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Communications in Computer and Information Science 2819

Artificial Intelligence Based Smart and Secured Applications

4th International Conference, ASCIS 2025
Gujarat, India, September 11–13, 2025
Revised Selected Papers, Part I

Part 1

Springer

Improving Accurate Prediction in Cardiovascular Disease and Optimizing Using Novel Nesterov Accelerated Gradient in Comparison with Gradient Boosting Classification

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Abstract. Traditional approaches and machine learning (ML) incorporate the neural network process in predicting all medical complications and detecting the severity of health issues, mostly considered critical conditions. Heart diseases are common nowadays in all generations and occur in clinical challenges in all countries. Cardiovascular is one kind of heart disease that specialists and experts handle to diagnose in the early stages. Several ML classifiers were implemented and some produced results as incorrect diagnoses addressed as inaccurate in the medical field. The proposed work novelty Nesterov Accelerated Gradient approach produces optimal prediction due to finding the severity of cardiovascular disease. Data are preprocessed using the classification of severity in heart diseases using the Novel Gradient Boosting Classification (NGBC) algorithm which has the same classes observed manually and systematically. From the classification, output was achieved to categorize the classes that can obtain an accuracy of 94.8% accuracy based on training the model and testing in prediction. To improve performance analysis and suggest diagnosis, the proposed algorithm produces precision, recall, and confusion matrix metrics of heart disease using Novel Nesterov Accelerated Gradient (NNAG) compared with XGboost and Aquila optimizer. The better optimization demonstrates how healthcare based on heart diseases can be effectively handled at an earlier stage to save human lives.

Keywords: Classification · Heart Disease · Machine Learning · Nesterov Accelerated Gradient Approach · Prediction · XGboost

1 Introduction

The functioning of the heart and the blood vessels is also affected by the condition called HD which stands for heart disease. When this disease is left unnoticed, it may even lead to the death of a person and hence most of the people across the globe are affected by this. [1] Several people are affected by this disease irrespective of their ages (Sharma et al. 2020). Diagnosing such diseases must be done earlier as the patient's health deteriorates

R. Sridaran et al. (Eds.): ASCIS 2025, CCIS 2819, pp. 256–269, 2026.
https://doi.org/10.1007/978-3-032-17834-3_19

when left untreated. Electrocardiograms and phonocardiograms are utilized for finding diseases and are less expensive [1] (Rani et al. 2021). Figure 1 represents heart disease types. CAD is called coronary artery disease where the artery blockage helps in supplying blood with oxygen towards the heart. [2] Due to this blockage, the blood supply to the heart is reduced, making it available for less oxygen. In this way, plaque accumulates and the arteries are finally blocked. While considering cerebrovascular diseases, blood vessels get blocked while supplying the brain with the blood. Only limited blood and oxygen reach the brain because the supply of blood is reduced. In this way, the cells in the brain are affected and leakage of blood surrounds the brain [2]. When the arteries are blocked while carrying blood towards the limbs, the supply gets minimal thereby affecting the limbs in diseases such as peripheral artery. Pain is caused in the legs and hips accompanied by cramps and it also affects the calf muscles of an individual (Riyaz et al. 2022).

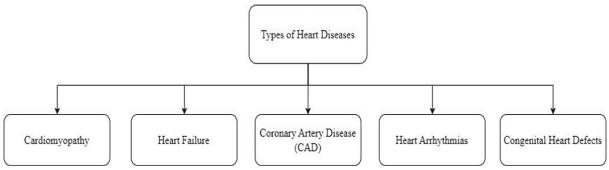

Fig. 1. Heart Diseases with its Types

Children are often affected by heart diseases such as congenital ones where the growth of the fetus is improper which occurs due to birth defects. [3] Chromosome abnormality also contributes to yet another factor that causes the disease. Weakness in the heart results due to artery blockage as a result of which the blood is not pumped properly leading to failure of the heart. This in turn leads to an individual's death [3]. The artery block affects the heart and makes it weak by which the pumping of blood across the circulatory system also gets reduced. [4] Failure of the heart also causes death of an individual and the failure of the heart is further classified as chronic type in addition to acute ones. When this failure occurs immediately it is termed an acute type whereas, in the case of chronic ones, blood pumping is not proper. Improper heartbeat results in arrhythmia where the beat of the heart is faster which affects the basic functioning of the heart. The supply of oxygen is also reduced which results in arrhythmia (Mamun et al. 2021) [4].

The functionality of the heart is affected by these diseases and it is shown by a variety of symptoms. [5] Pain in the chest along with discomfort occurs during this disease when there is pressure in the chest. This pain keeps spreading towards the shoulders besides arms in addition to the neck. While carrying out the physical activity, shortness of breath also occurs and at times certain people may have slight dizziness as the pumping of blood remains irregular towards the heart. In case of failure of the heart, the legs swell as the fluid gets retained in addition to wheezing. When the person gets severely affected, it may result in a heart attack which requires immediate monitoring of patients [5].

The estrogen effect helps women in lowering the risk related to heart disease while compared with men where the risk is higher. The level of cholesterol is raised when

estrogen level rises with decreased menopause and based on age it keeps on increasing. So, age is yet another risk to be considered while considering the diseases related to the heart. [6] Body fat keeps on increasing when there is a lower rate of metabolism accumulating fat in the human body. When the diet becomes unhealthy and lifestyle is improper, it may result in obesity causing heart disease. When the arteries become narrow, accumulation of plaque is more resulting in major risk. Blood vessels are also affected due to the habit of smoking in humans as it reduces the oxygen level in blood resulting in clots. This also affects the blood-pumping process for the heart [6]. Diabetic patients are also easily affected by this disease as the level of glucose being increased, hardens the blood vessels (Warsi et al. 2024).

The count of patients being affected by diseases related to the heart keeps on increasing in India affecting citizens of senior age. Models from machine learning help in finding the presence of diseases related to the heart to save the patients from serious illness. In this way patients may be treated successfully thereby avoiding the progress of disease to the advanced stage. Conventional techniques help in detecting the disease based on the symptoms observed in patients as a result of which intervention may be late too. Analysis of datasets is done with ML with the utilization of records related to healthcare, information about patient genetics, factors associated with their lifestyle in addition to data used in imaging. These help in the identification of patterns besides the factors of risk that are not able to be observed by the clinicians. [7] By this way, patients with risks are being identified prior to their symptoms. The complex data as well as with higher dimensions are being handled by the models in the domain of ML whose predictions are accurate by which patients can provide predictions in a personalized manner. They differ from the conventional methods in such a way of handling the situations (Salau et al. 2024) [7].

Based on the profile of the patient, treatment is customized and recommendations are given for preventing the disease at the earlier phase. Improvement of models in ML happens over time and the capability of continuous learning assists the data available newly for accurately making predictions besides reliable results. [8] Wearable technology in addition to applications based on mobile health is utilized for implementing ML to help in detecting diseases sooner. This can be achieved by monitoring the patients continuously besides indicators of health. By collecting data and performing analysis, users are alerted in addition to providers in healthcare for finding the presence of disease [8]. In this way, treatment can be made easier by setting strategies in addition to policies to handle critical situations. The outcome of improvisation for cardiovascular health is an advancement in technology and helps patients across the globe.

Objectives

- To develop an optimized predictive model for cardiovascular disease diagnosis using the Novel Nesterov Accelerated Gradient (NNAG) approach.
- To improve classification accuracy by integrating the Novel Gradient Boosting Classification (NGBC) algorithm for severity-based categorization.

2 Literature Survey

Existing approaches are reviewed for predicting the diseases affecting the heart to analyze the gaps in research for the proposal of an effective model.

Among the living organisms, one of the important organs for survival is the heart. The diseases affecting the heart need to be diagnosed correctly and predicted with better prediction. When the disease is left untreated, it may even result in a person's death. [10] The rate of death is increasing in an exponential manner making the necessity of proposing a model for effectively predicting the disease. One of the significant branches of AI is machine learning, ML supports prediction for any event type based on the natural events occurring. Computation of accuracy is done by utilization of algorithms in machine learning to predict diseases in the heart. The algorithms utilized include decision trees in addition to linear regression as well as SVM. The dataset is downloaded with the help of the UCI repository. Both training along testing are performed (Singh et al. 2020) [10].

The model for predicting the diseases affecting the heart needs to be developed for better accuracy results and this stands to be a challenging task. Lack of sufficient expertise and improper diagnosis of the diseases are the major pitfalls in several countries. This leads to the development of a model for predicting this disease at the earlier stages to support the decision taken with the records of patients available digitally. [11] The classifiers from ML with better accuracy are utilized for investigation and the models are compared with the other models based on accuracy as well as performance. The classifier with better accuracy compared to other models is recommended for diagnosis purposes. The score is computed for every feature that is related to prediction algorithms followed by their ranking which helps in better prediction. The dataset is taken by the usage of Kaggle with the algorithm utilized for classification including k-NN besides the decision tree in addition to the random forest [11]. The value of accuracy in addition to sensitivity is also higher when compared with the other ones for prediction (Mamun et al. 2021).

The rate of mortality is affected by diseases such as those targeting the heart and it has become a threat to their personal life. When this prediction is done at the earlier stages, the individual is also given treatment and saved. These diseases are not able to be accurately identified by clinical experts as a result of ML models providing a solution for accurately making predictions. Sectors of the healthcare industry have utilized models from the domain of ML and help in predicting the diseases of the heart. [12] The dataset utilized for examination is Cleveland and the techniques from data mining including regression in addition to classification are employed. For examination purposes, the algorithms from ML employed are random forests besides decision trees in addition to the hybrid approach by combining both models. The level of accuracy is 88.7% when performing prediction by utilization of a hybrid approach (**Kavitha et al. 2021**) [12].

The health of a patient deteriorates when the individual gets affected by heart disease thereby raising the need for models for performing detection. The research aims to investigate the complaints related to cardiac health along with the utilization of algorithms from ML. The dataset chosen for analysis consists of various parameters such as age, level of cholesterol in addition to blood pressure, and so on. Various techniques from ML are utilized including decision trees as well as logistic regression for analysis

purposes. Some of the techniques used are point selection as well as cross-validation for improvisation of model delicateness. This helps the healthcare clinicians also to analyze the results at the earliest stages and take appropriate measures based on this. Validation of models is also necessary for the analysis of system efficiency (Swathisree et al. 2024).

The diseases related to the heart are analyzed so that the cardiologists can adequately treat the patients. Applications in the field of ML help in the recognition of patterns among the data. Misdiagnosis is reduced by performing the classification process with the help of classifiers from ML. The research focuses on the development of a model for the prediction of diseases related to the heart by which the rate of fatality is reduced. Clustering is done with k-modes and the overall accuracy is improvised. Various ML models included for examination are random forests besides XGBoost in addition to decision trees and so on. The hyper tuning of parameters is done with the GridSearchCV for optimization of the result. The dataset consists of instances of count 70,000 and the training is performed with a policy of 80:20. The classifiers obtained an accuracy level of 86% for the decision tree and the AUC with the decision tree has 0.94%. Among all the algorithms taken for investigation, multi-layer perceptron besides cross-validation while considering the value of accuracy of 87.28% (**Bhatt et al. 2023**).

Human society has recently been affected by diseases related to the heart and this has emerged as the biggest problem. As this kind of illness affects individuals, the treatment opportunity is very limited for them. The prediction model helps in identifying the disease at the earlier phases, as a result of which the treatment can be started before. This in turn saves the life of a human. With the implementation of a feature selection method in order to select the features that are relevant. The methods employed for classification include decision trees besides random forest in addition to gradient boosting employed with the dataset as well as features that are selected. Comparison of the proposed model is done with models working based on the selection in a backward manner along with models based on the elimination of features in a recursive manner. These results show the efficacy of the proposed model while comparing it with the others (Lakshmi et al. 2024).

3 Dataset Description

The database popularly mentioned by Kaggle is cardiovascular disease with major feature types as follows, initial one is factual data observed from patients, assessment through medical examination as the second feature, and subjective data categorized from person to person as the third type of features are involved. Table 1 represents the description of dataset dispensing on feature identification.

These features are fetched from the database for predicting cardiovascular diseases with various kinds of patients along with 70,000 records with necessary features. Labeling the required features from the table. Are considered to represent the severity of cardiovascular disease. A type of data is ordinal or nominal based on the data as integer, Boolean and so on which are assessed during the review of affected patients. The selection of parameters is determined based on the performance and analysis for measuring the disease based on severity. The number of features helps to determine the optimization where factors depend on the categorical or assessment data which are highlighted in Table 1.

Table 1. Dataset Description based on identification of feature

Feature Name	Description	Type
Age	Entity Derived Attribute E	Integer
Height	Entity Derived Attribute	Integer
Weight	Entity Derived Attribute	Float
Cholesterol	Observation Attribute	Severity level 0 is assigned for low; 1 is assigned for medium; 2 is assigned for high
Glucose level	Observation Attribute	Severity level 0 is assigned for low; 1 is assigned for medium; 2 is assigned for high
Shortness of breath & fatigue	Clinical Symptoms Assessment with Categorical or binary type	Boolean
Blood Pressure level	From the medical examination Diastolic or Systolic	Integer
Smoking/Drinking	Subjective type	Binary

4 Proposed Work

The stochastic gradient descent (SDG) optimization algorithm handles the huge size of databases and is efficient in estimating any random data without using the entire data set. Randomness was involved in the learning procedure where each iteration mostly relied on SGD classification. To overcome the randomness and limited iterations proposed model addressed as a Novel Gradient.

Boosting Classification (NGBC) is suitable for accurate predictions that are visualized in Fig. 2. Machine Learning approaches majorly handle complex data with relationships between each pattern that require prediction. From the dataset, relationships are based on several samples involved and trained according to the size of the records. Since medical problems are based on a huge amount of data and high dimensionality selection also requires data to be analyzed initially.

Data Processing Interpretation and Encoding

The dataset from the description of cardiovascular diseases is in binary format and Boolean format which can be considered for objective and assessment processing. Predictions of heart diseases from the attributes of 11 and 70000 records are involved with the subset information along with the categorical data. Many researchers focused on the subsets where the target column indicates the various classes with the level of difference between the two main classes. The first class is glucose level and the second class is cholesterol level which illustrates the basis of disease severity. The attribute chosen for

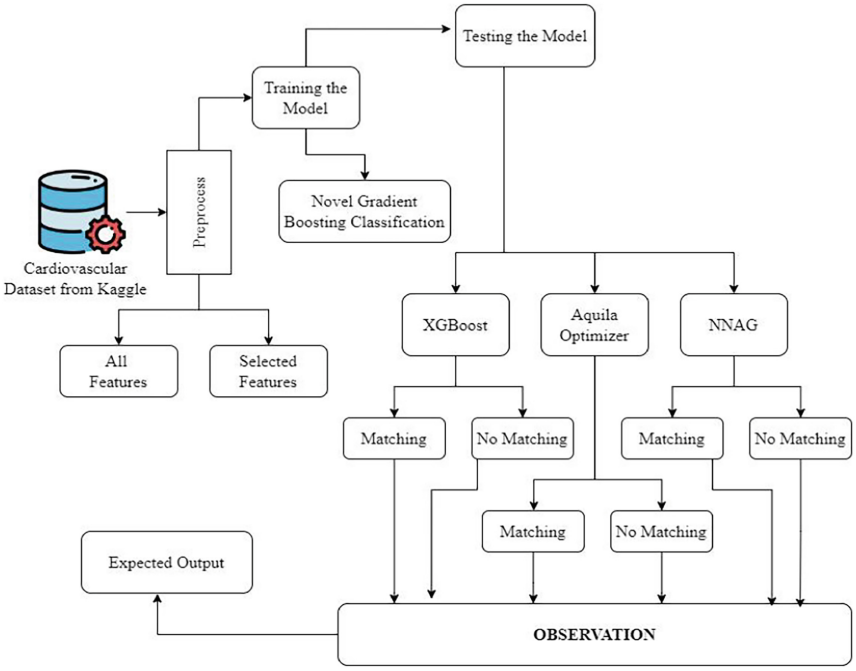

Fig. 2. Proposed Model NGBC

finding the risk factor is based on deviations such as 0 defining low, 1 defining medium, and 2 defining high heart disease.

Novel Gradient Boosting Classification

Each attribute is observed where the risk factor is identified based on defects and features distributed. An Ensemble ML-based classifier applied with the multiple features learned from the boosting model. The proposed model Novel Gradient Boosting Classification is compared in training a sequence of regular models that are applied to improve the previous results without overfitting. Each process is implemented by fitting the proposed model to the opposite loss function in gradient which is negative compared to the previous model. At the end of the process, prediction is finalized by combining the ensemble model based on their results. When the complexity increases in human health conditions by dynamic changes in cholesterol variation or heart rate deviation overfitting can cause.

$$\text{Input} : \text{Data}\{\text{Chi, hri}\}\text{j} \;\&\; \text{i} = 1,\ \text{Loss function Ls(hri, F(ch))} \tag{1}$$

Extracted features from the dataset are evolved from column Cholesterol and column Glucose levels which are observed from the 70000 records based on the target attributes and their loss function. Equation (1) defines the parameter chosen to calculate the likelihood of the previous learning logistic model. From the probabilistic results based on prediction (pr) and target value hri variation is observed continuously.

To achieve the prediction accurate likelihood should be increased to avoid loss function. The formulation used to calculate the log with an equal likelihood of achieving better by multiplying the overall function using a negative value.

In the proposed work predecessor with the help of a unique predictor minimizes the errors regularly. Gradient boosting on individual epochs for its iteration-based compilation fitting to a new predictor can enhance the error that occurred in the previous term addressed as residual. From the 11 features and their instance classes, initial prediction is observed and the target features are observed from the log values that are deviated from original and false values. From both the values estimation of the base which performs logistic probability function efficiently. Based on the continuous log difference the prediction works according to the instances from the residual calculation and prediction range. There are two labeled terms training and testing which make decisions based on the multiple instances derived from the same classes for making accurate predictions.

Optimization Using Novel Nesterov Accelerated Gradient (NNAG)

I. **Novel Nesterov Accelerated Gradient (NNAG)**

1. **Evaluate Gradient:**
   Implement the gradient of function as loss in terms of referring lookahead points that are considered as the extrapolation of the suitable features which are mentioned as current selection by choosing momentum term with its values.
2. **Update Velocity:**
   From the calculation of gradient update, the velocity which incorporates the range with the lookahead point can support in anticipating the future position.
3. **Feature updation:**
   Change the model features by adjusting the value which was updated in the velocity, this adjusted velocity can help to minimize the loss value in performing the function.

XGBoost Optimizer

1. **Evaluate Loss:**
   Operate to calculate the loss based on the number of iterations that are currently functioning using the values that are predicted and compared with the true label of the cardiovascular dataset.
2. **Update Tree Structure:**
   To build the new decision trees and construct the same iteratively by optimizing a regularized objective function. It also includes both the loss function and a complexity term.
3. **Update Predictions:**
   Update the predictions by adding the outputs of the new decision trees to the ensemble, effectively improving the model's accuracy.

Aquila Optimizer

1. **Evaluate Performance:** Use the Aquila optimizer to enhance the prediction performance by selecting the best features and optimizing the model parameters.
2. **Update Weights**: Continuously refine the model weights through iterations to achieve better predictive accuracy.
3. **Feature Selection**: Enhance the model's capability by optimizing feature selection, which helps in reducing overfitting and improving generalization.

II. Nesterov Accelerated Gradient (NAG) for Cardiovascular Heart Disease Prediction

1. **Evaluate Gradient:** Compute the gradient of the loss function at a lookahead point. This involves predicting the outputs of the model with the current weights adjusted by the momentum term and then calculating the gradient of the loss function at this extrapolated point.This step helps in anticipating the future position and making more informed updates.
2. **Update Velocity:** Update the velocity using the gradient calculated in the previous step. The velocity update rule incorporates both the momentum from the previous iteration and the gradient at the lookahead point:

$$\text{velt} + 1 = \mu\text{velt} - \eta\nabla\text{f}(\theta\text{t} + \mu\text{velt}) \tag{2}$$

   where velt + 1 is the updated velocity, μ is the momentum coefficient, η is the rate of learning, ∇f(θt + μvt) is gradient at lookahead point that is highlighted in Eq. (2).
3. **Update Parameters**: Adjust the model parameters using the updated velocity:

$$\theta\text{t} + 1 = \theta\text{t} + \text{vt} + 1 \tag{3}$$

   where, θt + 1 is the parameter which is the updated vector, θt is the current parameter vector, and vt + 1 is the updated velocity.

This update moves the parameters towards the minimum of the loss function more efficiently which is mathematically shown in Eq. (3).

NNAG with XGBoost and Aquila optimizer comparison involves iterative updates for optimizing the functions. NNAG focuses on refining gradient-based parameter updates using momentum for faster convergence, whereas XGBoost builds and adds decision trees iteratively to enhance the model's predictive power. In the context of predicting diseases such as those in heart, these methods are used to optimize different aspects of the model training process, ultimately improving classification accuracy.

5 Results and Discussion

Nesterov Accelerated Gradient (NAG) optimizer delivers competitive performance metrics of accuracy, precision, and recall when applied to cardiovascular disease prediction. Although XGBoost exhibits robust convergence properties, NNAG outperforms it in

accuracy due to its superior handling of structured data and the ability to capture complex interactions. Aquila Optimizer, on the other hand, shows promising results with efficient feature selection and faster convergence, contributing to balanced performance across various metrics.

Fig. 3. Comparison of performance metrics using NNAG

However, XGBoost and Aquila Optimizer offer distinct advantages over NNAG that can enhance predictive capabilities in specific circumstances. Figure 3 represents the analysis of comparison regarding performance for the proposed algorithm and other existing algorithms.

Every Deep Learning model is trained with 70% of the training approach and a balance 30% for testing in terms of proposed model efficiency. To enhance 5-fold cross-validation with training results are composed for effective selection that can improve the efficiency. There are steps used for performing the model which are shown below:

1. With random values, data is shuffled initially
2. Split the data into necessary groups probably to apply 5-fold improvisation five groups are categorized.
3. For individual groups:

Four folds of the data are utilized in case of training, as well as the remaining fold is utilized to estimate the model performance.

Performance measures including accuracy besides precision in addition to recall were evaluated for each model. These traditional classification performance metrics are based on confusion matrix values: TP which stands for True Positives, FP called as False Positives,

TN termed to be True Negatives, and FN which stands for False Negatives.

Added with confusion matrix parameter AUC (Area Under the Curve) for the ROC termed as Receiver Operating Characteristics curve was plotted as shown in Fig. 4.

The performance metrics are defined as follows:

- **TrueP (Positives):** Instances count where the prediction of disease existence is done by the model correctly.
- **TrueN (Negatives):** Instances count where the prediction of disease non-existence is done by the model correctly.
- **FalseP (Positives):** Instances count where the prediction of disease existence is done by the model incorrectly.
- **FalseN (Negatives):** Instances count where the prediction of disease non-existence is done by the model incorrectly.
- **Accuracy:** Instances are predicted in a correct manner as ratio
- (TrueP + TrueN) to all instances
- (TrueP + TrueN + FalseP + FalseN). Formulated as

$$\text{ACC} = (\text{TrueP} + \text{TrueN})/(\text{TrueP} + \text{TrueN} + \text{FalseP} + \text{FalseN}) \tag{4}$$

We compared the performance of models optimized with the Nesterov Accelerated Gradient (NAG), XGBoost, and Aquila Optimizer. Equation (4) computes the number of accurate results shown in fig. And precision value is computed based on the ratio of the instances that are predicted in a correct manner to the total number of instances that are predicted performed in Eq. (5).

$$\text{Precision} = \text{TrueP}/(\text{TrueP} + \text{FalseP}) \tag{5}$$

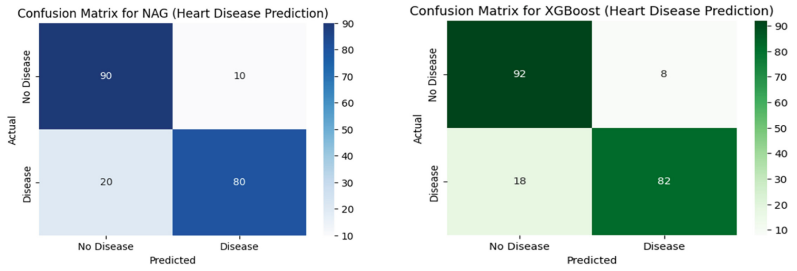

Fig. 4. Confusion matrix comparison of NAG and XGBoost

Figure 4 presents a confusion matrix comparison of NAG as well as XGBoost. To find the recall based on the presence, the ratio of predicted count of correctly positive instances to entire instances for the original class.

$$\text{Recall} == \text{TrueP}/(\text{TrueP} + \text{FalseN}) \tag{6}$$

The computation on all instances with the present class is done with the help of Eq. (6). Each optimization technique showcased unique strengths. NAG demonstrated strong convergence properties, XGBoost excelled in accuracy and handling structured data, and the Aquila Optimizer showed balanced performance with efficient feature selection and faster convergence.

By comparing actual and predicted classifications, a confusion matrix is utilized for evaluation of the performance while considering a classification algorithm. Classification

of heart disease severity, the confusion matrix implemented using the Novel Gradient Boosting Classification (NGBC) and Novel Nesterov Accelerated Gradient (NNAG) algorithms for accurate prediction.

The structure of confusion matrix as shown in Fig. 4 is:

- **TrueP:** Prediction of positive numbers correctly
- **TrueN:** Prediction of negative numbers correctly
- **FalseP:** Prediction of positive numbers incorrectly (T I error)
- **FalseN:** Prediction of negative numbers incorrectly (T II error).

Based on this structure, the calculation based on the proposed model is shown below.

Table 2. Confusion Matrix for NNAG model

	Predicted Positive	Predicted Negative
Actual Positive	TrueP = 90	FalseN = 10
Actual Negative	FalseP = 20	TrueN = 80

From Table. 2 the necessary results are obtained to find the accurate results using NNAG technique. This curve plot illustrates the precision value against the recall value based on the threshold value given. It shows the quantified mean value of precision achieved throughout the process and it is summarized by average precision.

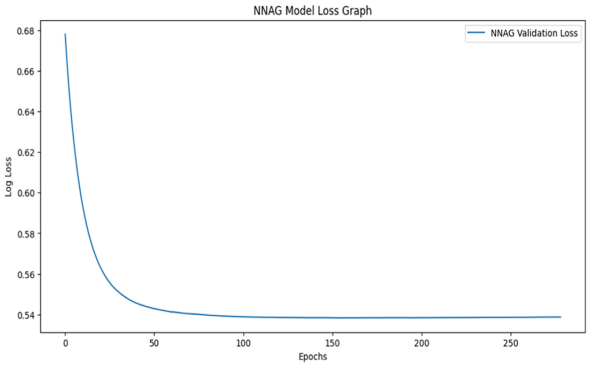

Fig. 5. Recall and its loss based on the Proposed model

NNAG model loss graphs define changes occurring at the time of the epoch. As the loss is lower, it represents that the proposed NNAG model enhances the performance, the predicted and actual data measures show the efficiency of the proposed model. Figure 5 presents the recall and its loss based on the proposed model.

Figure 6 presents the ROC curve using NNAG. This ROC curve illustrates conversions among rates of true positive as well as rate of false positive. It quantifies overall capability of model with the difference among classes such as positive as well as negative.

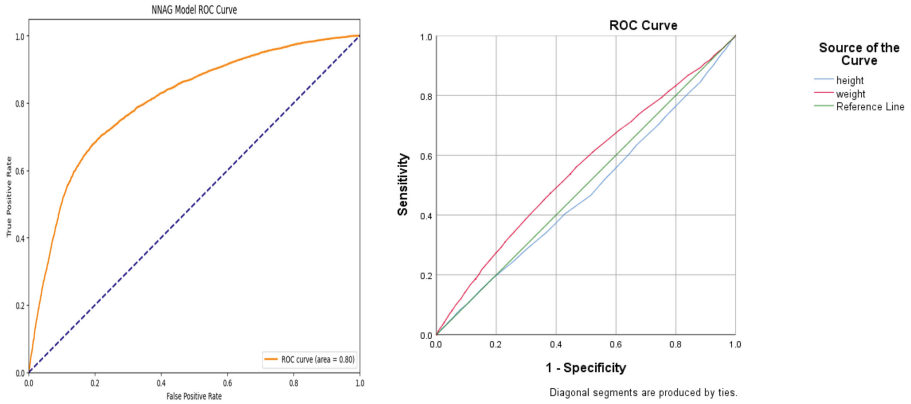

Fig. 6. ROC curve using NNAG

It is a probability curve, and AUC measures how well a model can distinguish between classes. An increased AUC indicates better performance when predicting cardiovascular disease using NNAG. It is plotted using TPR called as TrueP_Rate on y-axis and FPR called as FalseP_Rate on the x-axis. The TPR, synonymous with recall, computes the proportion of correctly recognized actual positives, while FPR indicates the proportion of incorrectly recognized actual negatives identified like positives. Models optimized with NNAG, XGBoost, and Aquila were evaluated to ensure robust cardiovascular disease detection.

6 Conclusion

Neural networks are frequently used to handle medical complications, such as detecting and diagnosing urgent health issues. Cardiovascular conditions afflict patients worldwide, needing early detection and treatment. Various machine learning classifiers have been used to predict heart disease, but many of them have produced erroneous findings. The suggested Novel Gradient Boosting Classification (NGBC) technique is critical for preprocessing the dataset and accurately classifying severity levels. The model is rigorously trained and tested, and it achieves an astounding accuracy of 94.8%, indicating its usefulness in precise prediction. To improve performance analysis, measurements including precision, recall, and confusion matrix are used. A comparison with XGBoost and the Aquila Optimizer illustrates the superiority of the suggested Novel Nesterov Accelerated Gradient. The comparison with XGBoost and the Aquila Optimizer demonstrates the superior performance of the suggested Novel Nesterov Accelerated Gradient (NNAG) technique for enhancing classification accuracy. This study suggests including NNAG extensively enhances prediction consistency and gives more information about cardiovascular disease classification. The findings highlight the importance of early detection and precise classification in eliminating serious medical conditions. This study provides a significant decision-support tool for healthcare providers to better diagnose heart disease by harnessing machine learning breakthroughs. Future study can look at further advances by incorporating deep learning techniques and real-time

patient monitoring, ensuring that predictive analytics for cardiovascular health improve continuously.

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