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Detection of Myocardial Ischemic Events from Echocardiogram using Linear Discriminant Analysis and Multilayer Perceptron

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Abstract: ***In the recent past, Myocardial Ischemia has emerged as a major cause of death worldwide, and hence we should look at its timely diagnosis and care. The cause of Ischemia is due to clogging of blood supplying arteries leading to the heart by a substance called plaque. This leads to reduced supply of oxygen to heart without which the heart muscles begin to die leading to a myocardial infarction or heart attack. Early detection of ischemia is of critical importance because, in most of the cases, the effects of myocardial ischemia are reversible if detected early enough. The objective of this paper is to detect Myocardial Ischemic events from Echocardiography data. The echocardiography data reports used in this work is obtained from M.S.Ramaiah Narayana Heart Centre from June 2018 to June 2019. It has 344 patient data and 42 features extracted for each patient. The two events identified to be detected are Left ventricular hypertrophy(LVH) and Left ventricular diastolic dysfunction(LVDD). Firstly the data is preprocessed for removal of noise and outliers. Then we apply feature reduction techniques to retain only those features which are meaningful to the purpose of prediction of events identified. The predictive models are then developed on the reduced feature set. In this research, we have proposed the algorithms LVH-PRED-MODEL and LVDD-PRED_MODEL for detection of LVH and LVDD ischemic events. The proposed algorithm uses Linear Discriminant Analysis for feature reduction and Multilayer perceptron for training the models. The results show excellent accuracy of 88.37% for LVH-PRED-MODEL and 86.04% for LVDD-PRED-MODEL using the proposed approach. The Area Under Curve is 83.5% and 73.37% for LVH-PRED-MODEL and LVDD-PRED-MODEL events respectively. These models can be applied in real time to detect myocardial ischemic events by healthcare workers.***

Keywords **: *Myocardial Ischemia, Data Mining, Linear Discriminant Analysis, Multilayer Perceptron, Left ventricular hypertrophy, Left Ventricular diastolic dysfunction, Heart disease***

I. INTRODUCTION

The heart is a two-stage electrical pump that circulates blood throughout the body. The anatomy of the heart includes four chambers and four valves.

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The four chambers of the heart are left atrium, right atrium, left ventricle and right ventricle. The four valves are mitral valve, tricuspid valve, aortic valve and pulmonary valve, These structures of the heart have to work in a coordinated manner for the normal functioning of the heart so that blood flows in and out of each chamber in the proper direction[1,3]. Myocardial ischemia is a condition of the heart which occurs because of the reduced supply of oxygen to the heart. This may be due to the blockage in the coronary artery which is the main blood supplying vessel to the heart. If the heart does not receive enough oxygen for an extended period the tissues of the heart begin to die, thus leading to a heart attack. The perished tissue becomes non functional Tissue that has died is no longer functional and thereby the pumping function of the heart is reduced. If Ischemia is detected well in advance casualties can be avoided. It is required to perform general examination and screening of the patient because Ischemia can be present without showing up any symptoms[2,3].

An **echocardiogram** is an ultrasound test of the heart to evaluate the structure of the heart and the direction of blood flow within it. Sound waves are used to generate images which capture the movement of fluid in the hearts chambers, blood vessels and walls. A transducer is passed over the chest of a patient. The probe produces sound waves that bounce off the heart and "echo" back to the probe. These waves are changed into moving images and viewed on a video monitor. It is a non-invasive way of assessing heart functionality. Echocardiography is one of the most widely used diagnostic tests for heart disease[4].

An echocardiogram can help to monitor the conditions of the heart, analyze flow of blood through the chambers and assess the functionality of the heart. ,

II. LITERATURE REVIEW

To diagnose heart disease, medical examination of a patient is done based on medical records, historical information, physical examination and laboratory reports. Early diagnosis can help reduce the rate of mortality and morbidity. Echocardiography is one of the methods to diagnose a heart disease. As given in American Heart Association, echocardiograph can detect the thickening of the walls of the heart, narrowing of arteries, fluid formation in the pericardium, and flow of blood through the chambers of the heart. Many researchers have worked on diagnosis of heart disease. The researchers in [5] have developed an automatic classifier for assessing risk in patients suffering from congestive heart failure.

Here the parameter used to develop the classifier is long term heart rate variability. A model is developed to assess the risk factors associated with coronary heart diseases by the researchers in [6].

The model is developed using the algorithm C4.5. The most important risk factors are smoking and hypertension among others. A study was taken up by the researchers in [7] which resulted in a model for assessing the severity of heart failure and predicting the presence of adverse events related to destabilizations, re-hospitalizations and mortality. As reported in the work by the researchers in[8], a comprehensive risk model for predicting mortality from heart failure is developed using an improved random forest. Here the model uses a novel split rule and stopping criterion to improve accuracy as well as identify more accurate predictors. The researchers in[9] have developed a Classification tree for assessing the risk in patients suffering from long term heart variability. This work analyzes the heart rate variability on nominal 24 h recordings and selects the best feature subset with the least misclassification error. Risk factors have been assessed for coronary heart events based on data mining with decision trees. The objective is to assess heart event related risk factors targeting in the reduction of CHD[10].An Intelligent Heart Disease Prediction System (IHDPS) is developed by the researchers in [11] using Decision trees, Naïve Bayes and Neural Network. This system was able to extract patterns, relationships, and medical factors for heart related diseases. A predictive model for the Ischemic Heart Disease (IHD) was presented in [12] in which the researchers applied Back-propagation neural network (BPNN), the Bayesian neural network (BNN), the probabilistic neural network (PNN) and the support vector machine (SVM) to develop classification models for identifying IHD patients on a data obtained from magnetic resonance imaging. The result showed that BPNN and BNN gave the highest classification accuracy of 78.43 %, while SVM gave the lowest classification accuracy of 60.78 %.

Many researchers have been working on feature selection techniques in the area of data mining in healthcare. An attribute selection measure based on distance for the decision tree induction is proposed in [13]. This method produces smaller trees in the case of data which has attributes having different number of values. The researchers have developed a feature selection method in neuro and fuzzy modeling based on multi-objective genetic algorithm in [14]. The technique uses the concept of dominance for multi objective feature selection and fast subset evaluation. It is applied to small and high dimensional regression problems. In [15] a local dimension reduction framework based on partial least squares is proposed. It focuses on extracting features from high dimensional multicategory microarray data to determine the biomarkers. Cancer Biomarkers are identified using feature selection in a micro-RNA of gene expression, where the expression levels of genes are monitored in [16]. The authors have proposed a combination of kernelized fuzzy rough set and semi supervised Support Vector machine for finding cancer biomarkers

III. DATA AND PREPROCESSING

The echocardiograph data is obtained from M.S.Ramaiah Narayana Heart Centre Bangalore. The data obtained is raw data in the form of unstructured Echocardiograph reports. The first step was to prepare the dataset for mining useful patterns. Advice and recommendation was taken from the domain expert and a template consisting of the features from echocardiograph data was created. The data entry was then done in these templates. It was observed that some of the reports had incomplete data. Since it is medical data, we could not use missing values imputation. We were able to fill some of the missing values manually after taking advice from domain expert. It was found that there were also outliers, which had to be dealt with. To find outliers, statistical methods were applied. The mean and the standard deviation were computed and the values which deviated away from the mean were detected as outliers. Once again, domain expert advice was taken to standardize the data after outlier detection.

The dataset thus created has 344 patient data and about 42 features are extracted. The dataset had features which were a combination of text, nominal, categorical and numeric types. The features Date, Name of Doctor, Patient Name, Patient ID, Visit type were removed based on domain knowledge and having no significance to the task of classification. Some of the features like Echowindow, Pulmonary valve had very low variance and hence were discarded during preprocessing. The features which had string or character data type were transformed to categorical type and encoded in numeric form. The final dataset has 34 features, which are predictors. The details of the features and their description is given in table 1

The objective of this paper is to predict myocardial ischemic events from echocardiograph data and detect heart structure abnormalities (Left ventricular hypertrophy,LVH) and Left ventricular diastolic dysfunction (LVDD).

In this paper, our objective is to predict

i) Left ventricular hypertrophy
ii) Left ventricular diastolic dysfunction

Left ventricular hypertrophy is the enlargement and thickening of the left ventricle of the heart. It can develop due to high blood pressure or a condition due to which heart has to pump harder. Due to the increased workload of the heart, the heart tissues get calcified thus thickening the walls of the heart. The enlarged heart muscle loses elasticity and eventually may fail to pump with as much force as needed. Left ventricular hypertrophy usually develops gradually. There may not be any symptoms, especially during the early stages of the condition.

Analysis of the structure of the heart with respect to Left ventricular hypertrophy is an initial step in predicting the occurrence of coronary heart disease.

The values for the target attribute LVH in the reports included {Normal, Concentric LVH. Severe Concentric LVH, Dilated LVH}. Each identified class had 179,100,35 and 30 instances respectively.

Diastolic dysfunction occurs when the left ventricle is not able to accept blood in a normal fashion from the left atrium. This can be a normal physiologic change with aging of the heart or result in elevated left atrial pressures leading to the clinical manifestations of diastolic congestive heart failure. There are 4 grades of diastolic dysfunction namely Grade I to Grade IV,

where Grade I is normal with a age, Grade II is elevated left atrial pressure and enlargement, Grade III is significant elevation of left atrial pressures and Grade IV is highly elevated left atrial pressure. Taking this into consideration, the target attributes LVH and LVDD were created.

Since the values of these attributes were of string data type, they were transformed to categorical type and encoded in numeric form. .The target attributes thus created are listed and described in table 2. The values of the target attribute LVDD are {Normal, Grade I, Grade II, Grade III,}

Table1 : Dataset description.(Predictors)

Sl No	Attributes	Description
1	Age	Age of the patient in years
2	Gender	Gender ={Male, Female}
3	AO	Size of the Aortic root diameter (cm)
4	IVSD	Interventricular septum thickness at end-diastole(mm)
5	IVSS	Interventricular septum thickness at end-systole(mm)
6	LVIDD	Left ventricular Internal Dimension at end-Diastole(mm)
7	LVIDS	Left ventricular internal dimension at end-systole(mm)
8	LVPWD	Left ventricular posterior wall thickness at end –diastole (mm)
9	LVPWS	Left ventricular posterior wall thickness at end -systole (mm)
10	LA	Size of the Left atrium : systole diameter (mm)
11	EF	Ejection fraction (%)
12	RWMA	Regional wall motion abnormality
13	EW	Echo Window
14	MV	Mitral valve
15	TV	Tricuspid valve
16	AV	Aortic valve
17	PV	Pulmonary valve
18	RA	Right atrium
19	RV	Right ventricle
20	LA	Left Atrium
21	LV	Left ventricle
22	IAS	Inter auricular septum
23	IVS	Interventricular septum
24	Aorta	Aorta
25	PA	Pulmonary Artery
26	Pericardium	Double walled sac containing heart and roots of the vessels
27	mitral_flow	E : Early ventricular filling velocity A: Late ventricular filling velocity Doppler study
28	aortic flow	Flow of blood though Aorta (m/s) Doppler study
29	tricuspid flow	E : Early ventricular filling velocity A: Late ventricular filling velocity Doppler study
30	pulmonary flow	Flow of blood through pulmonary artery(m/s)
31	Mitral flow:	Flow of blood from left atrium to left ventricle Color flow mapping
32	Tricuspid flow:	Flow of blood from right atrium to right ventricle Color flow mapping
33	Aortic flow:	Flow of blood though Aorta Color flow mapping
34	Pulmonary flow	Flow of blood through pulmonary artery Color flow mapping

Table 2: Target attributes

Diagnosis 1	Heart structure abnormalities- Left ventricular hypertrophy -LVH	Class (LVH) / Code Normal / 0 Concentric LVH / 1 Dilated LVH, / 2 Severe LVH / 3
Diagnosis 2	Left Ventricular Diastolic dysfunction LVDD.	Class (LVDD) / Code Normal / 0 Grade I / 1 Grade II / 2 Grade III / 3

IV. METHODOLOGY

The block diagram of the proposed approach is shown in figure 1.

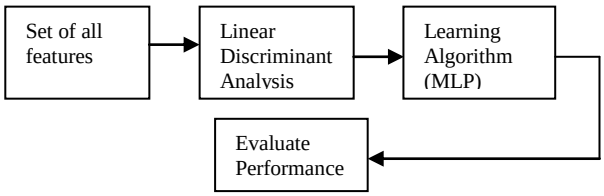

Figure 1: Proposed Method

A. Feature Selection

The dataset contains large number of features and probably also noise. In order to obtain a generalized predictive model, it is required to use feature selection techniques to obtain just the right number of features for the purpose of prediction. The different feature selection techniques explored are chisquare, feature ranking, correlation, SelectKBest, mutual Information, ANOVA, regression, Linear Discriminant Analysis(LDA). It is observed that LDA gives good result as compared to other methods. Hence LDA is explored further in this work.

B. Linear discriminant analysis (LDA) is used as a dimensionality reduction technique which is used in this research to reduce the number of features to a more manageable number before the process of classification. The linear discriminant function finds a new feature space to project the data with the objective of maximizing class separability.

Suppose we have a d-dimensional dataset and we wish to reduce the dimensions by projecting it to a k dimensional subspace where k<d.

The LDA approach is used to reduce the dimensions and is described as follows:

1. Compute mean vectors of dimension d for every class

Mean $\mu_i = \frac{1}{n}\sum_{x \epsilon Di}^{ni} x_k$ for class i=1 to n (1)

2. Compute scatter matrix for all objects within class(SWC).

$$Sw = \sum_{i=1}^{c} Si \quad (2)$$

where

$$Si = \sum_{x \epsilon Di}^{n} (x - \mu i)(x - \mu i)' \quad (3)$$

3. Compute scatter matrix for all objects between classes (SBC)

$$SB = \sum_{i=1}^{c} Ni(\mu i - \mu)(\mu i - \mu)' \quad (4)$$

4. Compute eigen vectors (e_1,e_2,…e_d) and corresponding eigen values (λ_1, λ_2.. λ_d) for SWC and SBC.

5. Arrange eigen vectors in reverse sorted order and select k eigen vectors with the largest eigen values. This is a d × k matrix W

6. Use W to transform the samples onto the new featire space.

$$Y = X \times W \quad (5)$$

C. Learning Algorithm

The machine learning algorithm namely, Multilayer Perceptron(MLP), was considered for training the data. Since the features in the dataset are of numeric type, it would be suitable to use this algorithm. The selected features obtained after feature reduction by LDA are used to train the algorithm.

D. MultiLayer Perceptron

A multilayer perceptron is a feed forward artificial neural network which consists of an input layer, one or more hidden layers and an output layer as shown in figure 2. Each layer is made up of units called nodes or neurons and weights associated with them. The input layer receives the input and passes them to the hidden layer along with their weights. The weighted output of the last hidden layer is passed to the output layer, which then gives the prediction.

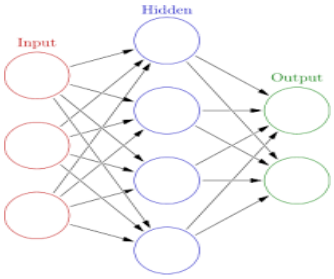

Figure 2: Multilayer Perceptron

The working of Multilayer perceptron is as follows:

1. For a hidden layer and output layer j, net input I_j is computed as

$$\mathbf{I_j} = \sum \mathbf{w_{ij} O_i + \Theta_j}$$

where w_{ij} is the weight from neuron i to j, O_i is the output of weight i and Θ_j is the bias.

2. For output of neuron j O_j is computed as

$$Oj = R(\mathbf{I_j})$$

Where $R(\mathbf{I_j}) = \max(0, \mathbf{I_j})$

3. Backpropogate the error

$Err_j = O_j(1-O_j)(T_j-O_j)$

Where O_j is actual output, T_j is target output

4. Update weights and bias

$w_{ij} = w_{ij} + \delta w_{ij}$

where $\delta w_{ij} = (l) Err_j O_i$ and l is the learning rate.

E. Proposed Algorithm

i. To predict left ventricular hypertrophy, we propose an hybrid algorithm, in which LDA is used for feature reduction and multilayer perceptron is used as a learning algorithm to train the data**.**

Algorithm LVH-PRED_MODEL

Input: Training Dataset D with attributes F <f1…fm> and class attribute LVH

Output: Predictive model for detection of Left Ventricular hypertrophic(LVH) events

- Compute the number of linear discriminants required for classification.
- Apply LDA and get a new sample sub space Y
- Train the Multilayer Perceptron on dataset Y

ii. To predict left ventricular diastolic dysfunction, we propose a hybrid algorithm, in which LDA is used for feature reduction and multilayer perceptron is used as a learning algorithm to train the data **p**ertaining to LVDD.

Algorithm LVDD-PRED_MODEL

Input: Training Dataset D with attributes F <f1…fm> and class attribute LVDD

Output: Predictive model for detection of Left Ventricular Diastolic dysfunction(LVDD) events

- Compute the number of linear discriminants required for classification.
- Apply LDA and get a new sample sub space Y'
- Train the Multilayer Perceptron using dataset Y'

V. RESULTS AND PERFORMANCE ANALYSIS

The experimental results of the proposed technique for LVD correctly classified 50 examples as Normal, 21 examples as Concentric LVH, 3 examples as Dilated LVH and 2 examples as Severe LVH. For LVDD, the technique correctly classified 38 examples as Normal, 35 examples as Grade I, and 1 example as Grade III.

The graph of figure 3 shows the feature importance for top 20 features from the echocardiograph data. The same was verified with the domain expert and the results were in consensus.

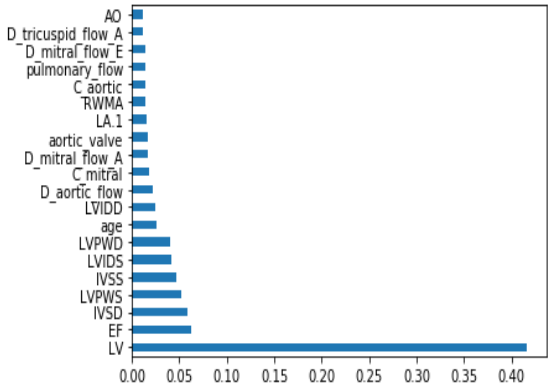

Figure 3: Feature Importance

The graph in figure 4 shows the new feature space for top 2 features after applying the linear discriminant analysis. Indeed the number of linear discriminants for LVH was computed as 3.

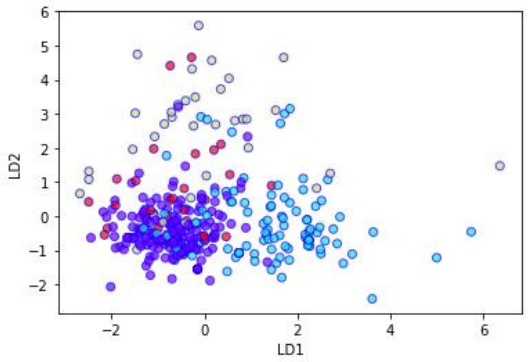

Figure 4: New feature space after LDA

In this work, we have compared the performance of the LVH prediction models with feature selection and without feature selection. The accuracy, error rate, sensitivity, specificity and area under curve for LVH prediction model is as shown in Table 4

Table 4: LVH Prediction Model

Model	Accuracy %	Error %	Sensitivity %	Specificity %	AUC %
LVH - MLP	58.77	41.23	93.1	39.2	60
LVH-LDA-MLP	88.37	11.69	96.1	85.2	83.5

The graph in figure 5 shows the comparison of the predictive models before and after applying LDA. It is observed that the performance of LVH-LDA-MLP outperforms LVH-MLP in accuracy, error and AUC and is shown in figure 6.

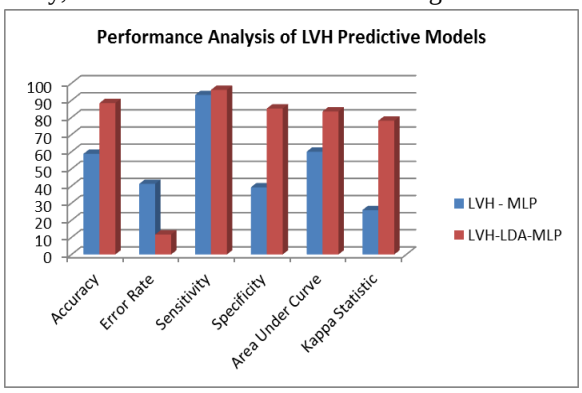

Figure 5: Performance results of LVH

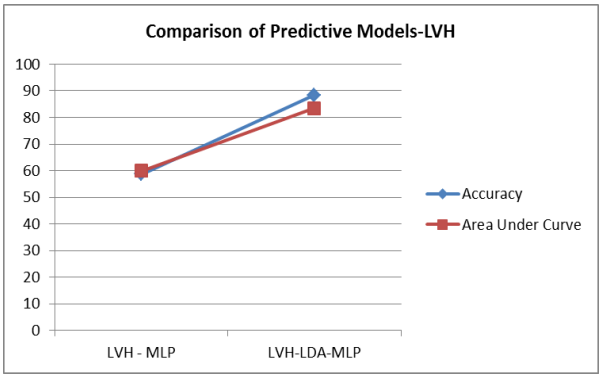

Figure 6: Comparison of LVH Models

The results of LVDD predictive model are tabulated in Table 5.

Table 5: LVDD Prediction Model

Model	Accuracy %	Error Rate %	Sensitivity%	Specificity%	AUC%
LVDD-MLP	74.56	25.44	82.14	70.68	63.51
LVDD-LDA-MLP	86.04	13.96	90.47	84.09	73.37

The graph in figure 7 shows the comparison of the predictive models before and after applying LDA. It is observed that the performance of LVDD-LDA-MLP outperforms LVH-MLP in all measures. And is shown in figure 8

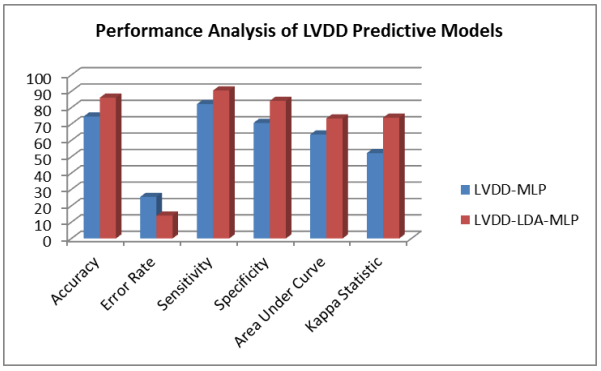

Figure 7: Performance results of LVDD

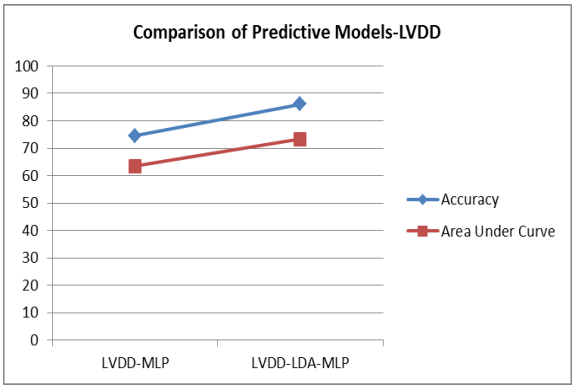

Figure 8: Comparison of LVDD Models

VI. CONCLUSION

In this paper, we have developed predictive models for the myocardial ischemic events LVH and LVDD. The proposed method gives good accuracy and AUC characteristics for both the models. There is good improvement in Sensitivity and Specificity measures in both the events. Also we have compared the models before applying LDA and after applying LDA. It is observed that there is a steep increase in performance. With respect to the usage, these models are useful to the medical fraternity in two ways

i) They can be used to detect ischemic events automatically

ii)They can be used by junior doctors to deal with emergencies caused due to ischemia.

Future work involves exploring other myocardial ischemic events and thereby deriving a decision model for interpreting ischemic events using echocardiograms.

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