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An Explainable Hybrid Intelligent System for Prediction of Cardiovascular Disease

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Abstract

Cardiovascular disease is one the major cause of death around the world. Even while medical science continues to assist efforts to save lives, qualified medical professionals are still in limited. Accurate diagnosis at the right time is crucial in cardiovascular disease cases, as patients might live a long life with the right medical care. Machine learning and artificial intelligence have a significant impact on the early and precise prediction of cardiovascular disease. In this paper a machine learning based model for cardiovascular disease prediction has been proposed applying Logistics Regression, Naïve Bayes, K-Nearest Neighbor, Support Vector machine, Kernel SVM, Decision Tree classifier, Random Forest and Artificial Neural network with model explanation using Explainable AI. Based on the precision, specificity, and sensitivity scores of each method, the most effective one has been selected. Local Interpretable Model Agnostic Explanation (LIME) and Shapely Value (SHAP) have been used for model explanation.

Keywords: *Artificial Neural Network; Decision Tree, Explainable AI; Kernel SVM; K-Nearest Neighbor; Local Interpretable Model Agnostic Explanation Logistic Regression; Random Forest; Shapely Value; Support Vector Machine.*

1.0 Introduction

This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers.

According to the report from World Health Organization Cardiovascular, disease is the major cause of death in world. It kills 7 million people each year. It is also being identified that more than 60% of global burden of coronary heart disease occurs in developing countries. There are different factors behind this non communicable disease like high blood pressure, abnormal blood lipids, stress, heredity, gender, use of alcohol and tobacco, diabetes, obesity etc. Still this disease can be prevented addressing the major factors and life risk can be mitigated by identifying it at an early stage.

This paper is focusing on the prediction of cardiovascular disease by using machine learning where total eight supervised learning mechanism – Logistic Regression, Naïve Bayes, K Nearest Neighbor, Support Vector Machine, Kernel SVM , Decision Tree, Random Forest and Artificial Neural Network have been used and analyzed.

The propose model has also the feature of explanation of the predicted outcome based on artificial neural network. Local Interpretable Model Agnostic (LIME) and Shapely Value (SHAP) have been used for providing the explanation

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regarding the predicted result though neural network approach. The user of any AI based model has to be properly understood, i.e. when AI based model is predicting a disease the doctor has to understand the justification of the prediction. So it is essential for building trust on the model developed.

Among these eight methodologies used, most competent one has been chosen for real prediction based on precision, specificity and sensitivity scores.

In following section different machine learning and AI techniques used in the proposed model have been discussed.

A. Logistic Regression

Logistic Regression is a supervised learning mechanism where dependent variables are categorical. By fitting the data in logistic curve the probability of occurrence of an event is estimated[1]. The logistic function is represented with following equation:

$$L(X) = \frac{1}{1+\exp(-X)} \quad \text{... (1)}$$

B. Naive Bayes

Naive Bayes is probabilistic model of classification based on Bayes theorem which can also be used for clustering. It is also a supervised learning mechanism. The theorem is named after Reverend Thomas Bayes who have studied detailed regarding binomial distribution of probability parameter[2]. It can be described with following equation.

$$P(A \mid B) = \frac{P(B \mid A) + P(A)}{P(B)} \quad \text{... (2)}$$

where P(A|B) is the probability A given B. It is known as the posterior probability.

P(B|A) is the probability B given A.

P(A) is the probability of hypothesis A being true. This is called the prior probability.

P(B) is the probability of the B

C. K Nearest Neighbor

K Nearest Neighbor is the most simple and fundamental supervised learning mechanism used for classification. It is based on non-parametric method for pattern classification introduced by Fix and Hodges[3]. The mechanism can use different distance measure as Euclidean, Manhattan and Minkowski.

D. Support Vector Machine

Support Vector machine is a powerful machine learning mechanism for classification and regression. SVM is effective on the dataset with huge number of features. In the SVM different Kernel function can be applied. It chooses the line that separates the data and is the furthest away from the closet data points as possible. In 1963, Vladimir Vapnik and Alexey Chervonenkis developed the support vector machine[4].

E. Kernel SVM

Support Vector Machine with Kernel function is very useful for nonlinear classification. Different Kernel functions are being used for SVM as linear, nonlinear, polynomial, radial basis function (RBF), and sigmoid.

F. Decision Tree

Decision tree is a predictive tool used in machine learning. It is based on set of hierarchical decision on feature[5]. It can be used for regression and classification. When the predicted outcome is a class or categorical variable then the tree is known as classification tree and when the predicted outcome is a real number then the tree is known as regression tree.

G. Random Forest

Random Forest is a machine learning mechanism which uses multiple decision tresses. It is basically based on bagging method. It can be used for both classification and regression. The strength of the mechanism is based on the individual trees and their correlation[6].

H. Artificial Neural Network

Artificial Neural Network is a supervised learning mechanism based on the concept of human brain. It consists of three layers input layer; hidden layer and output layer[7]. The idea was first described by Warren McCulloch, a neurophysiologist, mathematician, Walter Pitts[8]. Artificial Neural Network is a proven efficient methodology in the field of machine learning. Activation function is used in Neural Network for computing the output from set of onputs. Relu is one of the mostly used and effective activation functions. In this proposed method Relu has been used as activation function.

I. Explainable Artificial Intelligence

Explainable AI means AI with proper explanation. The prediction result by any model must have proper understanding and interpretation by the developer as well as the user of the system. It's the right of the users. Scott, A.C et al. used the explainable AI approach for model explanation[9]. In recent years explainable AI gets much importance for the deep learning based methods which are really very efficient but very complex to understand the model responses in details. There are different explainable AI tools available like LIME, SHAP and Anchor. LIME and SHAP have been used in our proposed model.

2.0 Motivation

Plenty of works are going on in the field of disease prediction using machine learning and artificial intelligence. In this section few of such works have been studied as motivation of the proposed work.

M. AkhilJabbar et al. proposed model using KNN and Genetic Algorithm. They worked on UCI repository. They claimed that the combination of KNN and GA has given better performances on classification[10]. Mai Shouman et al. proposed a heart disease prediction mechanism using KNN and achieved an accuracy more than 90%[11]. Enriko, I Ketut et al. suggested a model of heart disease prediction based on KNN proposed where 8 different features were considered and achieved accuracy of 81.85%[12]. S. Raguvaran et al. proposed a hybrid model of heart disease prediction using Logistic Regression, Random Forest, Artificial Neural network and KNN among which Logistic Regression achieved highest accuracy[13]. Amin UlHaq proposed a hybrid model for heart disease prediction using ANN, KNN, Logistic Regression, Decision Tree, Naïve Bayes and Support Vector Machine[14]. Reddy Prasad and et al. proposed a model to predict heart disease using Logistic Regression and Naïve Bayes and the accuracy achieved using Logistic Regression was 86.89%[15]. M. Saw et al. authors represented a model for heart disease prediction using Logistic Regression accurate to 87%[16]. Apurb Rajdhan et al. proposed a hybrid model applying Naïve Bayes, Logistic Regression, Random Forest, and Decision Tree and achieved highest accuracy of 90.16% with Random Forest[17]. A Multi Linear Regression Analysis based model was proposed by K. Polaraju et al.[18] where t Test and F Test were used to analyze the significance of each individual coefficient and the intercept. An model was proposed by Kathleen H. Miaoa et al. using Deep Neural Network achieving accuracy of 83.67%[19]. They worked on dataset from Cleveland Clinic Foundation. A.S. Thanuja Nishadi proposed another heart disease prediction model using Logistic Regression achieving accuracy of 86%[20]. Jabbar MA proposed an efficient model of heart disease prediction using Particle swarm optimization for feature selection and KNN. The model achieved 100% accuracy in feature selection using PSO[21]. An improved ensemble classification of heart disease was proposed by Ibomoiye Domor Mienye et al.[22] where mean based splitting approach was used to split the dataset. Authors worked on Cleveland and Framingham dataset with 93% and 91% accuracy respectively. S. Sharanyaa et al. proposed a hybrid model to predict heart disease applying Decision Tree, Support Vector Machine, K Nearest Neighbor, Random Forest and achieved accuracy of 94%[23]. VanithaGuda, Shalini K, Shivani C proposed a model to predict heart disease using Hybrid Random Forest and Linear Model. They have worked on Cleveland dataset and Framingham dataset[24]. Madhavi Veeranki et al. proposed a hybrid model to predict heart disease using ANN, SVM, Naïve Bayes, Logistic Regression and Hybrid Random Forest with Liner Model[25]. SanchayitaDhar et al. proposed a model for prediction of heart disease using Random forest classifier and simple k-means algorithm. They collected data from ERIC[26]. Riddhi Kasabe suggested a machine learning based model to predict heart disease which achieved 87% accuracy[27]. A hybrid model for heart disease prediction was proposed by S. Shylaja et al.[28] where SVM and ANN were being used in combine and achieved accuracy of 88.54%.

3.0 Proposed Model

This is a hybrid model where multiple methods have been used for predicting heart disease and out of them most competent one has been chosen for actual prediction. Logistic Regression, Naïve Bayes, K-Nearest Neighbor, Support Vector machine, Kernel SVM, Decision Tree classifier, Random Forest and Artificial Neural network have been utilized in this proposed work. The model's performance has also been explained using the LIME and SHAP.

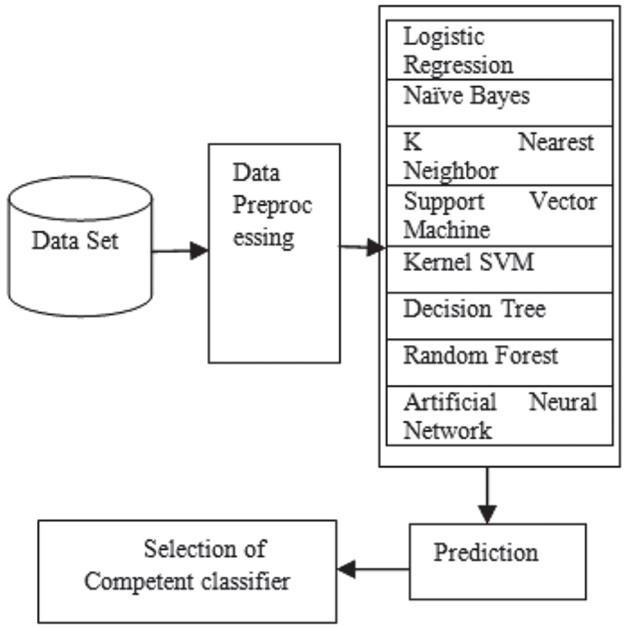

Figure 1: Proposed model block diagram

A. Dataset Description

Dataset used in this research has been collected from UCI data repository. It is a dataset of heart disease prediction model consisting of total 14 different features. Following figures give brief description regarding the dataset.

```
In [3]: dataset = pd.read_csv('F:\heart.csv')
        X = dataset.iloc[:, :-1].values
        y = dataset.iloc[:, -1].values

In [4]: dataset.head()
Out[4]:
```

	age	sex	cp	trestbps	chol	fbs	restecg	thalach	exang	oldpeak	slope	ca	thal	target
0	63	1	3	145	233	1	0	150	0	2.3	0	0	1	1
1	37	1	2	130	250	0	1	187	0	3.5	0	0	2	1
2	41	0	1	130	204	0	0	172	0	1.4	2	0	2	1
3	56	1	1	120	236	0	1	178	0	0.8	2	0	2	1
4	57	0	0	120	354	0	1	163	1	0.6	2	0	2	1

Figure 2: Dataset for proposed model

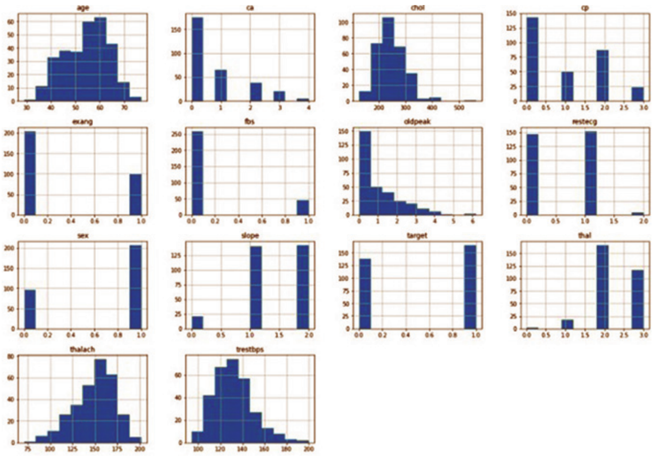

Figure 3: Histogram representation of dataset

B. Splitting of Data in Training and Test set

75% of the dataset is used for training and remaining 25% of dataset is used for testing in our proposed model.

In this proposed model following machine learning methodologies have been applied for prediction of cardiovascular disease.

C. Application of Different Machine Learning Models

(1) Logistic Regression: By applying the logistic regression mechanism 83% accuracy has been achieved.
(2) Naïve Bayes: The next mechanism applied over the dataset is Naïve Bayes achieving accuracy of 83%.
(3) K Nearest Neighbor: KNN is another mechanism has been applied in this model of heart disease prediction where 82% accuracy has achieved.
(4) Support Vector Machine: Support Vector Machine is another supervised learning mechanism that has been applied in this model. By applying the 86% accuracy has achieved.
(5) Kernel SVM: By applying the Kernel SVM 86% accuracy has been achieved in the proposed hybrid model of heart disease prediction. The Kernel function used over here is rbf.
(6) Decision Tree: Decision Tree has also been applied over the model and achieved accuracy of 80%.
(7) Random Forest: Random Forest is an ensemble mechanism by applying multiple decision trees. Applying the Random Forest 82% accuracy has been achieved.
(8) Artificial Neural Network: Next mechanism applied over our proposed model is Artificial Neural Network which has given the best performance with 89% accuracy.

D. Selection of Competent Classifiers

In the proposed model, eight different classifiers have been utilized for heart disease prediction. Based on the performance in classification one competent model would be chosen based on a weighted average formula mentioned below:

$$Performance = (2 * Sensitivity + Specificity + Precission)/4 \quad \dots (3)$$

The performance metric considered here are Precision, Sensitivity, Specificity and Precision. For any model, overall performance measured can be observed by accuracy. Accuracy is an excellent statistic, but only if datasets are symmetric. So few other metrics need to be considered. The degree of confidence in a true positive is known as precision. The percentage of actual positives that were correctly classified as positives is called recall or sensitivity. Another metric is specificity, which is the ratio of genuine negatives to all other negatives in the data. Sensitivity is a very important parameter for model justification since accurate identification of sick persons is necessary for medical diagnostics; otherwise, therapy may not begin, which could have serious consequences.

So in this proposed model sensitivity has given higher weightage than other two metrics.

4.0. Result Analysis and Performnace Evaluation

In this proposed model eight different machine learning algorithms have been applied. After the testing the confusion matrix generated have been depicted in following figures.

A. Model Performance Analysis through Accuracy measure

Any machine leaning based model performance can be measured using factors like accuracy, precision ,specificity and recall or sensitivity.

Accuracy is the measure of model's overall performance. It is the ratio of total number of correct prediction and total number of samples.

$$\text{Accuracy} = \frac{TP+TN}{TP+FP+TN+FN} \quad \text{... (4)}$$

$$\text{Precision} = \frac{TP}{TP+FP} \quad \text{... (5)}$$

$$\text{Sensitivity} = \frac{TP}{TP+FN} \quad \text{... (6)}$$

$$\text{Specificity} = \frac{TN}{PF+TN} \quad \text{... (7)}$$

Where TP: True Positive, FP: Flase Positive TN: True Nehative and FN: False Negative.

1. Logistic Regression Performance

By applying logistic regression 83% accuracy 85.72% precision, 61.90% specificity and 72.73% sensitivity have been achieved.

The following figure is displaying the confusion matrix.

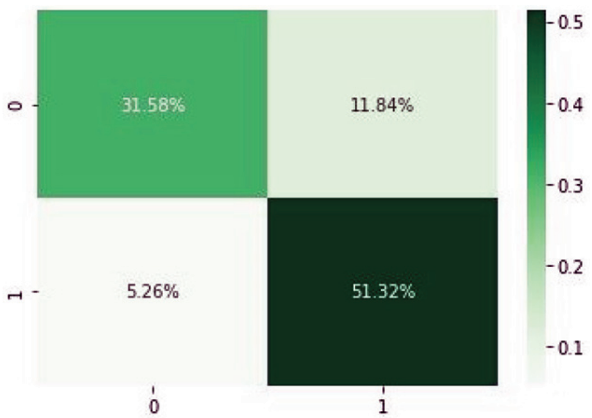

Figure 4: Confusion Matrix generated over Logistic Regression Model

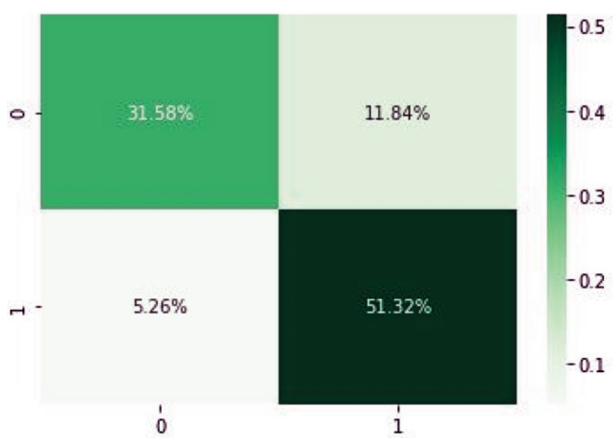

Figure 5: Confusion Matrix generated by applying Naive Bayes.

2. Naïve Bayes Performance Evaluation

83% accuracy, 85.72% precision, 61.90% specificity and 72.73% sensitivity have been achieved achieved by applying Naïve Bayes.

3. K Nearest Neighbor Performance Evaluation:

By the KNN learning mechanism the accuracy, precision, sensitivity and specificity achieved in the proposed model are 82%, 85.19%, 69.69% and 62.90%. Confusion matrix is shown below.

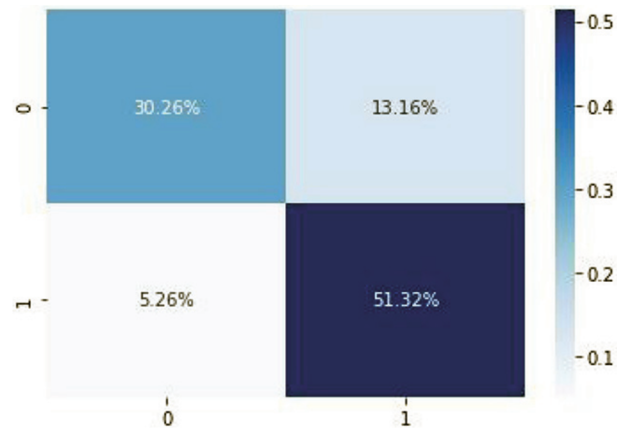

Figure 6: Confusion Matrix generated by applying KNN

4. Support Vector Machine Performance Evaluation

SVM has also been applied in the model and achieved accuracy, precision, specificity and sensitivity are 86%,92,31%, 63.03% and 72.73 %.

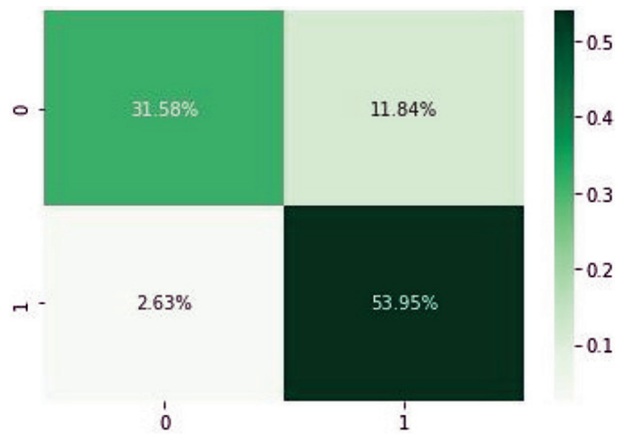

Figure 7: Confusion Matrix generated by applying SVM

5. Kernel SVM

SVM with kernel function rbfhas also been applied and achieved accuracy of 86%. Precision, specificity and sensitivity achieved are 89.27%, 61.54% and 75.74%.

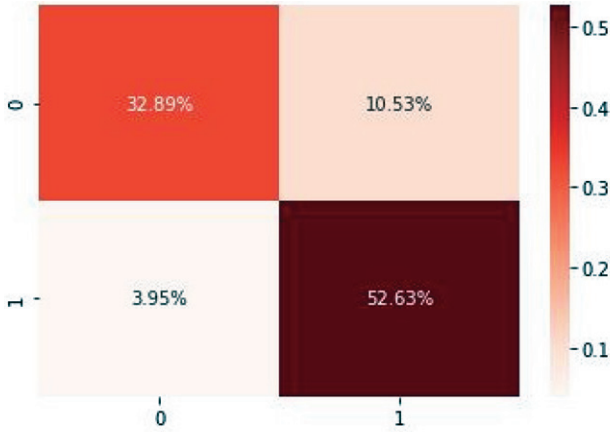

Figure 8: Confusion Matrix generated by Kernel SVM

6. Decision Tree Performance Evaluation

By applying decision tree in the proposed model, accuracy achieved is 80%. Precision, specificity and sensitivity achieved are 80.01%, 60.65% and 72.73%.

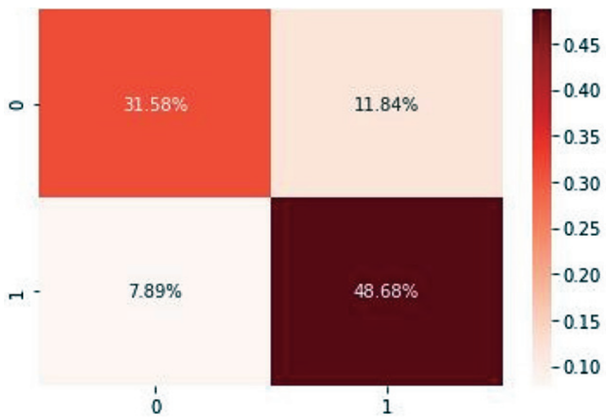

Figure 9: Confusion Matrix generated by applying Decision Tree

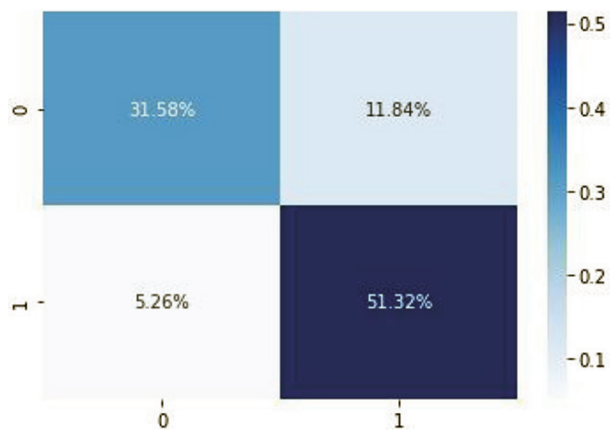

Figure 10: Confusion Matrix generated applying Random Forest

7. Random Forest Performance Evaluation

Random Forest method has achieved accuracy of 83%. Precision, specificity and sensitivity achieved are 85.72%, 61.90% and 72.73%

8. Artificial Neural Network Performance Evaluation

By applying the ANN the accuracy achieved is 89%, which is maximum among the other entire model. Precision, specificity and sensitivity achieved are 88.45%, 57.51% and 85.17%.

In following figures, the performances of different model have been analyzed.

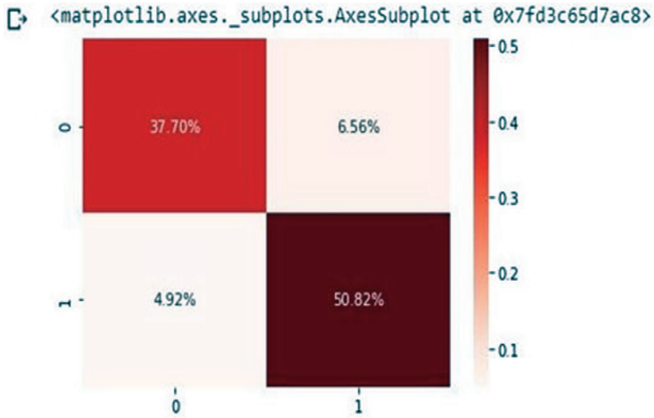

Figure 11: Confusion Matrix generated applying ANN

B. Identification of Competent Classifier

In this proposed model, eight different classifiers have been used and analyzed. Classifier performances may vary

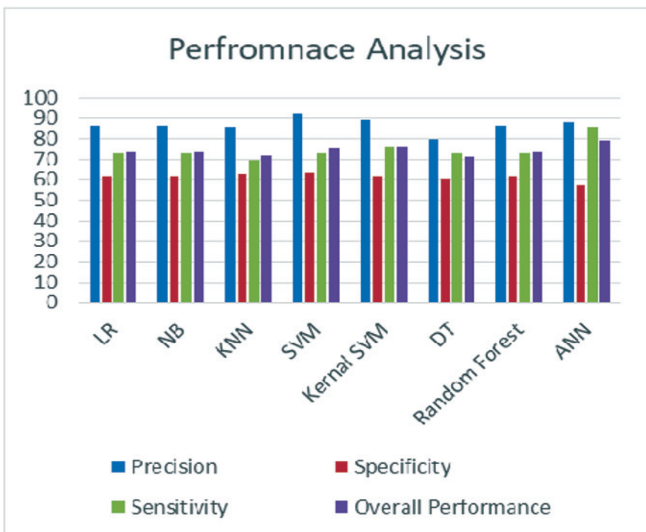

Figure 12: Overall Classifiers Performances

based on dataset distribution. Among the eight classifiers best one would be chosen for heart disease prediction based on Specificity, Sensitivity and Precision scores. In Figure 12 the overall performances have been shown. According to the score Artificial Neural Network has given best performance.

C. Model Explanation using LIME and SHAP

As mentioned, earlier in this proposed model the explanation and interpretation of the model has been introduced using LIME and SHAP. In Figure 13 explanation of the model prediction using one sample with five most important features through LIME has been depicted and in Figure 14 the summery plot of training set and test set has shown applying SHAP.

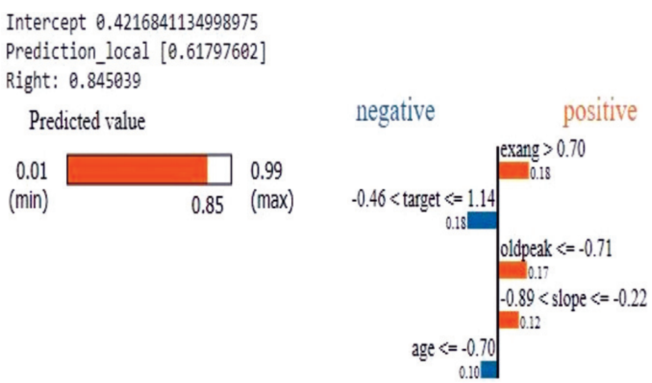

Figure 13: Model Explanation using LIME

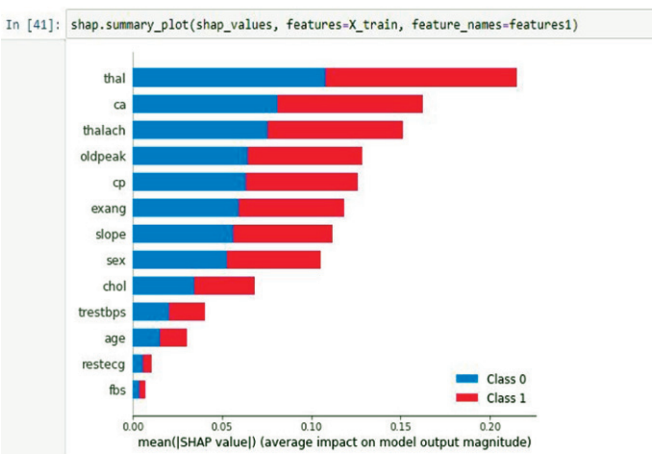

Figure 14: SHAP Summery Plot of Training and Test Data set

5.0 Conclusion

In this paper a heart disease prediction model has been proposed using multiple machine learning mechanisms i.e. Logistic Regression, Naïve Bayes, KNN, SVM, Kernel SVM, Decision Tree, Random Forest and Artificial Neural Network. Out of eight classifiers, most competent one has been chosen based on precision, specificity and sensitivity. Another interesting and effective feature of the proposed work is its explanation capability so that the users of the model can understand the predicted outcome. The model has explained with LIME and SHAP which helps to justify the model performance.

6.0 Acknowledgment

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