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Comparative analysis and prediction of coronary heart disease

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ABSTRACT

Cardiovascular disease (CVD) is now one of the leading causes of death worldwide and was also thought to be a serious illness in the mid and old ages. Artificial intelligence and machine learning have a huge impact on the healthcare areas. As a result, getting a familiar individual with data processing techniques suitable for numerical health data. Although, the most often used algorithms for classification tasks will be incredibly advantageous in terms of time management. In particular here, a common procedure has been proposed for predicting cardiovascular disease. Accordingly, we herein consider nine typical classifiers of both machine learning and deep learning technology for the comparative analysis and prediction of coronary heart failure. These models are computationally inexpensive and easy to build. Moreover, these classifiers are tested and compared using a confusion matrix in the Jupyter notebook, yielding classification measures such as accuracy, f1-score, recall, and precision. As a result, the logistic regression classifier gives the maximum possible accuracy, precision, and f1-score of 90.78%, 90.24%, and 91.35% respectively.

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1. INTRODUCTION

Heart disease (HD) is one of the world's most serious diseases nowadays, which shows the difficulty in identifying it, therefore making it a convenient time for both physicians and patients. Early detection of HD aids in the improvement of patients' health through preventative measures. Cardiovascular disease (CVD) refers to a group of diseases affecting the heart and blood arteries that cause 13% of CVD deaths, while tobacco is responsible for 9%, diabetes for 6%, lack of exercise for 6%, and obesity for 5% [1]. CardioHelp is a technology that uses a deep learning algorithm called convolutional neural networks to estimate the probability of a patient having a cardiovascular illness (CNN) [2].

Figure 1 displays the outer view of the human heart system, where the right atrium is the area where blood returns to the heart from the rest of the body. The blood has been delivering oxygen to the body and now has to be replenished. This blood fills the right atrium, which subsequently goes into the right ventricle. The right ventricle will pump blood into the lungs to replenish oxygen levels. The right ventricle contracts when it is full, propelling blood into the lungs. The blood travels from the lungs to the left atrium, and the right atrium pumps oxygen-depleted blood into the right ventricle, whereas the left atrium pushes oxygenated blood into the left ventricle from the previous cycle. The blood flows back to the right atrium, and the cycle begins again. Therefore, early detection of heart problems like coronary artery disease, arrhythmias, infection or defect in the heart, and disease in the heart muscle are much important both for the physicians as well as patients.

Thus, machine learning (ML) is one of the most effective ways of predicting whether or not a person is suffering from a specific ailment in the field of medical analysis [3], [4]. The greatest algorithm for predicting a person's heart illness is the random forest classification algorithm, which is the most accurate way to perform analysis [5]. Data-driven approaches based on ML algorithms such as K-nearest neighbor (K-NN), decision tree (DT), logistic regression (LR), and many more are viable alternatives [6]–[8]. In the coming section 2, the methodology has been described to predict HD; section 3, provides the performance result of all models; finally, sections 5 and 6 concluded with results and conclusion respectively.

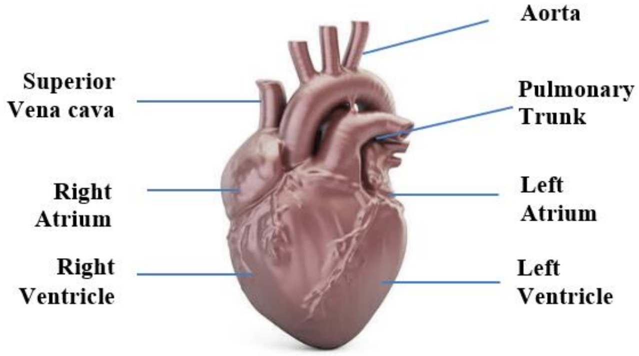


Figure 1. Outer view of the human heart

2. RESEARCH METHOD

The electronic health record (EHR) is one of the strategies for keeping track of a patient's whole medical history and analyzing the data in the future. The complete process for comparative analysis and prediction for HD undergoes some basic steps, as shown in Figure 2. Although, there have been analyzing the heart dataset with different machine learning models, to predict the HD in advance, in avoidance to death.

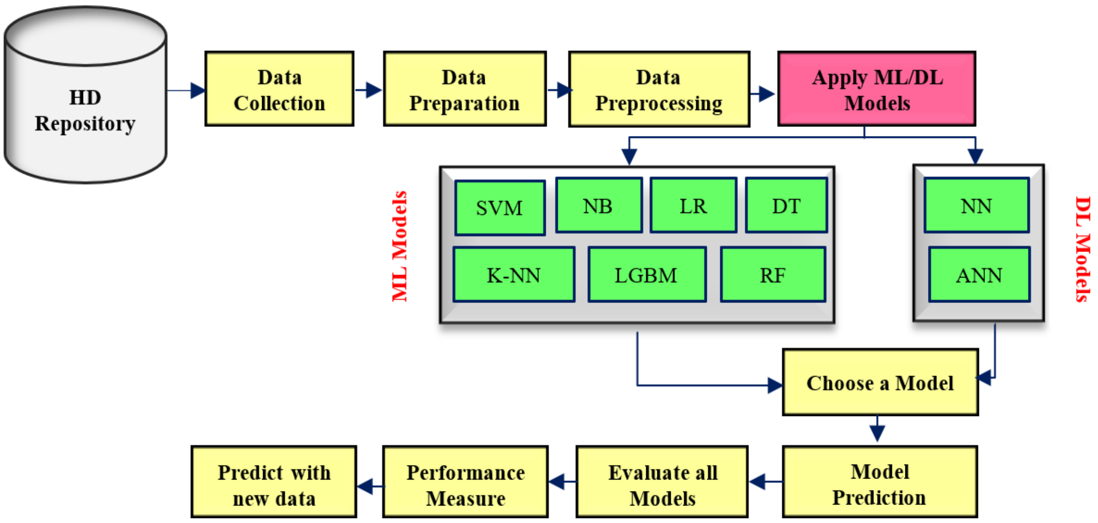


Figure 2. Methodology for heart attack prediction

2.1. Data collection

Data collection is the process of gathering, measuring, and evaluating correct insights for research using defined distinguished techniques. In this work, the HD dataset has been collected from the UCI repository. It contains 303 individual patient records and 14 dependent features, as described in Table 1.

Table 1. Features and descriptions

No. of features	Features	Description
1	Chest pain (cp)	0: Typical angina, 1: Atypical angina, 2: Non-anginal pain, and 3: Asymptomatic
2	Restecg	0: Nothing to note, 1: ST-T Non-normal heartbeat, and 2: Hypertrophy of the left ventricle
3	thal	1, 3: normal, 6: fixed defect, and 7: reversible defect
4	trestbps	Anything exceeding 130-140 in the resting blood pressure is usually caused worry.
5	fbs	'>126' mg/dL indicates diabetes if fasting bs is greater than 120 mg/dL (1 = true; 0 = false).
6	age	age in years
7	Sex	(1 = male; 0 = female)
8	chol	Serum cholesterol in mg/dl
9	thalach	Attained maximal heart rate
10	exang	exercise induced angina (1 = yes; 0 = no)
11	oldpeak	ST depression generated by exercise compared to rest examines heart stress during activity;
12	slope	The slope of the ST portion of the peak exercise
13	ca	Number of major vessels (0-3) colored with fluoroscopy-colored vessels
14	output	predicted HD or not (1=yes, 0=no) (= the attribute

2.2. Data pre-processing

Preprocessing the data is the major step before moving to predict any disease in a healthcare firm due to its incompleteness and unreliability, so likely to be riddled with errors. So, there is the requirement of cleaning by removing duplicate, null or irrelevant values from the dataset. To make our models train, the HD dataset has been splitted into train set and test set (i.e. 80 percent for training and 20 percent for testing).

2.3. Apply machine learning and deep learning models

2.3.1. Machine learning

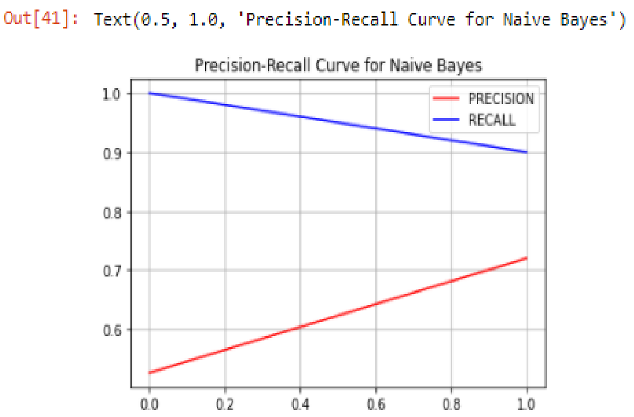
The most common type of artificial intelligence (AI) is ML which analyses and discovers patterns in massive data sets. This aids in decision-making and builds a cost-effective model for correctly predicting cardiac disease [9]. The best threshold for a model can be calculated by using Precision-Recall Curve (PRC) that has been discussed here.

a. Naive Bayes classifier

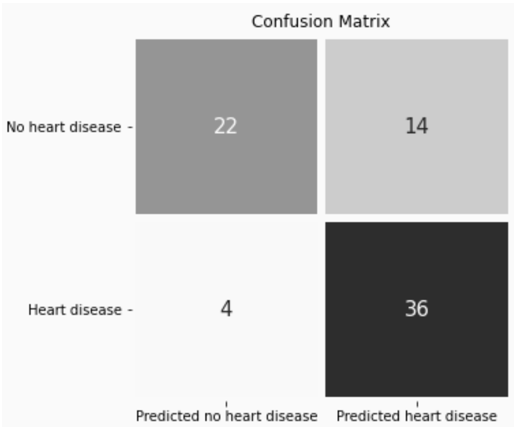
Naive Bayes (NB) finds the probability of one event occurring based on the probability of another event to predict an accurate class. Thus, the HD prediction system accurately identifies and predicts it more efficiently based on medical data [10], [11]. Figure 3 shows the result of NB model on test data, where Figure 3(a) shows the PRC plot and Figure 3(b) gives the result of the confusion matrix that predicts a total of thirty-six HD patients.

Algorithm:

- Create a frequency table from the dataset, and a Likelihood table by calculating the probabilities.
- Now applying the NB equation for calculating the posterior probability for each class.
- Finally, the highest posterior probability will be considered as the predicted outcome.



(a)



(b)

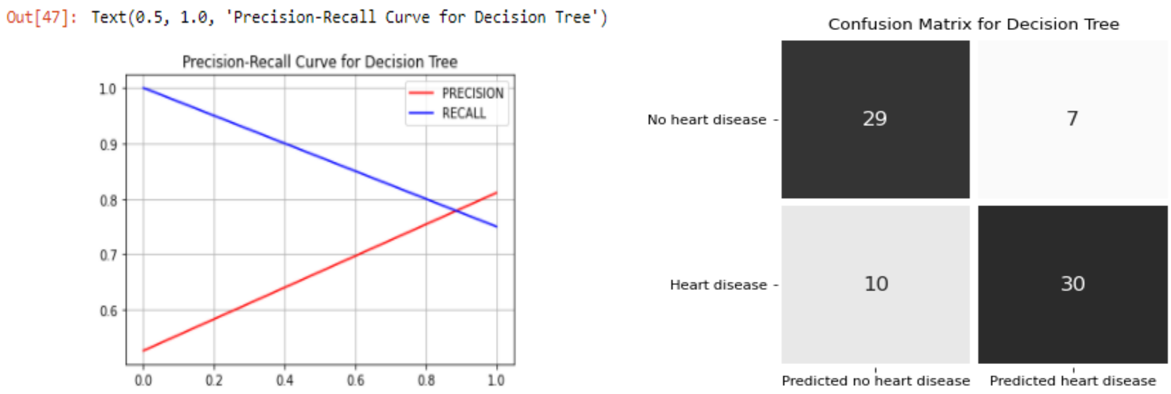
Figure 3. Heart disease prediction for NB model using (a) PRC plot and (b) confusion matrix

b. Decision tree classifier

A decision tree (DT) model is mostly used to address the classification problems like determining HD using NetBeans and Weka software [12]. DT uses iterative feature elimination to produce accurate cardiac disease prediction at an early stage [13]. The PRC and cm for the DT model have been shown in Figure 4(a) and Figure 4(b).

Algorithm

– Starts from the root node and moves forward to its branch node to find the best attribute.
– Calculate the Entropy (H) and Information Gain (IG) of each attribute to select the attribute having the lowest H and highest IG. On each subset, the process repeats itself (i.e. not selected previously).
– Go to step 1 until getting the outcome.



(a) (b)

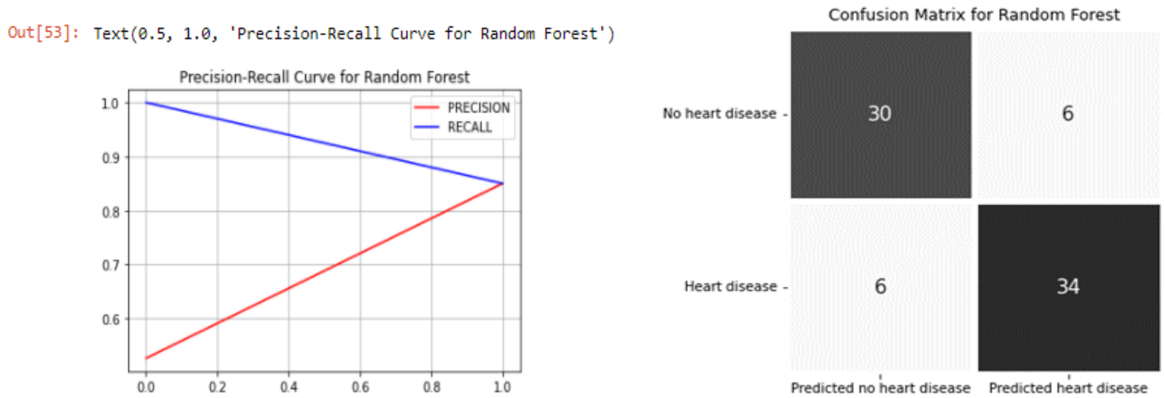
Figure 4. Heart disease prediction for DT model using (a) PRC plot and (b) confusion matrix

c. Random forest

Random forest (RF) uses the data analysis technique to anticipate and detect CVDs such as stroke and heart attack efficiently [14]. Although, RF predicts cardiovascular disorders with a 90.3 percent accuracy [15]. The PRC and cm for the RF predict thirty-four HD patients has been shown in Figures 5(a) and 5(b).

Algorithm

a. Randomly select the “k” features (i.e. k=13) from the heart dataset from a total number of “m” features (i.e. m=14) where k << m. Also, apply DT for every sample.
b. Consider the text features and apply rules to predict the outcome and store the predicted result.
c. Find the majority for every predicted result and choose the highest result as the final prediction.

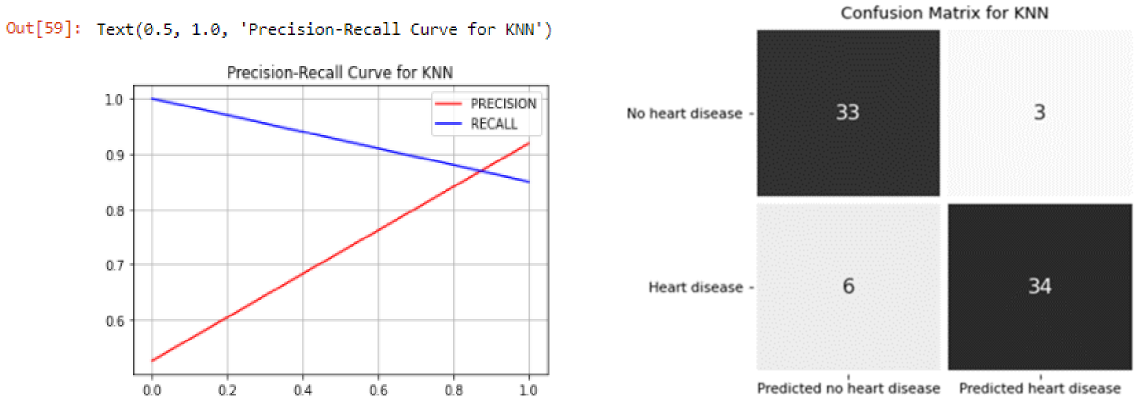


(a) (b)

Figure 5. Heart disease prediction for RF model using (a) PRC plot and (b) confusion matrix

d. K-nearest neighbor classifier

The K-nearest neighbor (K-NN) classifier assumes that the new case/data and previous cases are the same, and allocates the new case to the extant categories only in the most similar group. When diagnosing the HD dataset, K-NN produces an effective classification and optimal solution than NB and DT [16], [17]. The PRC and cm for the K-NN classifier on test data predict thirty-four HD patients that have been shown in Figure 6(a) and Figure 6(b).

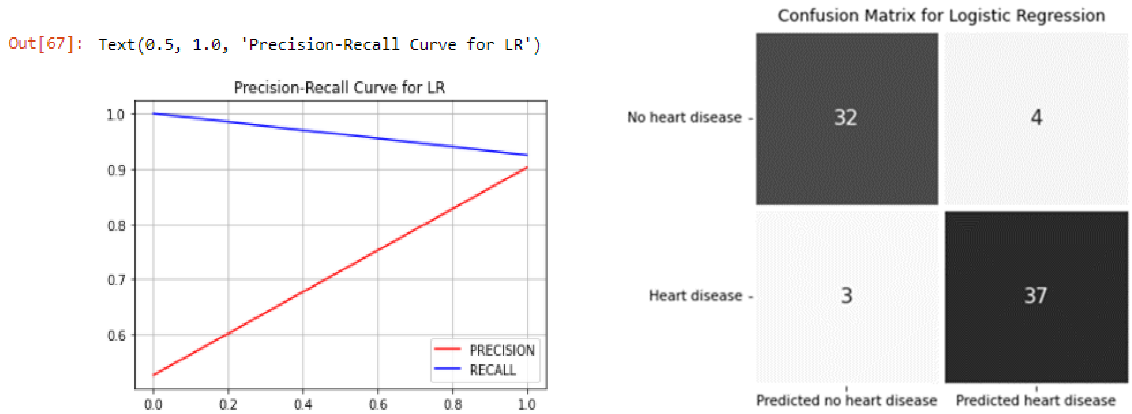


(a) (b)

Figure 6. Heart disease prediction for K-NN model using (a) PRC plot and (b) confusion matrix

e. Logistic regression classifier

Logistic regression (LR) performs on calculating the probability of a categorical dependent variable. The dependent variable is a binary variable with data coded as 1 or 0. When the accuracy of LR was compared to other models, it was found that it was suitable in the field of HD prediction [18]. However, the PRC and cm for the LR model on test data predict thirty-seven HD patients that have been plotted in Figure 7(a) and Figure 7(b) respectively.



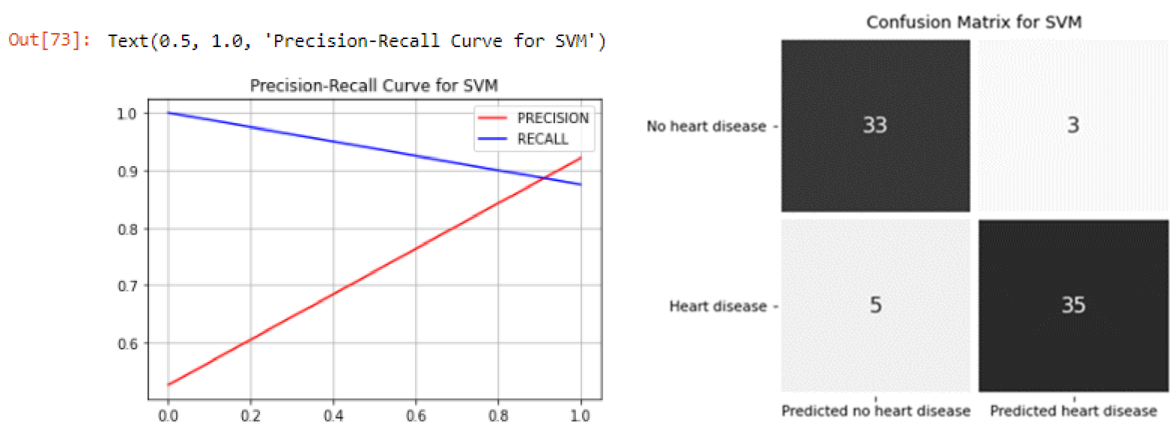
(a) (b)

Figure 7. Heart disease prediction for LR model using (a) PRC plot and (b) confusion matrix

f. Support vector machine

The support vector machine (SVM) algorithm uses a line to separate data points which is called a hyperplane. Hyperplane has been used to classify the most significant of the closest data points into two separate classes. HD prediction using a PSO-based SVM algorithm outperforms the DT, NB, NN, and SVM by a factor of 100 [19]. The PRC and cm plot for the SVM model that predicts thirty-five HD patients has been shown in Figure 8(a) and Figure 8(b).

Algorithm:
- Create hyperplanes to separate the dataset into two classes and identify the right hyperplane for SVM.
- Check if this hyperplane is properly segregated from the dataset. If not, apply the kernel trick to it.
- Now check whether the data points are linearly separable or not.
- Next, find the margin on both sides that are closest to the hyperplane and should be at the maximum point. If yes, then this model is now ready for prediction.



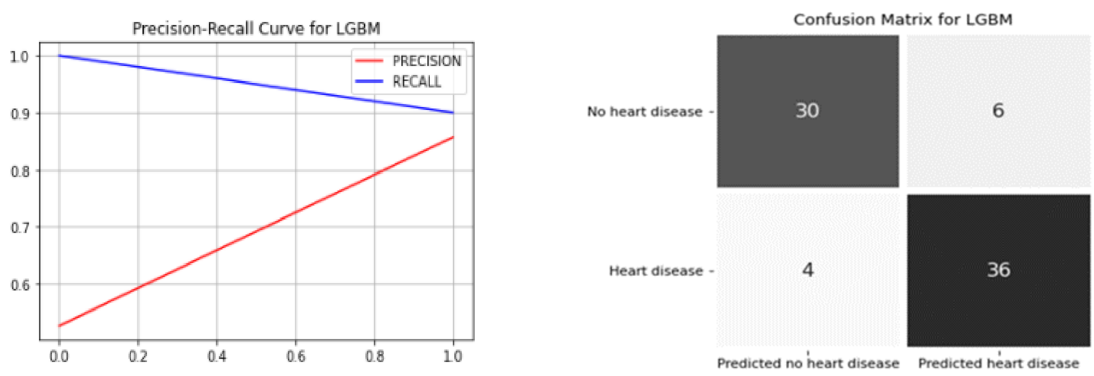
(a) (b)

Figure 8. Heart disease prediction for SVM model using (a) PRC plot and (b) confusion matrix

g. Light gradient boosting machine (LGBM)

It follows the best-first search to find the optimal path. This model grows trees vertically i.e. leaf-wise whereas other decision trees grow horizontally i.e. level-wise. The PRC and cm plot for the SVM classifier on test data that predicts a total of thirty-six HD patients has been shown in Figure 9(a) and Figure 9(b) respectively.

Algorithm:
- Create hyperparameters and the number of DT. Next, recall the DTs to improve prediction.
- Assign the number of trees i.e. here n_estimators is 20 and measure the model's performance.
- Explore the tree depth (i.e. here max_depth is '5), the number of terminal nodes, and the learning rate.



(a) (b)

Figure 9. Heart disease prediction for LGBM model using (a) PRC plot and (b) confusion matrix

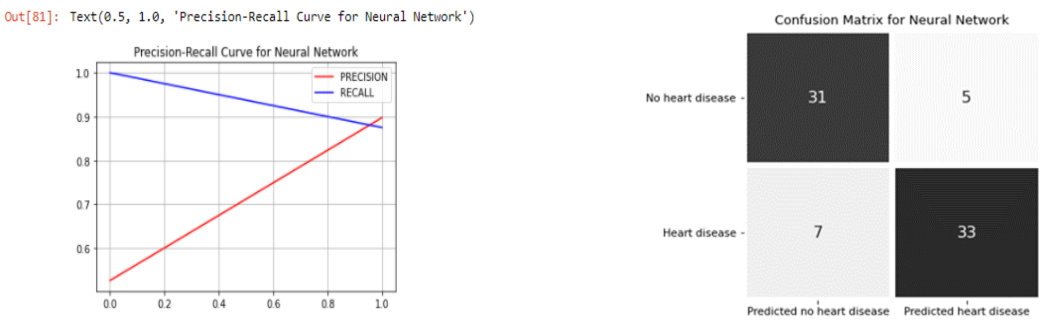
2.3.2. Deep learning

One AI mechanism called deep learning (DL) mimics the network of neurons in a brain. An advanced DL model can build a knowledge-rich environment that can assist clinical decision-making for predicting CVD patients [20].

a. Neural network

The neural network (NN) algorithm is based on biological neural networks and aims to mimic the nervous system of humans in the learning process. The results reveal that for the HD prediction tasks, a three-layer NN model using a backpropagation algorithm and an Adam optimizer reached a promising accuracy [21]–[24]. The PRC and cm plot for the NN model predicts thirty-three HD patients, has been shown in Figure 10(a) and Figure 10(b).

Algorithm:
- Starting from the input layer, each neuron takes weight and bias (i.e. weight x inputs).
- Move forward to the hidden layer and assign an activation function to every output from it.
- The outcome is displayed on a single output layer (i.e. at the softmax layer).

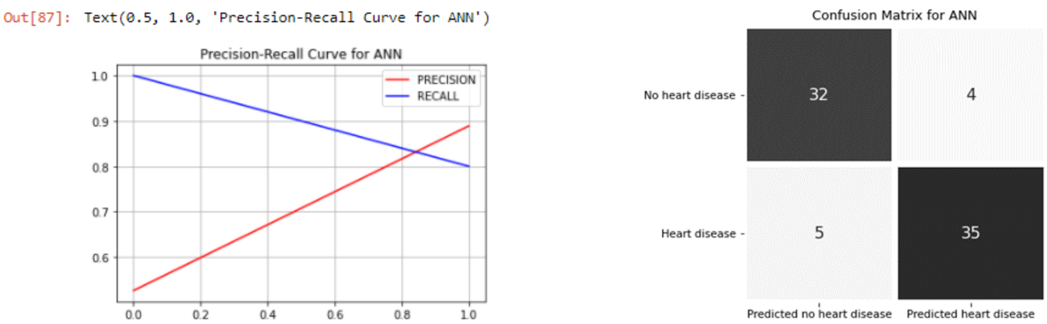


(a) (b)

Figure 10. Heart disease prediction for NN model using (a) PRC plot and (b) confusion matrix

b. Artificial neural network

Artificial neural networks (ANNs) are a versatile and effective tool that can assist doctors in analyzing, and modeling complex clinical data in a variety of medical settings. The proposed system creates an effective methodology for collecting clinical and electrocardiogram (ECG) data to train an ANN to detect heart problems [25]. A smart health care framework, for identifying CVD generates predefined numbers of NNs after training and evaluating the framework [26], [27]. Figure 11 shows the result of ANN model on test data, where Figure 11(a) shows the PRC plot and 11(b) gives the result of the confusion matrix that predicts a total of thirty-five HD patients.



(a) (b)

Figure 11. Heart disease prediction for ANN model using (a) PRC plot and (b) confusion matrix

3. PERFORMANCE METRICS

The performance of a model can be measured using performance metrics. Thus, to measure the performance of all nine models, we have taken four performance metrics precision, recall, accuracy, and F1 score as shown in (1) to (4). Precision (P) determines the accurateness used to assess a classifier's performance as shown in (1). Recall (R) determines the classifier's completeness as shown in (2). When R improves, P often suffers as a result. Accuracy is for identifying the best model for finding relationships and patterns between variables as shown in (3). The F-score is a combination of accuracy and recall that may be measured using the (4).

4.1. Precision (P)

$$P = TP / (TP+FP) \quad (1)$$

4.2. Recall (R)

$$R = TP / (TP+FN) \quad (2)$$

Where,
TP, FP, and FN stand for True Positive, False Positive, and False Negative respectively.

4.3. Accuracy

$$Accuracy = (TP+TN) / (TP+TN+FP+FN) \quad (3)$$

4.4. F1 Score

$$F1\ Score = 2 * ((P * R) / (P + R)) \quad (4)$$

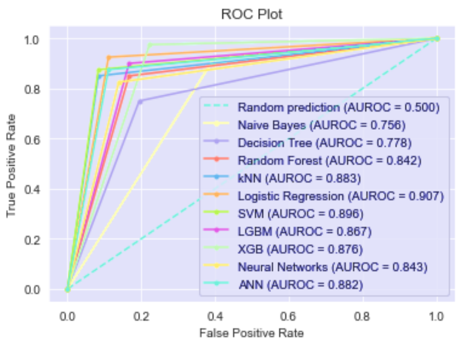
4. RESULT AND DISCUSSION

HD prediction at an earlier stage may help to avoid deaths from heart attacks. A good classification system can assist a doctor in predicting the existence of CVD before it happens. HD dataset has been collected from the UCI repository, consisting of 303 records, which undergo pre-processing to remove all the null values if present in the dataset. Furthermore, for the ML side of this project, the sklearn module and, for the DL side, Keras layers are used. Further, to evaluate all nine models successfully, the next move forward is to measure the performance by using a cm and ROC Curve, as described in above Figure 12. Figure 12(a) represents the cm and Figure 12(b) shows the ROC curve, containing the TPR (true positive rate) and FPR (false positive rate) for all nine models. This plot demonstrates that LR (indicating orange color) model proves as the best predictive classifier (i.e. accuracy of 90.7%) in detecting heart attack.

Out[128]:

	Model	Accuracy (%)	Recall (%)	Precision (%)	F1 (%)	AUC
0	Naive Bayes	0.763158	0.900	0.720000	0.800000	0.755556
1	Decision Tree	0.776316	0.750	0.810811	0.779221	0.777778
2	Random Forest	0.842105	0.850	0.850000	0.850000	0.841667
3	kNN	0.881579	0.850	0.918919	0.883117	0.883333
4	Logistic Regression	0.907895	0.925	0.902439	0.913580	0.906944
5	SVM	0.894737	0.875	0.921053	0.897436	0.895833
6	LGBM	0.857143	0.900	0.857143	0.878049	0.866667
7	XGB	0.829787	0.975	0.829787	0.896552	0.876389
8	Neural Networks	0.868421	0.825	0.916667	0.868421	0.870833
9	ANN	0.842105	0.825	0.868421	0.846154	0.843056

(a)



(b)

Figure 12. Comparative models prediction for HD using (a) performance metric and (b) ROC Curve

5. CONCLUSION

The leading cause of death in the country is HD. Manually calculating the chances of developing HD based on risk factors such as age and sex is difficult. To predict the output from data, the relevant technologies of ML and DL are applied that might give a significant result. They can assist professionals in identifying, diagnosing, and treating cardiovascular disease. In this work, a total of nine classifiers are tested and measured using a cm for predicting a heart attack. Moreover, a PRC plot has been carried out that entirely focuses on all models' performance on the test set. The results demonstrate that the LR model outperforms the strategies with 90.7 percent accuracy, which specifies that this model has a greater extent of identifying HD. In conclusion, it might find that the LR model would predict more effectively on the real-time HD datasets. However, both ML and DL advances in healthcare will continue to revolutionize the business in the future.

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