Neural Networks

Traditionally, the neural network refers to a network of biological neurons. Artificial neural network (ANN) is the mimicking of the human neuron on a system. It is a multilayer network made up of input layer neurons, hidden neurons and output neurons.[1][2]. Artificial neural networks are efficient means of prediction, optimization and recognition that are difficult for conventional computers or human beings.[3]. They are used for non-parametric prediction that learn from the surroundings, retain the learning and later use it subsequently. Basically, the ANNs are constituted by the set of interconnected groups of artificial neurons and information processing units which are grouped following a connectionist approach.[4]. It demonstrates non-linear processing and excel in performing pattern matching, prediction and recognition etc. based on a method that uses continuously updated connectionist weights during learning and training. It is thus able to relate input data to the expected class decisions. ANNs are adaptive networks by origin and keep changing its own internal structure and information which flows along the system during its training stage [5]. ANNs are found very effective means in pattern classification and prediction problems. The important advantages of ANNs are:

1. They are more robust, even in noisy environment, because of weights.
2. ANN improves its performance by learning which continues even during the training phase also.
3. ANN can be parallelized for better performance.
4. There is low error rate and once the appropriate training has been performed.

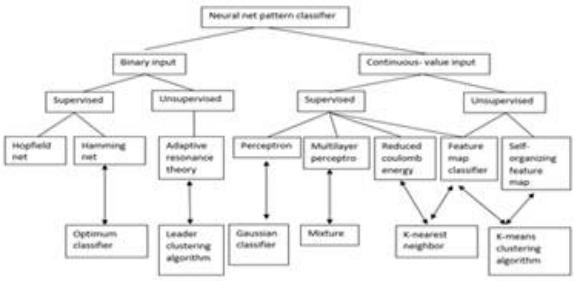

Fig.(1.0) : Taxonomy of 8 NN classifiers. Most similar pattern classification algorithms to neural network algorithms are shown at the bottom layer

In the Fig.(1.0) taxonomy of 8 Neural Network classifiers have been shown along with classification algorithms.

An Artificial neural network is a parallel, distributed information processing structure consisting of multiple number of processing elements, which are called Nodes.They are interconnected. Each processing element has a single output connection that branches into many other connections carrying the same processing element output signal. A simple model of a typical biological neuron is shown in Fig.(2.0) below.

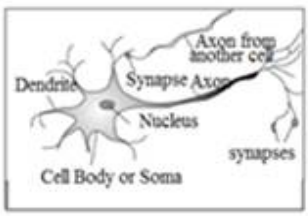

Fig.(2.0) ; Symbolic representation of a biological neuron

Similar to the biological case, the fundamental information processing unit of the ANN is the McCulloch-Pitts Neuron (1943)[6]. Figure (3.0) shows the model of a McCulloch-Pitts neuron used for designing ANNs.

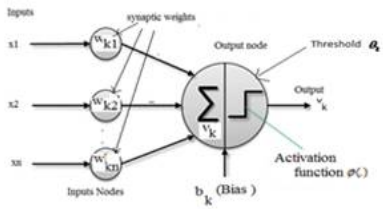

Fig.(3.0).

Elements of NN/ANN: The three basic elements of ANN or NN –model are:

1. A set of synapses or connecting links, each of which is characterized by weight or strength of its own. For example, a signal x_j at the input of synapse j connected to v neuron , k is multiplied by the synaptic weight w $_{kj}$,refers to the neuron in question and the second subscript refers to the input end of the synapse [7]
2. An adder to summing up the input signals which are weighted by the respective synapses of the neuron.
3. To limit the amplitude of the output of a neuron, an activation function is used.
4. From this model the interval activity of a neuron k is expressed as:

$$u_k = \sum_{j=1}^{m} w_{kj} x_j \tag{1}$$

And $y_k = \phi(u_k + b_k)$ (2)

Where, $x_1, x_2, ..., x_k$ are the input signals, $w_{k1}, w_{k2}, ..., w_{km}$ are the synaptic weights of neuron k, b_k is the bias, $\phi(.)$ is the activation function and y_k is the output signal of the neuron. Thus the output is defined as:

$$v_k = (u_k + b_k) \tag{3}$$

Activation function: The three basic types of activation functions, commonly used, are:

Sigmoid Function: This function is strictly an increasing function.It exhibits a balance between linear and non-linear response. Usually, its values covers the ranges -1 to 1, but usually the values between 0 and 1 are preferred. The Sigmoid function is defined as:

$$\varphi(v) = \frac{1}{1 + \exp(-a * v)} \tag{4}$$

Where 'a' is the slope of the Sigmoid function.

Threshold Function: This activation function $\varphi(v)$ takes a value of 0 if the summed input is less than a certain threshold value v, and takes 1 if the summed input greater than or equal to threshold value v. This function is defined as :

$$\varphi(v) = \begin{cases} 1, if\ v \geq 0 \\ 0, if\ v < 0 \end{cases} \quad (5)$$

This function is also called Heaviside function. The output of neuron k is thus expressed as -

$$y_k = \begin{cases} 1, if\ v_k \geq 0 \\ 0, if\ v_k < 0 \end{cases} \quad (6)$$

Where v_k is the induced field of the neuron. The threshold function defined by the equation (5)have the range between -1 to +1 , then this threshold function is called Signum function and is defined as given in equation (7).

$$v_k = \begin{cases} 1, if\ v_k > 0 \\ 0, if\ v_k = 0 \\ -1, if\ v_k < 0 \end{cases} \quad (7)$$

$w_{k1}, w_{k2}, ..., w_{km}$

Piecewise –Linear Function*:* The piecewise-Linear function, in addition to 0 or 1 value , it can take values in between , depending upon the amplification factor in a certain regions of linear operation. Such a function is defined as given in equation (8).

$$\varphi(v) = \begin{cases} 1, if\ v \geq +\frac{1}{2} \\ v, if +\frac{1}{2} > v > -\frac{1}{2} \\ 0, if\ v_k \leq -\frac{1}{2} \end{cases} \quad (8)$$

Where the amplification factor inside the linear region of operation is assumed to be unity.

Theory of Training ANN*:* The training of the ANN is done following two Passes, (i) A Forward Pass, and (ii) a backward computation with error determination and connecting weight updating in between. It is expected that the training must be undertaken to accelerate the speed of training and the rate of convergence of the Mean Square Error (MSE) to the desired value [7]. The sequential the steps are :

Initialization of weight matrix: At first we are to initialize the weight matrix 'w' with random values between [-1,1] if we use tan-Sigmoid function as an activation function . If we use log-Sigmoid function as an activation function then we have to initialize the weight matrix with random values between [0,1]. The weight matrix 'w' is a matrix of [C x P], where, P is the length of the feature vector used for each of the C classes.

Presenting the Training Samples: Taking the input to ANN as $P_m = [P_{m1}, P_{m2}, ..., P_{mL}]$ and the desired output as $d_m = [d_{m1}, d_{m2}, ..., d_{mL}]$, we are to follow the steps below :

Compute the values of the hidden nodes as –

$$net_{mj}^h = \sum_{i=1}^{L} w_{ji}^h\ p^{mi} + \emptyset_j^h \quad (9)$$

Next, we are to compute the output from the hidden layer as

$$O_{mj}^h = f_j^h\ (net_{mj}^h)$$

$$\text{Where, } f(x) = {}^1/_{e^x}$$

$$\text{Or} \qquad f(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad (10)$$

Calculate the values of the output node as:

$$O_{mk}^0 = f_k^0\ (\ net_{mj0}\ ) \quad (11)$$

Forward Computation*:* The computation of errors is done as follows , given by equation (12):

$$e_{jn} = d_{jn} - O_{jn} \quad (12)$$

Calculation of MSE, equation (13)

$$\text{MSE} = \frac{\sum_{j=1}^{M} \sum_{n=1}^{L} e_{jn}^2}{2M} \quad (13)$$

Computation of error for the output layer, equation (14):

$$\delta_{mk}^0 = O_{mk}^0(1 - O_{mk}^0)\ e_{mn} \quad (14)$$

Computation of error for hidden layer, equation(15):

$$\delta_{mk}^h = O_{mk}^h(1 - O_{mk}^h) \sum_j \delta_{mj}^0\ w_{jk}^0 \quad (15)$$

Weight Update:

Between the output and the hidden layers, equation (16):

$$w_{kj}^0(t+1) = w_{kj}^0(t) + \acute{\eta}\delta_{mj}^0 O_{mj} \quad (16)$$

Where η is the learning rate $(0 < \eta < 1)$.For faster convergence, a momentum term (α) may be added as, equation (17):-

$$w_{kj}^0(t+1) = w_{kj}^0(t) + \acute{\eta}\delta_{mj}^0 O_{mj} + \propto (w_{kj}^0(t+1) - w_{kj}) \quad (17)$$

Between the hidden layer and the input layer , equation(18) :-

$$w_{ji}^{h}(t+1) = w_{ji}^{h}(t) + \acute{\eta}\delta_{ji}^{h}P_i \quad (18)$$

A momentum term can be added as -, equation (19):-

$$w_{ji}^{h}(t+1) = w_{ji}^{h}(t) + \acute{\eta}\delta_{ji}^{h}P_i + \propto (w_{kj}^{0}(t+1) - w_{ji}) \quad (19)$$

One cycle through the complete training set forms one epoch. The above steps are repeated till MSE meets the performance criteria.

Training Algorithm*:* The two main training variants involved with **nnff( )** , a Matlab function, are:

a. Incremental, where the training process is initiated by the function adapt( ).
b. Batch , where the training process is initiated by the function 'train ( ) '

When the function adapt( ) is used , the possible values of the parameter are :

- <'learned'>: It corresponds to the serial standard Back-Propagation derived using the gradient decent method.
- <' learngdm'>: It corresponds to the momentum variant of Back-Propagation.
- <'learngda'>: It represents the variant with adaptive learning rate.

When the function **train ( )** is used the possible values of this parameter are:

- <'traingd' > :It corresponds to the classical batch Back-Propagation derived using the gradient decent method.
- <' traingdm '> :It corresponds to the momentum variant of Back-Propagation.
- <' trainlm '> :It corresponds to the variant based on the Levenberg Marquardt minimization method.

Back Propagation Algorithm*:* One of the most frequently used NN /ANN supervised training algorithm is the Back-PropagationAlgorithm. The training of a NN/ANN by Back-Propagation algorithm involves three stages, namely

1. Feed forward the input training pattern ,
2. Find and back propagate associated error, and
3. Weight balancing.

In the present study and analysis of CVD/CHD and their early prediction we have used the Back-Propagation Algorithm.
While training the MLP we have used two training functions :(i) adapt( ), and (ii) train ( ).Their syntaxes are given below :
adapt( ) :<syntax> : [fftrain,y,err]=adapt(ffnet,input_data,desired_output) ;

We are to set the following parameters to start the learning process, Table (1):

Table 1 etting of parameters to start learning process

Parameter Name	Implicit value
Learning rate -lr	0.01
Number of epochs-passes , i.e the required number of passes through the training set	10
Maximum value of the error(goal)	0.001

Examples :ffnet.trainParam.epochs=10;
ffnet.trainParam.goal=0.001;
ffnet.trainParam.lr=0.1;

For example, ffnet.adaptParam.passes=10;
Ffnet.adaptParam.lr=0.1; etc.
train( ) : <syntax> : [fftrained,y,err]=train(ffnet,input_data,desired_output);
We are to set the following parameters before starting the learning process, Table(2):
Table(2) : Parameters to set before starting the learning process.

In the present study we have defined the function **train ( )** as given below:

[net1.tr]=train(net,I,T);

The train parameters are set as follows, Table(3):

Table 3 Setting of train( ) parameters

Parameter Name	Implicit value
Learning rate	net.trainParam.lr=0.05
Maximum number of iterations	net.trainParam.epochs=500
Stopping condition	net.trainParam.goal=0.001

Specifications of ANN: The ANN specifications , considered for the present analysis of CVD/CHD data and predicting the disease , are as follows , Table (4):

Table 4 ANN specifications considered for the present study.

Input data size	Length of sample vector(for the sets considered for training, validation and testing)
SNR	0 – 3 dB
ANN type	MLP with two hidden layers. First hidden layer is 1.5 times the length of feature vector and second hidden layer 0.75 times of the feature vector.
ANN training method	Back-Propagation with Levenberg-Marquardt optimization.
Average training epochs	MLP- 200 to 1000
Mean Square Error (MSE) goal	10^{-4}
Validation check	06
Minimum performance gradient	10^{-7}

ANN configuration and Back-Propagation Algorithm (Levenberg –Marquardt (LM) algorithm)*:* In the present study a feed forward back propagation ANN is configured for the classification and recognition of Cardiovascular/Coronary heart disease. In this approach we have considered the ANN input layer as being having 12 neurons and is trained for 200 to 1000 epochs. The results obtained are the average values of at least 10 to 15 trials for the epochs considered. Here, the ANN considered have two hidden layers and its key specifications are provided in table(4). The ANN is configured in such a way that it can handle size and SNR variations. The feature sizes varies from (1050 x 4) for training, (225 x 4) for testing and (225 x 4) for validation check. In all the testing stages some noise have been added with SNR varying from 0 to 3dB. While testing the ANN, we have used error back propagation algorithm coupled to gradient descent with Levenberg-Marquardt (LM) [8-10][13]optimization , which is fast and suitable for supervised training. It is found that the LM optimized back propagation gives efficient learning despite variations in patterns (during training, testing and validation), though it consumes a little bit of more memory. The Algorithmic steps of Back-Propagation with Levenberg-Marquardt(LM) algorithm[7] used for the present work.

1. Take all Inputs [Blood pressure(BP), Fasting Blood Sugar(FBS), Thalach(THAL), Cholesterol(CHOL) of 1600 heart patients]

2. Forward computation
3. Procedure Lev_Mar
4. for all layers do
5. for all neurons in a layer do
a. Find the net output(product of neuron and connectionist weight + bias);
6. find the output of the activation function;
7. determine the gradient;
8. end for ;
9. end for;
10. Backward computation
11. Take initial delta value as gradient
12. for all outputs do
13. find the error(difference between present and expected output);
14. end for;
15. for all layers do
16. for all neurons do
17. Neurons present in the previous layers;
18. feed errors;
19. for all neurons present in the current layer do
20. find product of delta and weights;
21. add the backpropagated delta at proper nodes;
22. end for;
23. multiply delta by slope;
24. end for;
25. end for;
26. end procedure(Lev_Mar)

The fundamental steps followed to apply ANN for the purposes of diagnosis of Heart diseases with sufficient confidence is shown in Fig.(4)below:

While designing the algorithm it is assumed an initial momentum value (around 0.001) with a decreasing factor of 0.1 and increasing step of 10. The minimum performance gradient is taken as 10^{-7}. Validation checks are made to monitor the performance of ANN.

Training the proposed ANN: To train the ANN for our present ANN based prediction for Cardiovascular Diseases, we considered the followings:

1. ***Back-propagation (BP) with Gradient Descent (GD):*** The BP algorithm is used to learn the weights of a MLP which is a static in nature. Through the gradient descent it minimizes the sum squared error between the network's output values and the given target values [7].
2. ***BP with Momentum (M):*** By changing the weight the convergence is improved. This is achieved by the observation of BP based on the modification on the momentum.
3. ***BP with GD and M and varying learning rate (LR):*** The LR parameter determines the speed of the BP to reach the convergence. When the learning rate is higher, the step size will be bigger and speed-up the convergence. To speed-up the convergence time, the variables GD,LR and BP uses higher LR when the neural network model is far from the solution and smaller LR when ANN is near the solution[11].

Data Collection: The data used in the present studyis collected from five medical healthcare organizations, including Govt. Hospitals and Private Nursing Home , all located at and around the greater Guwahati(this has already been mentioned in chapter-III), which is the prime healthcare centre of the entire north-east region. There are, total 76 attributes in the medical database, but in the present study of Cardiovascular Disease(CVD)/Coronary Heart Disease(CHD) using ANN we are taking only 08 attributes.
attributes. They are shown in Table (5) below:

Experimental Details and Results

In the present study of early prediction & detection of Cardiovascular Disease (CVD) and Coronary Heart Disease (CHD) using ANN, a total of 1500 heart patients have been studied. The records of the patients have been collected from the Govt. Hospitals and Private Nursing Homes, as mentioned in chapter-III. The prediction using ANN have been made using four primary heart attributes, namely:- Blood Pressure(BP), Fasting Blood Sugar(FBS) Thalach(THAL.) and Cholesterol(CHOL.). With respect to a particular heart disease, no distinction has been made with respect to sex. Further, in the present analysis age and family history are also not considered as cues causing heart diseases. However, a tree representation of 1500 heart patients on the impact of Age, Family history,T_2DM(Type -2 diabetes), HTN(Hyper-tension) etc. have been shown in Fig(5) for male and for females.

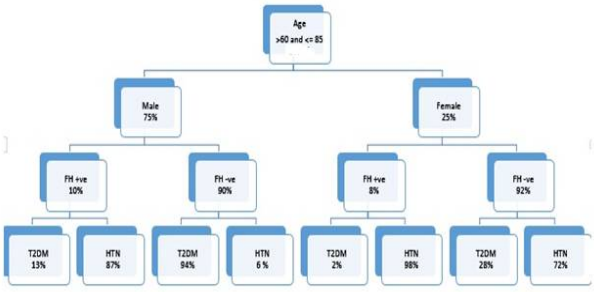

Fig 5a A Tree representation of Heart patients within the age limit >60 years and <= 85 years.

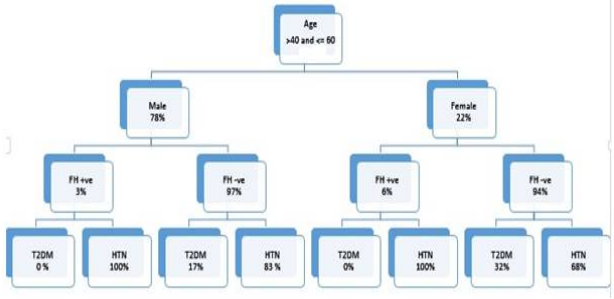

Fig 5b A Tree representation of Heart patients within the age limit >40 years and <=60 years.

In the present study of heart disease using ANN, out of 1500 heart patients data , 70% of data has been used for training the ANN, 15% data used for validation test and rest 15% of data used for testing the ANN's performance.

The disease to be predicted by the ANN with respect to 1500 heart patients are listed in Table (6) below.

Table 5 List of Heart Disease to be predicted by the ANN

Serial No.	Disease	Full Form
1.	CHB	Complete Heart Block
2.	DCM	Dilated Cardiomyopathy
3.	CAD,COAD,MI	Coronary Artery Disease,Chronic Obstructive Airways Disease,Myocardial Infarction
4.	Post PPI,EOL	Post-Permanent Pacemaker Implementation, End of Life
5.	RHD with MS	Rheumatic Heart Disease with Mitral Stenosis

6.	SSS	Sick Sinus Syndrome
7.	AF with slow rate	Atrial Fibrillation
8.	CSA	Chronic Stable Angina
9.	HOCM	Hypertrophic Obstructive Cardiomyopathy
10	ICMP	Ischemic Cardiomyopathy
11.	RBBB+LAFB	Right Bundle Branch Block+ Left Anterior Fascicular Block

In the figure (6), a snapshot of the training state of ANN is given.

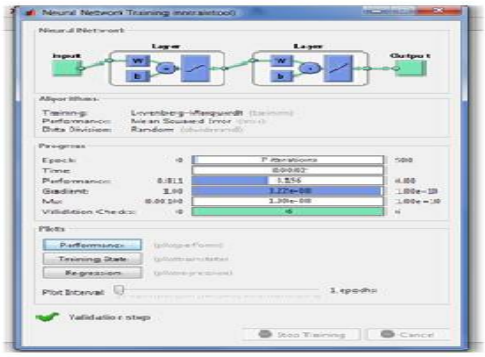

Fig 6 Snapshot of typical ANN with one hidden layer and one output layer feeding BP,FBS,THAL and CHOL as input (feature vectors).

A total of 70% (1050) of the heart disease data, with four major attributes i.e BP.FBS, THAL, and CHOL. have been used for training the ANN. 15% (225) data(BP,FBS,THAL.,CHOL) have been used for validation test and rest 15% (225) data of {BP,FBS,THAL. and CHOL } have used for testing the ANN. In figure (7) a typical snapshot of our ANN performance has been shown.

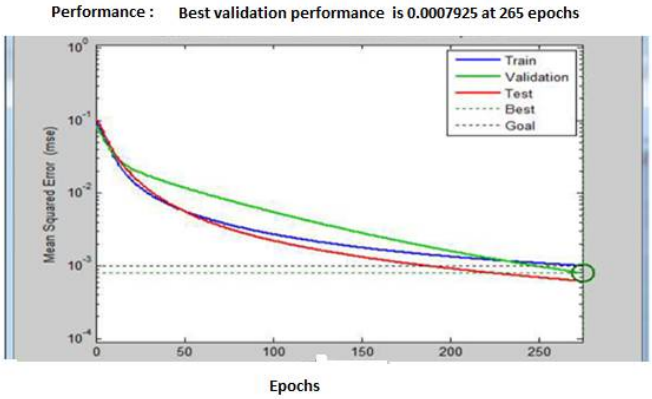

Fig.(7) : **A Typical Snapshot of ANN performance plot at 265 epochs**

A typical Snapshot of regression plot has been shown in Fig.(8) below.

Fig (8) shows the regression analysis chart for mse error performance function with logsig activation function. Within this graph the training R=0.90091 and the test R=0.043058 and the validation is 0.061327. Finally the all R =0.2828. The results obtained after training the data under different scenarios MSE gives better validation results.

The confusion matrix for different success rate achieved during training and testing have been shown in Fig.(9a) and Fig.(9b)below.

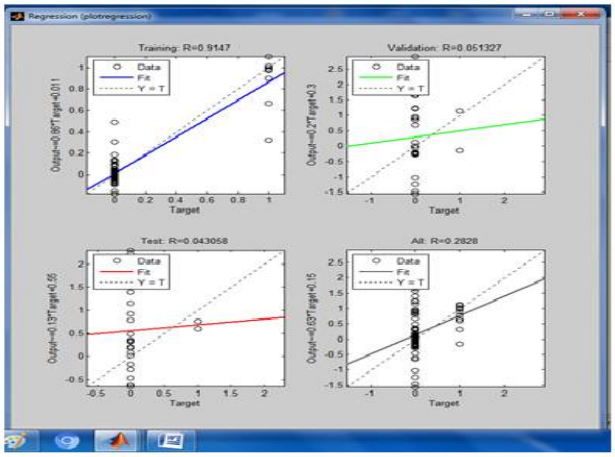

Fig.(8) : **Snapshot of typical Regression Plot**

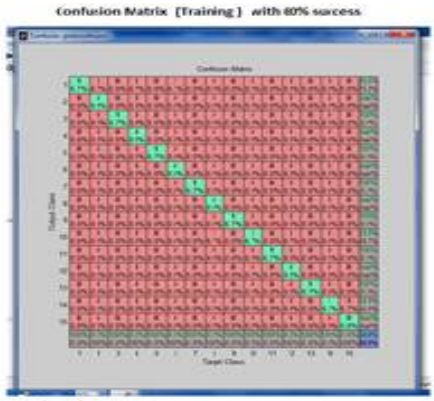

Fig.(9a) : **Snapshot of a confusion matrix (training) with 80% success.**

Fig.(9b) : **Confusion matrix with 80% success during Training**

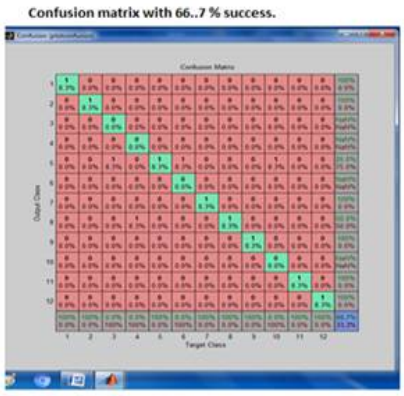

Fig.(10) : **Confusion matrix with 66.7% success (validation)**

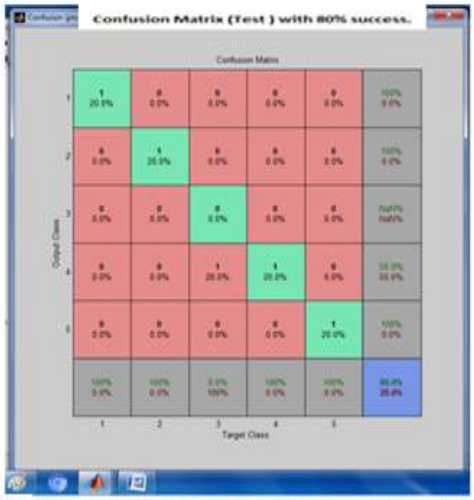

Fig.(12) : **Confusion matrix with 80% success (Testing)**

It is thus seen from the graphical outputs of the three phases of ANN, i.e Training, Validation and Testing, the following observations have been made:

1. The best performance is achieved at error 0.001, which is as our initial assumption (goal).
2. During Training, nearly 60%to 80% success has been achieved, as shown in the confusion matrix, Fig.(9a) and Fig(9b) respectively.
3. During validation, about 66.7% success has been observed, Fig(10).
4. During Testing, the success of recognition rate varies from 80% to 60% without noise and with noise (2dB), Fig.(11) and Fig.(12) respectively.

The following table, table(7), shows the summary of the recognition rate of the different Cardiovascular Diseases.

Table(7) : **Recognition efficiency of ANN with reference to Doctors diagnosis**

Disease Name	Success of Recognition	
	Without noise	with noise(2dB)
CHB	74%	70%
DCM	91%	82%
CAD,COAD,M1	80%	72%
ASD with L-R shunt	78%	72%
RHD with MS	92%	74%
SSS	85%	73%
AF with slow Rate	65%	62.5%
CSA	75%	62%
HOCM	76%	70%
ICMP	42%	38%
RBBB+LAFB	81%	74%

Further, the performance of the ANN using Back-propagation algorithm is also evaluated by computing the percentages of Sensitivity(SE), Specificity(SP) and accuracy(AC) using the following computational arithmetic, equation(20) (21) and (22). These parameters have been computed using the Confusion Table (8).

Table 8 Structure of Confusion matrix

		Actual Value		
Prediction	P'	p True positive	n False Positive	Total P'
	n'	False Negative	True Negative	N'
	Total	P	N	

$$SE = \frac{TP}{(TP + FN)} * 100 \quad (20)$$

$$SP = \frac{TN}{(TN + FN)} * 100 \quad (21)$$

$$AC = \frac{(TP + TN)}{(TN + TP + FN + FP)} * 100 \quad (22)$$

Where, TP : No. of True Positives,
TN: No. of True Negatives
FN: No. of False Negatives,
FP : No. of False Positives

Out of 1500 patients data on various health attributes, 70% have been used to train the algorithm, and the remaining 30% have been used for testing the performances. Following the steps, as mentioned in Fig.(9), the results obtained on SE,SP and AC have been shown in table (9).

Table 9 Result of Analysis

Algorithm used	Sensitivity	Specificity	Accuracy
MLPANN with Back Propagation Algo.	82%	87%	81%

It is thus seen from the above results that Heart Disease Diagnosis system using ANN with back propagation algorithm has better accuracy, sensitivity and specificity compared to other approaches as reported by earlier workers, mentioned in introduction. It is seen from the figure(5a) and Figure(5b) that Hereditary hardly a matter as a cause of any Cardiovascular Disease.

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