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Predictive analytics: Unveiling the potential of machine learning and deep learning

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Abstract

Machine and deep learning methods have gained significant prominence in the healthcare industry, particularly for the prediction of cardiac diseases. The increasing prevalence of heart-related diseases underscores the necessity for proactive and accurate healthcare interventions. Machine learning, a data-driven approach, can play a crucial role in recognizing and addressing cardiovascular risks. To achieve this, researchers have utilized a range of classification techniques, such as Support Vector Machines, Random Forests, and Naive Bayes, to unravel the intricate aspects of heart disease prediction. Additionally, ensemble learning techniques, especially Stacking Technique, is employed to further enhance predictive accuracy. However, the ensemble approach has certain limitations. Therefore, confusion matrices are utilized for thorough evaluation and validation, offering better classifier performance. As research advances, prediction models aim to achieve higher accuracy and generalizability. Insights from confusion matrices can help researchers to make more robust and dependable predictions. Future research will investigate the deep learning models to detect subtle patterns in electrocardiogram data, with the aim of enabling earlier identification of cardiovascular conditions. Additionally, the integration of wearable sensor technologies holds promise for continuous risk monitoring and the development of personalized healthcare interventions. These technological advancements possess the potential to fundamentally transform the field of cardiac care, facilitating earlier disease diagnosis and substantially enhancing patient prognosis. In conclusion, the convergence of machine learning and deep learning models heralds a novel era for precision medicine, where data-driven insights empower stakeholders to tackle formidable challenges with unparalleled effectiveness.

Keywords: Artificial Neural Network, Cardiovascular Diseases, Data Analysis Pattern Classification, Data Mining, Heart Disease Prediction, Support Vector Machine

1. Introduction

Cardiovascular diseases represent a significant health problem and pose a substantial threat to the human lifespan. Annually, an estimated 17.5 million individuals succumb to heart disease. Given the vital role that the heart plays in our body and its centrality to our survival, health awareness campaigns, and clinical practices frequently involve assessing an individual's risk of coronary heart disease (Dangare et al., 2012). To develop a risk prediction model, longitudinal studies utilizing multivariate regression analysis can be employed. As the digital landscape continues to evolve, healthcare organizations face the complex task of managing and analyzing substantial data within their databases.

Data mining techniques and machine learning (ML) algorithms are crucial tools for analyzing diverse types of data in medical facilities (Faldu et al., 2019). As shown in Fig. 1, these algorithms can be directly applied to datasets to generate models or derive valuable insights and conclusions from the data. The risk factors for heart disease include age, gender, hypertension, tobacco consumption, hyperglycemia, abnormal electrocardiogram (ECG) readings, and chest pain. Other risk factors include the number and location of obstructed blood vessels, maximum heart rate attained, and the presence of ST depression on ECG. Obesity, hypertension, and poor eating habits are additional risk factors for heart disease.

Cardiovascular diseases (CVDs) are major contributors to morbidity and mortality worldwide, accounting for 70% of all global fatalities. CVDs were responsible for over 43% of all deaths, as per the Global Burden of Disease Study 2017. In high-income countries, an unhealthy diet, smoking, excessive sugar consumption, and obesity are common risk factors for CVDs. However, chronic diseases are on the rise in low- and middle-income countries. According to estimates, the global economic burden of CVDs was roughly USD 3.7 trillion between 2010 and 2015.

Approximately 17.7 million individuals worldwide die annually due to CVDs, according to WHO. Timely detection of health issues is crucial for reducing these fatalities. Conventional approaches for predicting CVDs involve a physician's evaluation or a series of medical tests like ECG, stress echo test, and cardiovascular magnetic resonance, among others. However, a significant amount of information is often hidden within existing healthcare data and can be leveraged to make informed decisions. It is possible to obtain the desired results by utilizing computer-based data and contemporary data-mining techniques.

Incorporating further data characteristics and considering the intricate nature of health has the potential to lead to innovative solutions for forecasting heart disease. In this study, we utilize Artificial Neural Networks (ANN) to predict heart diseases. The application of an ANN model in the initial diagnosis of heart disease is demonstrated in Fig. 2. ANNs are state-of-the-art ML algorithms which are capable of identifying relationships and trends in data. As a result, they are well-suited for predicting intricate medical issues such as CVDs. Our proposed strategies are based on the Cleveland Cardiovascular Disease dataset, which is available through a freely available ML repository hosted by UCI and Kaggle.

The data obtained was subsequently processed and utilized to train a model for ANN using supervised learning techniques. The algorithm was optimized to precisely predict the risk of heart disease in patients. The trained model was then assessed using a separate dataset to assess its routine (Mandal et al., 2017). The ultimate objective of this study is to develop a user-friendly interface that will enable medical professionals, including physicians and healthcare workers, to predict outcomes based on patient data. This proposed methodology has the potential to enhance the accuracy and speed of CVD diagnosis, allowing for timely intervention and enhanced patient outcomes. This initiative could have a significant impact on public health by contributing to the development of artificial intelligence (AI)-powered healthcare solutions.

2. Related Work

This study utilized the SMOTE technique to obtain class-balancing and correlation coefficients (Naseer et al., 2017). A standard scalar method was applied to standardize the data before the classifiers were implemented. The researchers evaluated the performance of their suggested models on diverse datasets against the existing research results. They stressed the need for improved data preprocessing strategies and a tailored hybrid model to attain satisfactory outcomes for predicting CVD. This study underlines the significance of dependable predictive models for CVD, given its status as a major cause of death globally. In summary, the research emphasized the superiority of the proposed hybrid model compared to conventional techniques in accurately predicting CVD. Utilizing ML algorithms and Internet of Things (IoT) technology, the model demonstrated the potential to enhance the detection of CVDs and influence real-world healthcare settings.

Abundant studies have been conducted in the healthcare sector to develop disease prediction systems using data mining and machine-learning algorithms. For example, Polaraju et al. (2017) showcased the efficacy of Multiple Linear Regression in predicting the risk of heart disease. This study exploited a dataset of 3,000 instances and 13 different features, which were categorized into two parts: 70% for training and 30% for testing. The results revealed that the regression method outperformed other algorithms in terms of accuracy.

The study by Agrawal et al. (2024) delves into the use of ML in predicting the probability of heart disease and implementing tailored interventions to enhance cardiovascular health outcomes. This emphasizes the significance of early detection and customized treatment approaches to reduce the global morbidity and mortality rates associated with CVDs. The study incorporated a comprehensive dataset

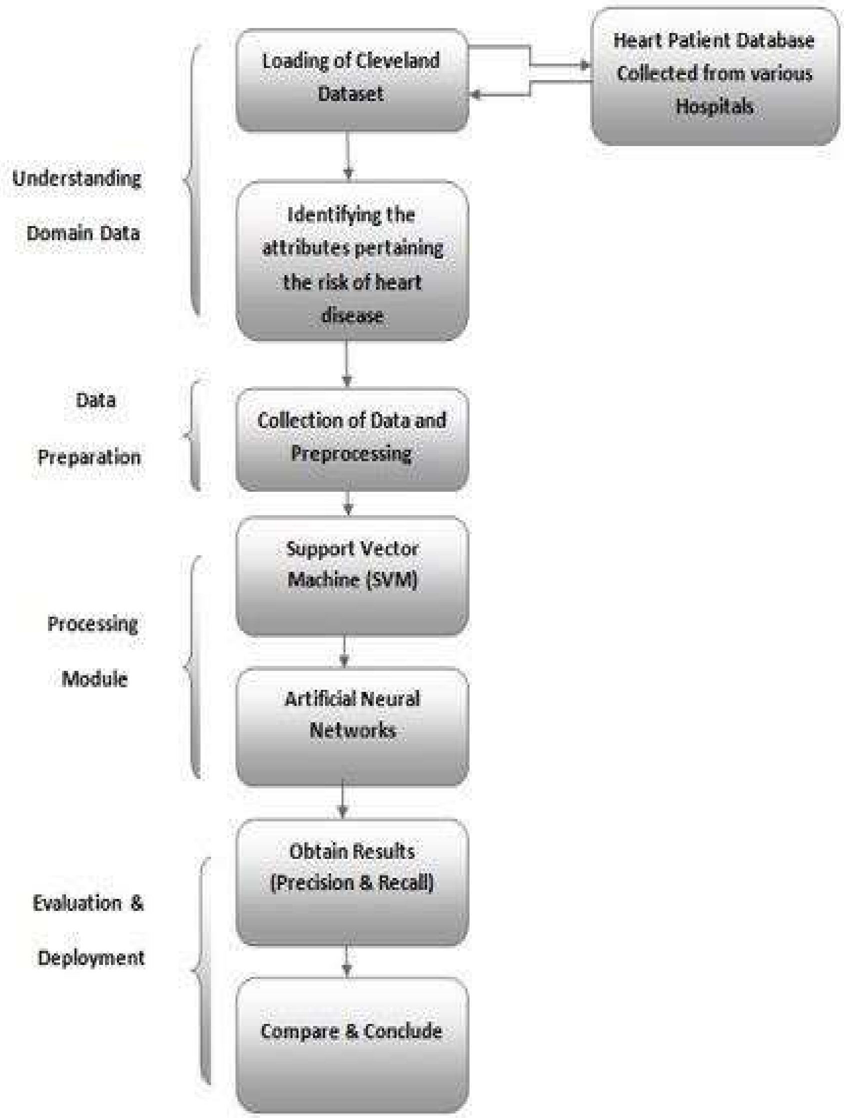

Fig. 1. Illustration of overall prediction of cardiovascular diseases.

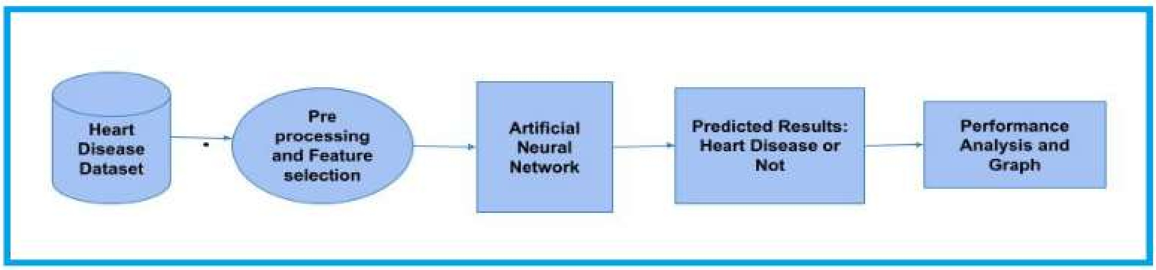

Fig. 2. Prediction of heart disease using Artificial Neural Network.

comprising various cardiovascular parameters to facilitate predictive analysis for identifying individuals at risk of developing heart disease. By leveraging machine-learning algorithms, healthcare professionals can proactively intervene and provide tailored strategies for individuals susceptible to CVDs, thereby improving patient outcomes and overall public health.

Rao et al. (2024) examined the capacity of ML algorithms in healthcare, especially in the field of diagnosing disease. This study emphasizes the importance of extracting valuable knowledge from healthcare datasets to improve the clinical decision-making processes. This article highlights the main usage of cutting-edge techniques for detecting CVDs in their early stages and it includes attribute selection and ensemble models. This study evaluated various algorithms in ML, like Sector Vector Machines (SVM), XGBoost, and Random Forest, for predicting heart disease. Additionally, this paper delves into the pros and cons of IoT-based applications in the prediction of heart disease. Ultimately, this study underscores the significant impact of ML and data mining in enhancing healthcare outcomes, reducing CVD mortality rates, and improving health policy through early disease identification and prevention strategies.

Chaudhary and Anwar (2024) delve into the potential of AI, including machine and deep learning (DL), to revolutionize the management of CVDs. AI offers advantages in detecting, diagnosing, and treating heart conditions, leading to enhanced personalized treatments with increased precision. The diagnosis and supervision of heart diseases can be transformed by integrating AI technologies into clinical practice. This review emphasizes AI's potential to enhance diagnostic techniques, such as echocardiography and ECG analysis. AI's role in improving CVD management is crucial for optimizing healthcare resources and improving patient outcomes. This study highlights the importance of interdisciplinary association among healthcare professionals, data scientists, and engineers to harness AI's potential in managing CVDs. The future of cardiovascular management relies on leveraging AI advancements and fostering collaboration among stakeholders. AI has a significant potential for transforming global health by addressing the increasing prevalence of CVDs. This study underscores the necessity for further investigation and collaboration to fully exploit AI's potential in cardiovascular medicine. Overall, AI holds promise for improved patient outcomes and more competent healthcare resource utilization in cardiovascular medicine.

3. Existing System

The current approach to predicting cardiac disease involves using various classification algorithms in ML, such as probabilistic classifier, SVM and Random Decision Forest. The extraction of meaningful insights from the abundance and diversity of large, complex datasets has long been a formidable academic challenge. The inherent "signal to noise" issues within these vast data repositories have made it exceptionally difficult to uncover the valuable information concealed (Maganathan et al., 2020). Advancements in computing power and more sophisticated predictive analytics techniques have revolutionized how organizations leverage their data assets. However, the widespread adoption of predictive analytics has been hindered by several challenges. As the volume, variety, and velocity of data continue to increase, the inherent uncertainty within the analytics process also grows, leading to a lack of confidence in the trustworthiness and accuracy of the results. This can result in hesitation in decision-making and the realization of the full benefits of predictive analytics. Predictive analytics, encompassing ML and DL algorithms, has emerged as a powerful tool for uncovering hidden patterns, discerning trends, and making precise forecasts. The proliferation of sensor-driven applications and the abundance of data have further amplified the potential of predictive analytics, empowering organizations to enhance their operational efficiency and effectiveness across diverse domains. Nevertheless, ensemble learning methods, a subset of predictive analytics, occasionally exhibit tendencies towards overfitting, which can lead to high accuracy on training data but subpar performance on unseen data. This may result in inaccurate predictions and unfavorable outcomes. Additionally, the complexity and capacity of ensemble learning techniques can present challenges in understanding the factors that contribute to predictions, making it difficult for healthcare professionals to integrate these models into their decision-making processes. Data bias is another critical issue that affects ensemble learning techniques, as imbalanced training datasets can lead to biased predictions, thereby compromising the precision and reliability of the forecasts. Moreover, the resource-intensive nature of this approach and the considerable computational resources required for training and fine-tuning may make it inaccessible in regions with limited access to high-performance computing and constrained financial resources. Finally, the necessity of expertise is evident in the case of ensemble learning methods, as they require a high level of proficiency in ML and data science to construct and fine-tune them, rendering these approaches less accessible to individuals lacking the necessary expertise. The limitations of existing ensemble techniques, such as SVM, Random Forests, and ANNs, in accurately predicting cardiac disease have been extensively explored in numerous studies. This underscores the potential of DL approaches to overcome the shortcomings of these traditional models and enhance the predictive accuracy in heart disease detection.

4. Proposed Methodology

The proposed approach leverages sophisticated ML technology, particularly an ANN, to accurately forecast heart disease occurrence. The advanced approach detailed in Fig. 2 entails developing an ANN prediction model capable of reliably identifying individuals at risk of contracting heart disease (Thansekhar et al., 2014). This method employs ANNs to forecast the likelihood of heart illness utilizing the well-known and extensive Cleveland Cardiovascular Disease dataset, which is widely accessible in both the Machine Learning Repository and Kaggle. The decision to utilize ANNs is grounded in their ability to effectively learn from large datasets and navigate intricate and noisy data, making them an ideal choice for medical diagnosis purposes. Since earlier years, ML and DL methodologies have emerged as crucial instruments in the prediction of CVDs. This section examines the assorted techniques that have been utilized, underscoring their advantages and disadvantages within the framework of CVD forecasting.

4.1. Machine Learning Approaches

A diverse array of ML algorithms have been widely employed in predicting cardiac diseases, leveraging their capacity to handle structured datasets. The most commonly employed algorithms include SVM, Random Forest, and Naïve Bayes.

4.1.1. Support Vector Machine

Support Vector Machines are known for their resilience in classifying intricate datasets, rendering them suitable for identifying risk factors associated with cardiovascular conditions. However, SVMs encounter challenges while dealing with high-dimensional data, mainly in the presence of noise, requiring the implementation of advanced preprocessing of data and feature selection techniques in order to overcome those limitations.

4.1.2. Random Forests

Random Forests represent a prominent ensemble learning approach that utilizes multiple decision trees to enhance classification performance. It has proven particularly effective in handling massive and imbalanced datasets in healthcare, which are frequently encountered in this domain. However, Random Forests may occasionally suffer from overfitting, a phenomenon where the model exhibits exceptional accuracy on the training dataset but experiences challenges in generalizing to unseen data.

4.1.3. Naive Bayes

The Naive Bayes classifier, a probabilistic model commonly applied in medical diagnosis, exhibits simplicity and effectiveness in specific scenarios, particularly when the underlying assumption of feature independence is met. However, this method may underperform when confronted with datasets characterized by correlated features, which are prevalent in the cardiovascular domain.

4.2. Deep Learning Approaches

Advanced DL techniques have demonstrated remarkable potential in analyzing complex, unstructured data such as ECG signals. These sophisticated approaches possess the capability to automatically extract and learn intricate patterns directly from the raw data without the need for manual feature engineering. The DL methodologies are ANN, Convolutional Neural Network (CNN), and Recurrent Neural Network.

4.2.1. Artificial Neural Networks

Artificial Neural Networks are fundamental components of DL. They are composed of multiple interconnected layers of artificial neurons, emulating the structure and function of the human brain. In the context of predicting cardiac diseases, ANNs can effectively learn from extensive ECG data, extracting crucial features allied with risk factors such as irregular heartbeats, ST-segment depression, and other abnormalities. However, a potential limitation of ANNs is their susceptibility to overfitting, particularly when trained on relatively small datasets.

4.2.2. Convolutional Neural Networks

To process the ECG signals, despite their typical application in image recognition tasks. By employing specialized filters that detect diverse patterns, CNNs can automatically identify features associated with cardiac conditions, such as arrhythmias and other heart function irregularities. This methodology proves effective for ECG signal classification due to CNNs' capacity to capture the spatial hierarchies inherent in the data.

4.2.3. Recurrent Neural Networks

Recurrent Neural Networks and Long Short-Term Memory (LSTM) are particularly well-suited for analyzing time-series data, such as ECG signals, owing to their capability to capture sequential information. LSTMs, with their capacity to retain long-term dependencies, are extensively utilized to predict the occurrence of arrhythmias or other cardiovascular conditions by effectively identifying temporal patterns within the ECG data.

4.3. Hybrid Deep Learning Approaches

Hybrid models, such as the Stacking Ensemble Learning Technique, combine traditional ML and DL techniques. They offer a promising approach to improving prediction accuracy.

4.3.1. Stacking Ensemble Learning Technique

The ANN model is designed for learning from preprocessed data and accurately forecasting the prospect of heart disease in patients, and its mathematical framework is inspired by the complex architecture of the human brain, which consists of neurons with components such as axons, dendrites, and synapses. The proposed system integrates a three-layered ANN model, which consists of an input layer, a hidden layer, and an output layer (Shakkera et al., 2024). This model has been applied as a web application utilizing the Flask web framework, which is accessible to any user, medical provider, or patient for the purpose of predicting the likelihood of heart disease. Fig. 3 shows the integration of ANNs into the Stacking Ensemble Learning Technique, which enhances its performance in predicting heart diseases. ANNs, known for their capacity to capture complex nonlinear relationships in data, serve as powerful additions to ensemble-based models. During the ensemble training phase, alongside baseline classifiers such as Decision Forest, SVM, Random Forests, and probabilistic classifier. Based on their input features, trained ANNs use their algorithms to generate predictions. These predictions, along with those from other base models, are fed into the meta-model for training purposes. The meta-model also uses these inputs to produce a final ensemble output, whether it be a classification decision or a probability score for the prospect of heart disease. This integration capitalizes on ANN’s ability of ANNs to discern intricate data patterns, thus complementing the strengths of simpler models. Through hyper-parameter tuning and optimization techniques, ANNs within the ensemble framework further refine predictive accuracy and robustness. Thus, by leveraging ANNs in Stacking Ensemble Learning, healthcare practitioners can gain a potent tool for precise heart disease prognosis, enabling proactive interventions and improving patient outcomes.

4.4. Detection of Cardiovascular Disease during The Embryonic Stage

Cardiovascular disease is a fundamental aspect of preventive healthcare in early detection, and the Stacking Ensemble Learning Technique, in combination with ANNs, reinforces this objective. Fig. 4 shows the CVD prediction analysis and highlights the primary objective of detecting CVD using a dataset with missing values to pinpoint critical features, such as age, hypertension, sex, and hyperlipidemia. After identifying these features, preprocessing techniques were employed to address the missing values through imputation and feature scaling to ensure scale consistency. The method of finding pertinent data is known as feature extraction, such as demographic data (age and sex), clinical measurements (blood pressure and cholesterol), and medical history (smoking status and family history), to build predictive models. Feature engineering refines this information by standardizing it, creating one-hot encodings for categorical variables, and generating interaction terms to capture complex relationships. Feature selection is guided by domain expertise, which ensures that the chosen features are both relevant and informative. Additional techniques, such as normalization, polynomial features, and dimensionality reduction, and also used to enhance the predictive authority of the dataset. The ultimate goal is to construct robust predictive models that can accurately diagnose disease for heart and aid clinicians in making decisions. Subsequently, various classifiers, including logistic regression and decision trees (Sharmila et al., 2017), were trained on their preprocessed data to approximate the likelihood of heart disease. Evaluating these classifiers using accuracy, precision, and recall metrics enables identification of the top-performing model. Finally, the most effective classifier was implemented to predict whether an individual was likely to have heart disease based on their feature values, which ultimately leads to enhance patient outcomes and timely interventions via a comprehensive approach.

4.5. Prediction Accuracy

Machine learning and deep learning approaches have emerged as critical tools for analyzing intricate health data. Combining ensemble learning techniques with SVM, RF, and ANNs aims to enhance the

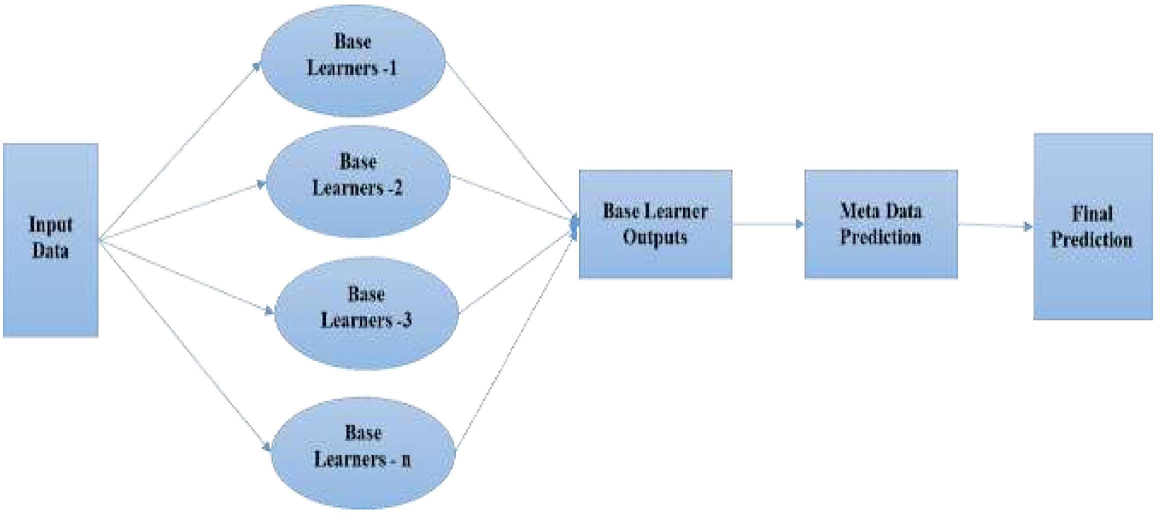

Fig. 3. Stacking Ensemble Learning Technique.

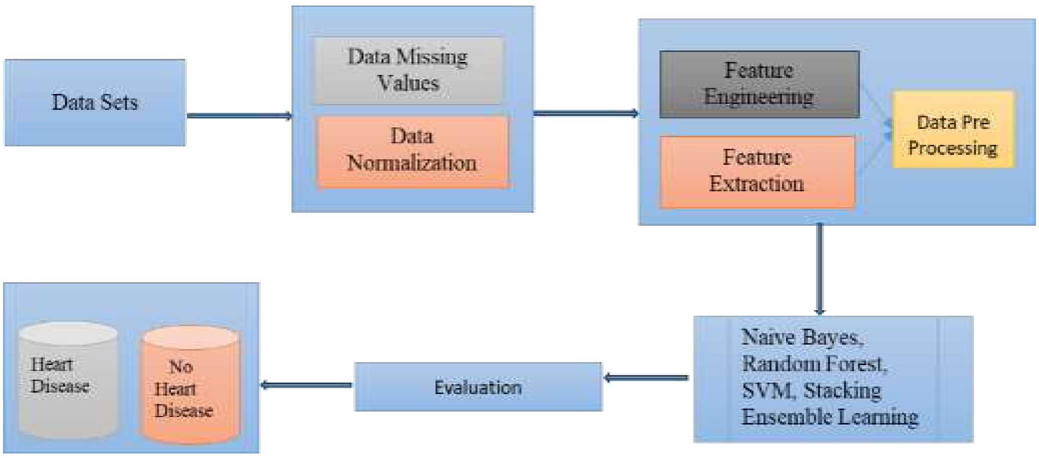

Fig. 4. Detecting cardiovascular disease.

predictive accuracy of heart disease detection by identifying subtle patterns in ECG data that may be overlooked by traditional analytical methods.

4.6. Complexity and Noise

Preprocessing techniques, such as feature extraction, dimensionality reduction, and noise filtering, play a vigorous role in addressing the encounters posed by noisy and high-dimensional medical data, like ECG data, for ML models. These preprocessing steps help to identify the most relevant and informative features, reduce the complication of the input space, and mitigate the effects of noise and artifacts, ultimately improving the predictive performance of the models for heart disease detection.

4.7. Early Detection and Intervention

The early identification of cardiovascular disorders is essential for mitigating severe health issues and enhancing patient prognoses. Advanced methodologies that leverage DL techniques aspire to analyze ECG data and other biometric indicators to detect early signs and markers of CVD. By harnessing the capabilities of these sophisticated ML approaches, clinicians can acquire valuable insights that facilitate timely medical intervention and proactive management of heart-related conditions, ultimately improving the prospects of successful treatment and disease prevention.

4.8. ANN-Based Prediction Advantages

Fig. 5 shows one of its key strengths in the model, which is its scalability. This capability enables the analysis of extensive datasets and population-wide evaluation (Hlaudi et al., 2014). It comprises 14 features, including age, gender, hypertension, tobacco consumption, hyperglycemia, abnormal ECG readings, and chest pain. This allows the identification of complex CVD risk factors and supports the implementation of targeted interventions on a larger scale. Another benefit of the ANN-based prediction model in an ensemble is its potential to reduce costs. By accurately identifying individuals at risk before disease progression to advanced stages, the healthcare expenses associated with severe treatments are

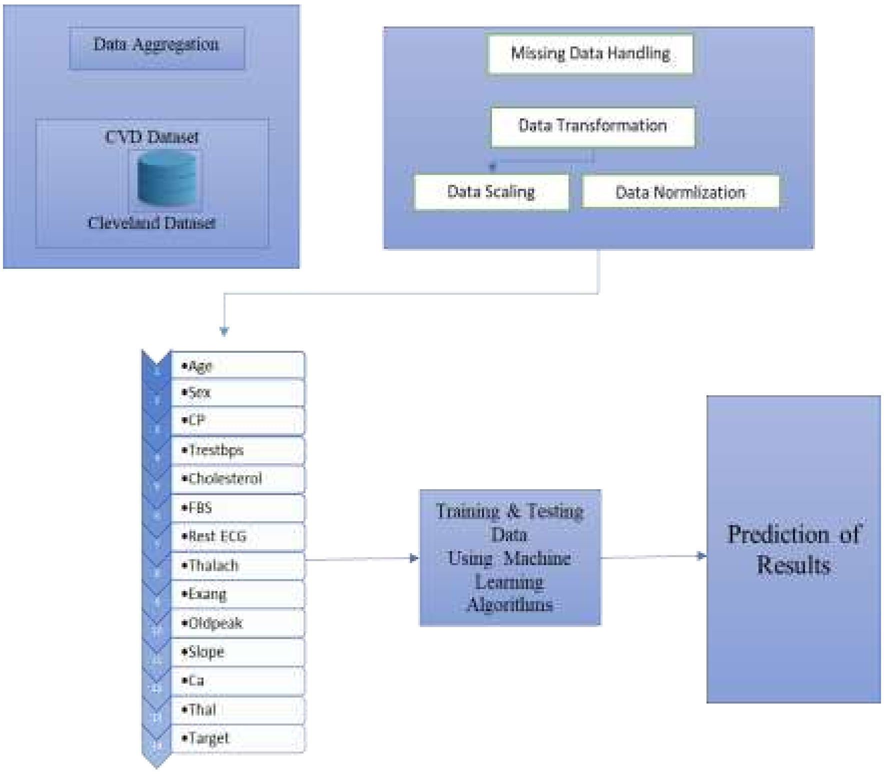

Fig. 5. Advantages of Artificial Neural Network.

minimized. This alleviates the financial burden on healthcare systems and financially benefits patients (Theresa, 2016).

Ultimately, the ANN-based prediction model within the ensemble aims to enhance patient outcomes. By accurately identifying at-risk individuals and facilitating early interventions, the ensemble reduces mortality rates and significantly improves patient well-being (Animesh et al., 2017). This transformative approach to cardiovascular healthcare highlights the pivotal role of the ensemble in improving patient outcomes and the overall healthcare system.

Fig. 6 shows that the proposed system has an impressive accuracy rate of 91.1%, thereby surpassing other existing models. It is also worth noting that the proposed system model may be pre-trained on ImageNet.

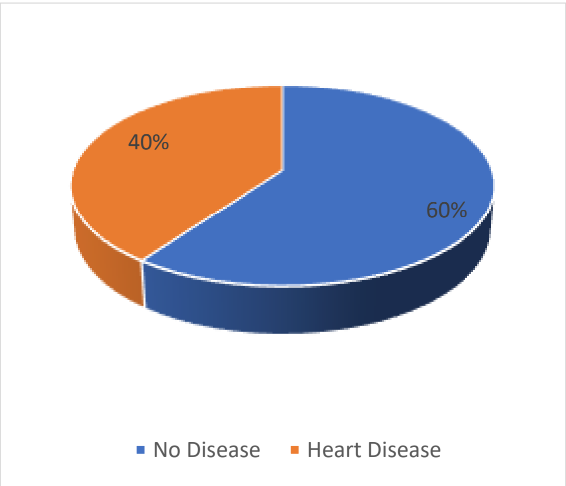

Fig. 6. Cardiovascular disease prediction.

5. Results and Discussion

This module evaluates the ANN model results and predicts the likelihood of heart disease in patients by using an actual dataset. Table 1 describes 14 features, including age, gender, hypertension, tobacco consumption, hyperglycemia, abnormal ECG readings, FBS, thalach, Exang, Oldpeak, Ca, Thai, and Target. Fig. 7 shows the result of training and validating the model once completed, and its performance was assessed using the test set, with the test set accuracy serving as a crucial performance metric.

5.1. Model Evaluation Using Confusion Matrices

In this study, performance evaluation metrics are confusion matrices generated for each ML algorithm employed, including SVM, Random Forests, ANNs, and hybrid models like the Stacking Ensemble Learning approach. Depth analysis provided a nuanced understanding of how effectively each model could distinguish between patients with and without heart disease.

5.2. Accuracy

Accuracy characterizes the total percentage of correct predictions made by the model. Despite a crucial metric, it can be misleading when dealing with imbalanced datasets, such as those commonly found in healthcare, where the number of non-disease cases may outweigh the disease cases.

5.3. Precision (Positive Predictive Value)

Precision represents the fraction of positive predictions that are truly correct. In medical applications, precision is crucial to minimize false alarms, ensuring that only patients at genuine risk are identified.

5.4. Recall (Sensitivity)

Recall measures the model's capability to correctly identify actual positive instances. A high recall value indicates that the model is effective at detecting the majority of individuals with heart disease.

5.5. F1-score

The F1-score represents the harmonic mean of the model's precision and recall. This metric is particularly valuable when seeking to strike a balance between precision and recall, especially in scenarios where the class distribution within the dataset is skewed or imbalanced. Fig. 8 shows a performance analysis of the confusion matrix, and Fig. 9 shows an overall comparison of the accuracy of various models. Our model Stacking Ensemble Technique achieved 99%, which involves the trained ANN model for future utilization, such as deploying it as a web application that healthcare professionals and patients can access to foresee the probability of heart diseases.

Table 1. Detailed description of the dataset, including its value ranges and data types.

No.	Feature Name	Feature Code	Description	Value Ranges	Data Type
1	Age	Age	Age in years completed	between 29 and 77	Numeric
2	Sex	Sex	Male: 1, female: 0	0 or 1	Nominal
3	Type of chest pain	CP	Typical angina: 1, atypical angina: 2 non-angina pain: 3, asymptomatic: 4	1 to 4	Nominal
4	Resting blood pressure	Trestbps	Patient's Resting Blood Pressure Range	94 to 200 mm Hg	Numeric
5	Serum cholesterol	Chol	Cholesterol level in mg/dl	126 to 564 mg/dl	Numeric
6	Fasting blood sugar	Fbs	Fasting Blood Sugar > 120 mg/dl (true:1, false: 0)	0 or 1	Nominal
7	Resting electro-cardiographic results	Restecg	Normal: 0, ST-T wave abnormality:1, Hypertrophy: 2)	0, 1 and 2	Nominal
8	Maximum heart rate	Thalach	Heart Rate of Patients	71 to 202	Numeric
9	Exercise-induced angina	Exang	Patient experienced angina during exercise(Yes=1, No=0)	0 or 1	Nominal
10	ST depression induced by exercise relative to rest	Oldpeak	Depression caused by exercise, Up sloping: 1, Flat: 2, down sloping: 3	1 to 3	Numeric
11	The slope of the peak exercise	ST segment Slope	Slope of peak exercise	1, 2, 3	Nominal
12	Number of major vessels (0–3) colored by fluoroscopy	Ca	Major Vessels colored by fluoroscopy with range 0 to 3	0 to 3	Numeric
13	Thallium	Thal	Represents thallium stress test, Normal:3, fixed defect: 6, reversible defect: 7	3, 6, 7	Nominal
14	Target	Target	Output, Heart disease present: 1, heart disease absent: 0	0 or 1	Nominal

6. Conclusions and Future Scope

In conclusion, predictive analytics, powered by ML and DL, holds immense promise in unlocking the hidden value within large, complex datasets. As the field of predictive analytics continues to evolve, addressing the challenges of uncertainty, overfitting, and accessibility will be crucial to realizing its full potential.

By continually improving the reliability, transparency, and scalability of predictive analytics techniques, organizations can harness the power of data-driven insights to drive strategic decision-making, enhance operational efficiency, and, ultimately, improve outcomes across a wide range of domains. In future research, incorporating wearable sensor technologies for continuous real-time monitoring of cardiovascular health is a promising area of study. Also, discovering progressive DL

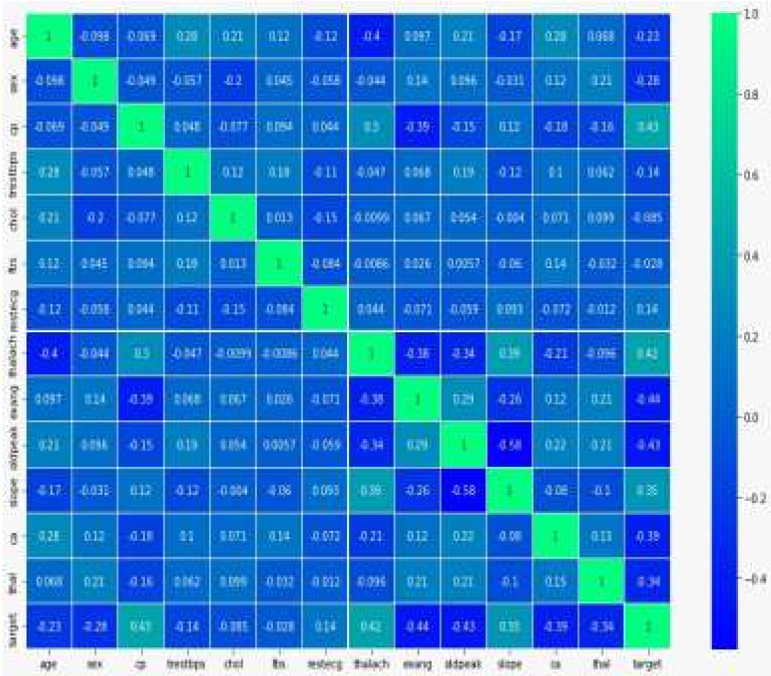

Fig. 7. Exploring correlated features in cardiovascular disease.

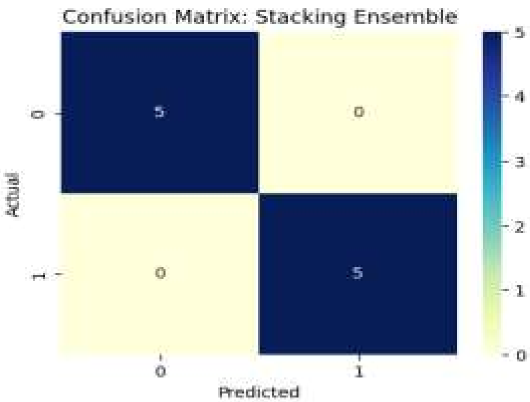

Fig. 8. Performance analysis of confusion matrix.

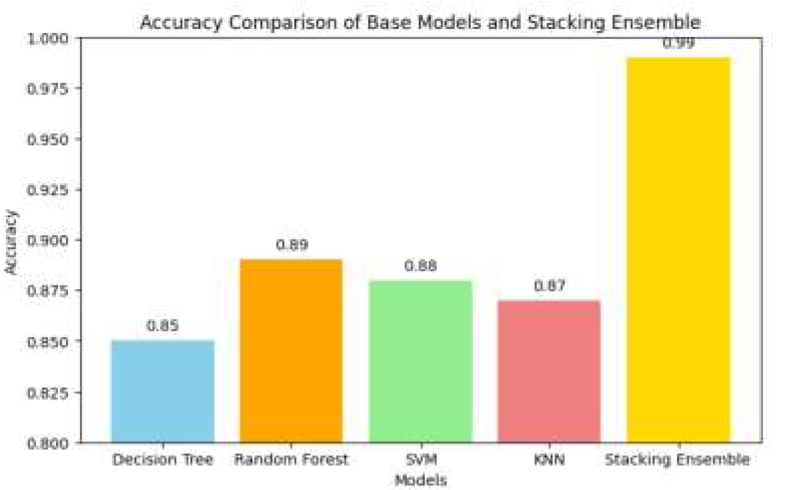

Fig. 9. Accuracy of stacking ensemble technique.

methods, such as graph neural networks for analyzing ECG signals, could further enhance the accuracy of disease prediction. Expanding the dataset to include diverse populations would improve the generalizability of the models. Investigating the potential of federated learning to enable privacy-preserving cardiovascular predictions is another valuable research direction. Finally, personalized healthcare interventions driven by AI insights could revolutionize early diagnosis and treatment of cardiovascular conditions. The Cleveland Cardiovascular Disease database was employed for training and estimating the algorithm, which resulted in the development effective model among various imperative-based combinations. Furthermore, we conducted a comparative analysis of accuracy and identified the optimal and balanced model.

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