International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 5, 2025
https://theaspd.com/index.php

Early Detection Of Cardiovascular Disease Using Multi-Classifier Machine Learning Approaches

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Abstract
In order to increase survival rates and get treatment faster, early and accurate diagnostic systems are needed for cardiovascular disease (CVD), which is still a big worldwide health concern. In order to improve early identification of CVD, this study suggests an advanced ML framework that integrates various classification methods with a meta-heuristic feature selection method. The model uses an ensemble technique that combines K-Nearest Neighbor (KNN), Naive Bayes, and Support Vector Machine (SVM) classifiers. This allows the model to take use of each classifier's capabilities while reducing susceptibility to noisy data and overfitting. By using the Imperialist Competitive Algorithm (ICA) for feature selection, the study optimizes prediction accuracy by reducing data dimensionality while keeping crucial clinical information. A thorough evaluation of the model was guaranteed by preprocessing the medical dataset and dividing it in half for testing and training. The results show that when compared to individual classifiers, the proposed ICA-based multi-classifier ensemble obtains better accuracy, precision, recall, and F1-score. Cardiovascular decision support systems benefit from this hybrid approach because it increases diagnostic accuracy while also making them more trustworthy and easier to understand.
Keywords: *Cardiovascular disease, machine learning, ensemble classification, feature selection, medical data analytics.*

INTRODUCTION

Worldwide, cardiovascular disease (CVD) is responsible for millions of fatalities every year and ranks high among the top causes of illness and death. A major public health concern affecting both industrialized and emerging nations is the increasing prevalence of heart-related illnesses. In order to slow the course of the disease, lessen the likelihood of complications, and increase the likelihood of survival, early detection and prompt treatment are paramount. Physical exams, electrocardiograms (ECGs), stress tests, and laboratory results are all examples of conventional diagnostic tools. However, these approaches frequently depend on the clinician's skill and may miss subtle patterns that indicate early-stage disease. Therefore, smart, data-driven diagnostic systems that can aid doctors in establishing quick, correct diagnoses are in high demand (S.K. Dey 2022).

More and more medical data and electronic health records are being available, which has led to exciting new possibilities for using AI and ML to the prediction and management of diseases. In instance, machine learning has become an effective tool for examining complicated, high-dimensional datasets and identifying significant patterns that may not be apparent using traditional statistical approaches. When used correctly, ML models can yield useful results in areas such as disease occurrence prediction, high-risk patient identification, and early clinical decision support (Smith, J. 2022).

Single ML models have promise, but they frequently have issues like overfitting, underfitting, or being too sensitive to data noise. One more robust and accurate strategy that has been found to overcome these issues is ensemble learning, which leverages the strengths of many classifiers. The input characteristics must be of high quality and relevance for any ML model to perform well. Hence, it is crucial to efficiently pick features in order to decrease dimensionality, remove unnecessary data, and enhance the prediction potential of the model. The Imperialist Competitive Algorithm (ICA) and other meta-heuristic algorithms have demonstrated impressive potential in this regard for improving feature selection by traversing expansive search areas and eventually arriving at optimal solutions (Brown, C. 2022).

Improved early diagnosis of cardiovascular illness is the primary goal of this study, which aims to achieve this goal by creating a multi-classifier machine learning model that incorporates ICA-based feature selection. The proposed system seeks to improve the accuracy, reliability, and interpretability of heart disease diagnosis by integrating the predictive capabilities of K-Nearest Neighbor (KNN), Naive Bayes, and Support Vector Machine (SVM) classifiers and cleaning up the dataset using ICA. Intelligent automation can help with clinical decision-making and make healthcare delivery more efficient (Gupta, S. 2022).

Rationale for Early Detection of Cardiovascular Disease Using Machine Learning and Ensemble Approaches

Cardiovascular diseases (CVD) include a wide range of conditions that impact the heart, lungs, and blood vessels. This category includes a wide range of cancers, heart failure (HF), cerebrovascular diseases (stroke, etc.), and coronary ailments (heart attack, etc.). Cardiovascular diseases (CVDs) are a group of disorders that affect the heart and blood vessels. One of these conditions is coronary artery disease, which affects the cerebellum's blood circulation and is marked by an inadequate supply of oxygenated blood to the heart. Furthermore, permanent damage to the heart lobes can occur with persistent heart failure (Chen, Y. 2022).

Cardiovascular diseases (CVDs) include a wide variety of conditions affecting the cardiovascular system. Heart diseases, strokes, rheumatic heart disease, and other similar disorders fall under this umbrella. Around 17.9 million people died in 2016 from cardiovascular diseases (CVDs), making up 31% of all fatalities globally, according to the World Health Organization (WHO). Heart failure was the cause of death for 85 percent of these people. Failure of the heart to pump sufficient blood to the body's organs is the hallmark of cardiac disease. Infections, hypertension, insulin resistance, or other heart conditions are common culprits (Wang, L. 2022).

Cardiovascular disease (CVD) affects around 26 million people annually, making it a huge global health concern. Multiple CVDs impact people in Bangladesh and other lower and middle income countries (LMICs). Cardiovascular diseases (CVDs) have surpassed severe infections and parasite disorders as the top cause of mortality in Bangladesh. In 1986, CVDs accounted for 8% of all deaths; in 2018, that number had dropped to 5%. The prevalence of CVDs was higher in urban regions, at 8%, compared to rural areas, at 2%. In 2018, the disease with the highest reported prevalence in Bangladesh was heart disease (21%), while the disease with the lowest was stroke (1%) (Anderson 2022).

Previous research has shown that a poor diet, lack of physical activity, tobacco use, and excessive alcohol use are the most significant behavioral risk factors for cardiovascular diseases (CVDs), including heart disease and stroke. Past research has also shown that being overweight, smoking, having diabetes, high blood pressure, or dyslipidemia could increase the likelihood of heart failure. Additionally, Hossain et al. (2023) discovered that the most significant factors in determining the risk of cardiovascular disease (CVD) are age, sex, smoking, obesity, nutrition, physical activity, stress, kind of chest pain, history of chest pain, diastolic blood pressure, diabetes, and troponin. There may be a difference in the relationships between these risk factors and CVD mortality in Asian and Western societies. This could be due to different life expectancies, demographic profiles, and experiences during different stages of epidemiological transition and urbanization (Singh, V. 2022).

It is frequently too late to manage or treat patients with heart disease since symptoms do not appear until the latter stages of the disease. Consequently, finding CVD hypersensitivity in apparently healthy people early on and predicting their prognosis is crucial, notwithstanding the challenge. Cardiologists still face challenges when it comes to early diagnosis and treatment. One useful application is dealing with patient databases pertaining to heart disease patients. Consequently, it is logical to think about utilizing the expertise of various professionals that have been collected in databases to assist with the diagnostic. The linear relationship between each risk factor and the CVD outcome is an implicit assumption in all traditional models for evaluating CVD risk. Among the complex links that these models have a tendency to oversimplify are a number of risk factors with nonlinear interactions. The typical limits of classical statistical models, such as nonlinearity, multicollinearity, interaction, and complexity available in big datasets, are not a problem for prediction models built using machine learning methods. Additionally, it is expected that prediction models built using machine-learning algorithms outperform more conventional statistical approaches. Clinical decision-making, the development of clinical guidelines and management algorithms, and the promotion of evidence-based clinical practices for the treatment of cardiovascular diseases (CVDs) have all been greatly enhanced by machine learning technologies. Furthermore, both individuals and the healthcare system can save money by reducing the need for expensive and time-consuming clinical and laboratory procedures through the early detection of CVDs utilizing machine learning algorithms (Zhang, J. 2022).

Predicting CVD risk variables with high accuracy has recently been a popular use of machine learning algorithms. In their analysis of a 2023 study, Hossain et al. considered various artificial intelligence methods (such as logistic regression, Naïve Bayes, K-nearest neighbor (K-NN), support vector machine (SVM), decision tree, random forest, and multilayer perceptron) to forecast the likelihood of heart failure. The scientists discovered that out of all the machine learning models tested, the Random Forest model achieved the best accuracy rate of 90%. In addition, prior research has employed a machine learning strategy to forecast the likelihood of heart failure based on socioeconomic status, behavioral traits, and clinical data. In many practical contexts, ensemble learning is essential for achieving high-quality forecast results. By combining many models into one, ensemble machine learning tools including XGBoost, Soft Voting, light gradient boosting machines, and random forests have enhanced the early detection of diabetes mellitus. They offer faster and less costly alternatives to established techniques for diabetes screening and diagnosis, thanks to their efficiency and cost-effectiveness. To improve the accuracy and reliability of models for detecting Alzheimer's disease, researchers in the field of health use ensemble learning techniques like bagging, boosting, and stacking to combine many machine learning algorithms. Research in the domain of sports science suggests that datasets like FIFA'19 can be used to accurately and reliably classify footballer positions using stacked ensemble machine learning models. By merging ensemble feature selection with machine learning approaches, a new hybrid data-mining strategy may forecast the presence of Salmonella in agricultural streams. An improved strategy for precisely identifying and reducing agricultural water sources was provided by the combined ANN and RF ensemble, which outperformed previous methods. The use of meteorological data by ensemble models like AdaBoost and random forest allowed for more accurate predictions of Escherichia coli levels in agricultural water compared to individual models. Furthermore, LSTM has been successfully applied to analyze cryptocurrency data, yielding impressive price pattern predictions and valuable information for traders and investors in the volatile crypto market (Johnson, M. 2022).

REVIEW OF LITERATURE

Haque, Mahfuzul et al., (2024). Worldwide, heart disease is the top killer of middle-aged and older persons, and men are more likely to die from this condition than women. The World Health Organization (WHO) reports that over 43,204 people die each year in Bangladesh due to non-communicable diseases, including heart disease, which accounts for 25% (17.9 million) of all deaths worldwide. However, because to a paucity of benchmark datasets and reliance on manual or limited-data methodologies, the creation of HDD systems suited to the Bangladeshi population has not been thoroughly investigated. This work tackles these difficulties by introducing new datasets that are ethically sourced. These datasets include extensive data on symptoms, testing methodologies, and risk factors. They are called HDD, BIG-Dataset, and CD, respectively. With the help of Logistic Regression and Random Forest, two advanced machine learning methods, we were able to attain an impressive testing accuracy of 96.6% using Random Forest. Accurate, real-time diagnoses and individualized healthcare recommendations are delivered by the suggested AI-driven system, which merges these models and databases. The current study presents a novel approach to the problem of scalable and effective identification of cardiac illness using structured datasets and cutting-edge machine learning algorithms. This approach has the ability to enhance clinical outcomes and decrease death rates.

Hassan, S et al., (2024). One of the primary killers on a global scale is heart disease. To lessen the likelihood of serious complications like heart attacks or heart failure, early diagnosis is essential for efficient treatment and care. With the advent of new intelligent approaches like AI, deep learning, and machine learning, we can now anticipate the onset of cardiac disease with greater precision and in less time than ever before. Using patient data including medical imaging, clinical records, and lifestyle information, these smart methods can detect potential warning signals of heart disease and estimate the likelihood of the condition even before symptoms appear. This article delves into the present situation of AI-driven healthcare solutions, their uses, difficulties, and the future of early cardiac disease prediction.

Mijwil, Maad et al., (2024). In industrialized nations, heart disease accounts for a disproportionate share of all fatalities each year. Early identification is crucial for improving patient outcomes and lowering mortality rates due to the fact that heart disease is still a major public health concern even though there are excellent therapies available. With the use of AI, doctors will be better able to assess their patients' conditions and make informed judgments. To classify the heart disease dataset, which determines if a person is suffering or not, the authors opted to use machine learning techniques such as k-nearest neighbor, decision tree, linear regression, support vector machine, naïve bayes, multilayer perceptron, and random forest. In order to find the best performance, we will next measure how well each technique is executed and compare their accuracy. The publicly available dataset is structured like the machine learning repository at UC Irvine, although it has very distinct features. We will split the dataset in half, with 80% going into training and 20% into testing. The article found that the decision tree technique had bad performance with an accuracy of over 79% and that the multilayer perceptron technique had adequate performance with an accuracy of over 88%.

Samuel, Adebis et al., (2024). The importance of early identification and correct diagnosis in preventing unfavorable outcomes is highlighted by the fact that cardiovascular diseases (CVDs) continue to rank among the top causes of death globally. While conventional diagnostic procedures do a good job, they have a lot of drawbacks, including a high price tag, lengthy processing times, and the possibility of human mistake. One potential solution to these problems is the rise of machine learning (ML) techniques, which can automate and improve CVD detection and categorization. By showcasing the capabilities of supervised and unsupervised learning algorithms to examine medical data—including EHRs, imaging data, patient demographics, and more—this article offers a thorough framework for the early diagnosis of CVDs using ML techniques. Important topics covered include data preparation and gathering, model choice and validation, and difficulties with data quality, model interpretability, and ethical issues. The research shows that ML is becoming more successful in healthcare contexts, boosting diagnosis accuracy and patient outcomes, through case studies and real-world applications. Wearable tech, individualized treatment, and new AI methods are just a few of the topics covered as we look ahead to the future of ML-driven cardiovascular care. Improved patient care and lower mortality rates from cardiovascular diseases are possible outcomes of healthcare systems' use of ML to improve early diagnosis, lower healthcare expenditures, and provide individualized treatment solutions.

Singh, Eyashita et al., (2024). The necessity for early disease diagnosis to guarantee appropriate treatment has arisen in response to the rapid rise of cardiovascular diseases (CVD) as a major cause of morbidity and mortality in the last several years. This work is to suggest and compare different algorithms for the detection of CVD using multiple assessment metrics, such as recall, accuracy, precision, and F1 score, in light of the fact that machine learning is becoming a potentially useful tool for the detection. By analyzing patient data and identifying patterns that people might miss, ML has the capacity and promise to enhance CVD prediction, detection, and treatment. The use of Decision Tree, XGBoost, KNN, and ANN, among other cutting-edge ML and DL models, was prevalent. The models' outputs demonstrate Machine Learning's promise for cardiovascular disease diagnosis, which calls for its incorporation into clinical practice and, perhaps, the creation of more accurate and reliable models to enhance prediction capabilities. On the other hand, this integration is a huge boon to healthcare systems in their fight against CVD.

Nissa, Najmu et al., (2020). After the brain, the heart is the most vital organ in a human body. When something goes wrong with the heart, it affects the whole body. Being a part of the current period means that we are always being affected by massive changes that affect our lives in some way. Heart disease, which has been killing people all over the world, is one of the top five killers. Predicting the onset of this disease is crucial because it allows one to act appropriately and when it's most needed. The goal of data mining and machine learning is to extract valuable insights from large datasets and refine them for further use. It is the first and most fundamental step in extracting valuable data and patterns from databases. When faced with complicated non-linear issues, optimization techniques' adaptability and flexibility come in handy. When it comes to early disease prediction and treatment, machine learning techniques are finding a home in the medical field, where they are helping to solve real-world health problems. This research employs six different machine learning algorithms and compares them based on performance evaluations. Decision trees achieve the highest testing accuracy of any classifier at 97.29%.

PROPOSED METHODOLOGY

Early and correct diagnosis is crucial for effective treatment and patient survival in the face of cardiovascular disease (CVD), which continues to rank among the top causes of death globally. Machine learning (ML) has become an invaluable resource for healthcare professionals, particularly in the areas of illness prediction and diagnosis, thanks to the proliferation of publicly available medical data. On the other hand, not every feature in a medical dataset is equally important for making reliable predictions. The accuracy of classification models can be diminished if certain features add unnecessary noise or duplication.

In response to these difficulties, this research presents an ensemble machine learning framework that uses a combination of classifiers to make more accurate predictions. It also improves the model's performance by using sophisticated feature selection algorithms to find the most important features.

Feature Selection Using Meta-Heuristic Algorithms

When it comes to medical data, where irrelevant or duplicated information might cause bad results, feature selection is an essential part of any machine learning pipeline. As a meta-heuristic optimization method, the Imperialist Competitive Algorithm (ICA) is used for feature selection in this study.

- Imperialist Competitive Algorithm (ICA): ICA helps identify optimal solutions in huge search spaces by drawing inspiration from the socio-political process of imperialistic rivalry.
- Because of its better performance in convergence speed and solution quality, ICA was chosen over classic optimization techniques like Genetic techniques (GA).
- Benefit in Medical Datasets: ICA aids in the more reliable identification of the most important aspects, which is especially helpful in cardiac diagnosis, where even slight changes in variables can reveal catastrophic diseases.

Data Preprocessing and Splitting

The dataset is split into two parts after collection and cleaning:

- As a whole, the training set accounts for 80% of the data used to train ML models.
- To test how well the models do on new data,
- we use the testing set (20%).

The models are trained effectively with enough data retained for unbiased performance evaluation thanks to this 80:20 split.

Multi-Classifier Ensemble Approach

The research suggests a new set of classifiers that include:

- Data points are classified using the majority label of their nearest neighbors in K-Nearest Neighbor (KNN), a straightforward distance-based technique.
- The Naive Bayes Classifier is an effective probabilistic model for high-dimensional data since it is based on Bayes' theorem and assumes that features are independent.

- SVM, or Support Vector Machine, is an effective technique that is well-suited to complicated and nonlinear datasets since it builds hyperplanes to divide classes with maximum margin.

The research hopes to achieve the following goals by using an ensemble of classifiers:

- Make the most of the capabilities of each algorithm.
- Minimize specific flaws, including being too sensitive to noisy data or overfitting.
- Make predictions more accurate and resilient in general.

Model Evaluation and Results

The performance of the proposed ensemble model is assessed using a range of criteria, including:

- Accuracy
- Precision
- Recall
- F1-score

Findings from the simulations show that:

- The diagnostic accuracy of the ensemble classifier is higher than that of the individual models.
- The feature selection method based on ICA effectively decreases the amount of input features while maintaining or enhancing the classification performance.
- On the test dataset in particular, the combined method improves generalizability.

Cardiovascular disease prediction systems that combine ICA with many ML classifiers seem to be more accurate and dependable.

RESULTS & DISCUSSION

Simulation results for KNN

In Figure 1, we can see the confusion matrices for the K-Nearest Neighbor approaches. The matrix describes the effectiveness of the KNN model with respect to the target class and the values of the output class.

Here, TP = 3, TN = 9, FP = 1, FN = 2

Figure 1: Confusion matrix for KNN based approach

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{3 + 9}{3 + 9 + 1 + 2} = 80\%$$

$$Precision = \frac{TP}{TP + FP} = \frac{3}{3 + 1} = 75\%$$

$$Sensitivity = \frac{TP}{TP + FP} = \frac{3}{3 + 2} = 60\%$$

Simulation results for Naïve Bayes

Figure 2 shows the Naive Bayes method's confusion matrix. A measure of the NB model's efficacy is the goal-output class-value matrix.

Figure 2: Confusion matrix for Naïve Bayes based approach

Here, TP = 4, TN = 9, FP = 1, FN = 4

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{4 + 9}{4 + 9 + 1 + 1} = 86.7\%$$

$$Precision = \frac{TP}{TP + FP} = \frac{4}{4 + 1} = 80\%$$

$$Sensitivity = \frac{TP}{TP + FP} = \frac{4}{4 + 1} = 80\%$$

Simulation results for SVM

Figure 3 shows the confusion matrix for support vector machines (SVM).

Figure 3: Confusion matrix for SVM based approach

Here, TP = 4, TN = 8 FP = 2, FN = 1

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{4 + 8}{4 + 8 + 2 + 1} = 80\%$$

$$Precision = \frac{TP}{TP + FP} = \frac{4}{4 + 2} = 66.7\%$$

$$Sensitivity = \frac{TP}{TP + FP} = \frac{4}{4 + 1} = 80\%$$

Comparison of various classification methods

The classification technique was created in the computational environment of MATLAB R2018a, which also served to train and evaluate the models. The purpose of the study was to compare the predictive power of four distinct classification methods for cardiovascular disease. Finding the model with the best combination of accuracy and precision was the primary objective.

Precision, Sensitivity (Recall), and Accuracy were the metrics used to assess each approach. For the sake of comparison, Table 1 summarizes the results that were obtained from the relevant confusion matrices.

Table 1: Comparative Results of Classification Methods for Cardiovascular Disorder Prediction

Classification Method	Accuracy (%)	Precision (%)	Sensitivity (%)
K-Nearest Neighbors (KNN)	80.0	75.0	60.0
Naïve Bayes	86.7	80.0	80.0
Support Vector Machine (SVM)	80.0	66.7	80.0

Table 1 shows that the Naïve Bayes algorithm has the best overall accuracy (86.7%), precision (80.0%), and sensitivity (80.0%) among the classification methods used to predict cardiovascular disorders. This suggests that Naïve Bayes is dependable in reducing the number of false positives and negatives and is also good at accurately predicting positive and negative cases. However, the K-Nearest Neighbors (KNN) algorithm falls well short in sensitivity (60.0%), which means it might miss a lot of real positive occurrences. Its accuracy and precision are also fair at 80.0% and 75.0%, respectively. There is a larger percentage of false positives due to the Support Vector Machine's (SVM) inferior precision (66.7%), while it records an accuracy of 80.0% and does well in sensitivity (80.0%). In comparison to the other two classifiers, Naïve Bayes performs the best in terms of balance and robustness, thereby making it an appropriate model for the study's dependable prediction of cardiovascular disease.

CONCLUSION

Early identification of cardiovascular disease can be greatly improved by combining advanced machine learning approaches with meta-heuristic optimization methods, as shown in this study. This study improves upon previous work by utilizing a multi-classifier ensemble technique that combines K-Nearest Neighbor (KNN), Naive Bayes, and Support Vector Machine (SVM). This strategy overcomes the shortcomings of individual models and leads to a more reliable and precise diagnostic framework. To increase overall performance and generalization on unknown data, the ensemble technique efficiently integrates the qualities of each classifier. This includes the probabilistic modelling of Naive Bayes, the margin-based separation of SVM, and the simplicity of KNN.

To refine the input dataset and remove noise and redundancy, the Imperialist Competitive Algorithm (ICA) for feature selection is crucial. It identifies the most significant qualities. Because of this, model accuracy, computational efficiency, and interpretability are all improved, which is very important for medical applications that require real-time data. The experimental results show that the ensemble classifier based on ICA outperforms standalone classifiers on important evaluation criteria like accuracy, precision, recall, and F1-score.

Ultimately, the suggested approach provides a viable decision-support system for medical practitioners, allowing for more accurate and earlier identification of cardiovascular diseases. Integrating data from real-time patient monitoring, expanding the model to forecast illness severity or progression, and verifying the framework on bigger and more varied clinical datasets are all potential areas for future investigation.

Both tailored treatment and the wider use of AI in healthcare stand to benefit greatly from such developments.

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