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An Efficient Artificial Intelligence-Based Early Prediction of Heart Attack Using Deep Learning CNN and SVM Models

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ABSTRACT

Artificial Intelligence (AI) has become an integral component of modern Cardiovascular disease diagnosis, treatment planning, and risk stratification. Its transformative potential is particularly crucial in developing regions. Cardiovascular issues cause most deaths worldwide. The World Health Organization states that about 17.9 million people die annually. Medical specialists spend considerable time diagnosing to identify the reason behind symptoms. Moreover, doctors cannot always keep up with their patients. Machine learning can assist doctors in predicting heart diseases by utilizing global health sector data, thus strengthening the base of this technology. The proposed system emphasizes temporal

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data modeling through the integration of Parallel CNN (P-CNN) and Support Vector Machine (SVM) classifiers to enable the early detection of Heart Failure (HF). This hybrid architecture facilitates the development of an effective decision-support system for the accurate diagnosis of Congestive Heart Failure (CHF). The model was trained and evaluated using the UCI Machine Learning Heart Disease dataset, and its performance was benchmarked against state-of-the-art algorithms such as Artificial Neural Networks (ANNs) and Recurrent Networks (RNs). Empirical evaluations reveal that CardioHelp achieves outstanding predictive performance, with an accuracy of 97%, an F1-score of 93.4%, and a precision improvement of 0.8% compared to existing baseline models. Furthermore, when compared with advanced hybrid architectures—including CNN-RNN, CNN-LSTM, and CNN-BLSTM—the proposed framework exhibits accuracy enhancements of 2.35%, 1.34%, and 1.95%, Predicting heart disease accurately and quickly is important but difficult. Machine learning becomes highly effective in identifying and categorizing patients. Advanced machine learning and deep learning models, like SVMs and CNNs, can forecast patients' medical histories and general well-being. Heart disease predictions lower global death rates. While reducing the cost of medical care. Minimizing expensive hospital stays, long-term care, and urgent medical help can save lives and reduce family and societal stress. Using machine learning in healthcare can help find heart disease early, make sure patients get treatment on time, and help them live better lives. Moreover, using these technologies can help doctors make better decisions, increase the accuracy of diagnoses, and offer patients custom treatment plans

Heart disease is recognized as one of the complex and deadly illnesses affecting humans globally. In the United States, 11.2% of adults are afflicted by heart disease. The prevalence is even higher among individuals aged 75 and older, reaching 37.3%. Research indicates that nearly 80% of heart disease cases might have been avoided through early detection and lifestyle changes [1]. Sadly, heart disease remains the leading cause of death, yet it is also one of the most preventable conditions. Taking timely precautions can significantly lower the risk of heart disease. Unfortunately, a lack of adequate knowledge within the general population results in unnecessary fatalities. The economic impact is substantial, with heart disease costing approximately $417.9 billion between 2020 and 2021 [2]. This figure encompasses healthcare services, medications, and productivity losses from premature deaths. It is crucial to recognize that there is a considerable variation in risk levels among individuals with heart disease. The mortality rates from heart disease differ based on sex, race, and ethnicity. Below are the percentages of all deaths attributed to heart disease in 2021, categorized by race and sex [3, 4]. Several factors contribute to the ongoing challenge of heart disease, including lifestyle-related risks such as poor diet, lack of physical activity, obesity, high blood pressure, smoking, and diabetes. Importantly, these factors are controllable. Additionally, variations in social and economic status, restricted access to preventive healthcare, and an aging population exacerbate the issue. Despite advancements in medical treatment and increased public awareness, the rise in heart disease rates indicates that these efforts are still inadequate [5, 6]. Deep-learning models that are based on a single deep-learning architecture are solo deep-learning models. Models that are produced by connecting two or more deep-learning architectures are hybrid deep-learning (HDL) models.

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$$\ln fl_{it}^{+} = \sum_{j=0}^{t} \Delta \ln w^{T} x + \quad b_{it}^{+} = \sum_{j=0}^{t} \max(\Delta w^{T}{}_{ij,0}) + \epsilon_{it}$$

Eq (1)

$$\ln fl_{it}^{+} = \sum_{j=1}^{t} \Delta \ln w^{T} x + \quad b_{it}^{+} = \sum_{j=1}^{t} \max(\Delta w^{T}{}_{ij,1}) + \epsilon_{it}$$

Eq (2)

Role of Machine Learning in Healthcare

Machine learning (ML) and deep learning (DL) came to the rescue medical diagnostics has shown tremendous potential, particularly in predicting critical conditions like heart attacks. By processing and analyzing the large amount of data, Machine learning (ML) and multi-layered neural network models are useful in predicting heart disease [7, 8]. The ability to examine the early risk of cardiovascular disease (CVD) can help improve the patient's health and reduce the associated risks. Over the last decade, cardiovascular research has increasingly integrated advanced computational methods, including artificial intelligence (AI), machine learning (ML), and deep learning (DL) [9, 10]. In recent years, most cardiovascular prediction studies have implemented machine learning techniques (ML) like support vector machines (SVM), decision trees (DT), and naive Bayes (NB) [11, 12].

Still, it is actually challenging to harness the vast amount of clinical data and use it for model training. Implanting in clinical settings remains challenging, usually resulting in less accurate results [13, 14]. Deep Learning (DL), a specialized branch of machine learning (ML) that enables the processing of large amounts of data at a very high speed without any accuracy issues. In recent years, researchers and scientists have been continuously exploring the application of deep learning in the medical field, as they have achieved good results in other fields. For example, researchers have successfully used deep learning (DL) models, including, convolutional neural network (CNN), a Long Short-Term Memory (LSTM), and a CNN-LSTM to predict heart diseases using multiple data sets [15].

$$\ln fl_{it}^{+} = \sum_{j=2}^{t} \Delta \ln w^{T} x + \quad b_{it}^{+} = \sum_{j=2}^{t} \max(\Delta w^{T}{}_{ij,2}) + \epsilon_{it}$$

Eq (3)

In addition, many datasets have been developed by researchers to predict heart disease. Remarkable datasets such as the UCI Heart Disease Dataset, the Framingham Heart Study, the Heart Failure Clinical Records, and cardiovascular datasets play a pivotal role in heart disease Studies claim that the proposed feature selection method needs to be able to optimally balance the most relevant features in the dataset to improve the predictions. The authors suggested that a new feature selection method is needed to choose the best mix of important features in a dataset so that prediction performance can be improved. Many heart disease prediction models are not suitable for real-world clinical use because their inner workings are difficult to interpret. Open-source models can help make these tools more

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accessible, but some are still not available to the public. Without open-source software, it is harder for medical professionals to build predictive heart disease prediction systems [16]. Developing new techniques also requires collaboration among experts from different fields. It is important to figure out how these systems can work on real-time data without always needing a physician to supervise them. At present, many large medical institutions do not have strong predictive or early diagnosis systems in place [17].

Heart feature extraction

The investigation involves the extraction of diverse attributes from the medical data obtained via healthcare devices. The improvement of prediction accuracy is one step towards extending classical DL approaches with specific and interpretable functions [16]. In addition, DL can also be effectively used along with other technologies to enhance accuracy, feature selection, and data classification. Additionally, stochastic methods might be considered to enhance the performance of heart disease prediction. Nevertheless, such hybrid models could decrease the predictive performance. Furthermore, there is a dearth of standard criteria for selecting performance evaluation procedures and metrics that can be employed in assessing the effectiveness of new technologies.

$$J_i^{(b,t)} = \beta^{(b)}(S_i^{(b,t)}) \quad \text{Eq (4)}$$

$$J^{(b,t)} = \beta^{(b)} \times (W^{(b)} \times J^{(b-1,t)} + W^{(b)} \times J^{(b,t-1)}) \quad \text{Eq (5)}$$

Accordingly, the establishment of new test evaluation indicators and rigorous verification is beneficial to improve sterilization prediction models [18].

These datasets contain a vast number of attributes that help in the accurate prediction of heart diseases. Both changeable and non-changeable factors contribute to the prediction of heart disease. Non- changeable factors include gender, ethnic background, and family history. On the other hand, changeable risk factors such as cholesterol level, blood pressure, unhealthy lifestyle habits, and smoking can be altered and controlled through specific measures and medical treatment [19, 20]. These characteristics influenced the creation of large datasets, and researchers have made considerable efforts to refine and enhance these datasets.

Table 1 underscores the techniques for enhanced preventive care, early diagnosis, and lifestyle changes to mitigate both the health and financial impacts of heart attacks across the nation.

Table 1. Summary of existing techniques on heart disease prediction

Method	**Key Contributions**	**Precision%**	**Recall %**	**F1 Score%**	**Ref**
Traditional	Survey of	92	90.3	91.9	[21]

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ML techniques	existing approaches for heart disease prediction				
Supervised learning models	Heart disease prediction using supervised learning algorithms	82	91.2	91.1	[22, 23]
ML classification methods	Summarized classification techniques for heart disease prediction	88.2	94.5	91.3	[24, 25]
ML & soft computing	Overview of ML and soft computing approaches for heart disease prediction	92.6	94.8	91.9	[26, 27]
ML with multiple data modalities	Summarized heart disease prediction with ML using multiple data sources	90.5	90.3	92.6	[28, 29]
AI in cardiovascular CT	Reviewed AI-based approaches in cardiovascular CT and future implications	92.5	89.2	87.5	[30, 31]
Soft computing for heart disease	Studied use of soft computing in heart disease prediction and diagnosis	88.1	83.4	91.9	[32]
ML and DL algorithms	Analyzed different heart diseases using both ML and DL methods	86.4	90.3	85.6	[33]

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AI for inherited heart diseases	Reviewed applications of AI models in inherited HD	93.2	92.8	96.1	[34]
ML on ECG signals	Focused on ML techniques for heart disease diagnosis from ECG data	94.2	84.3	86.3	[35, 36]

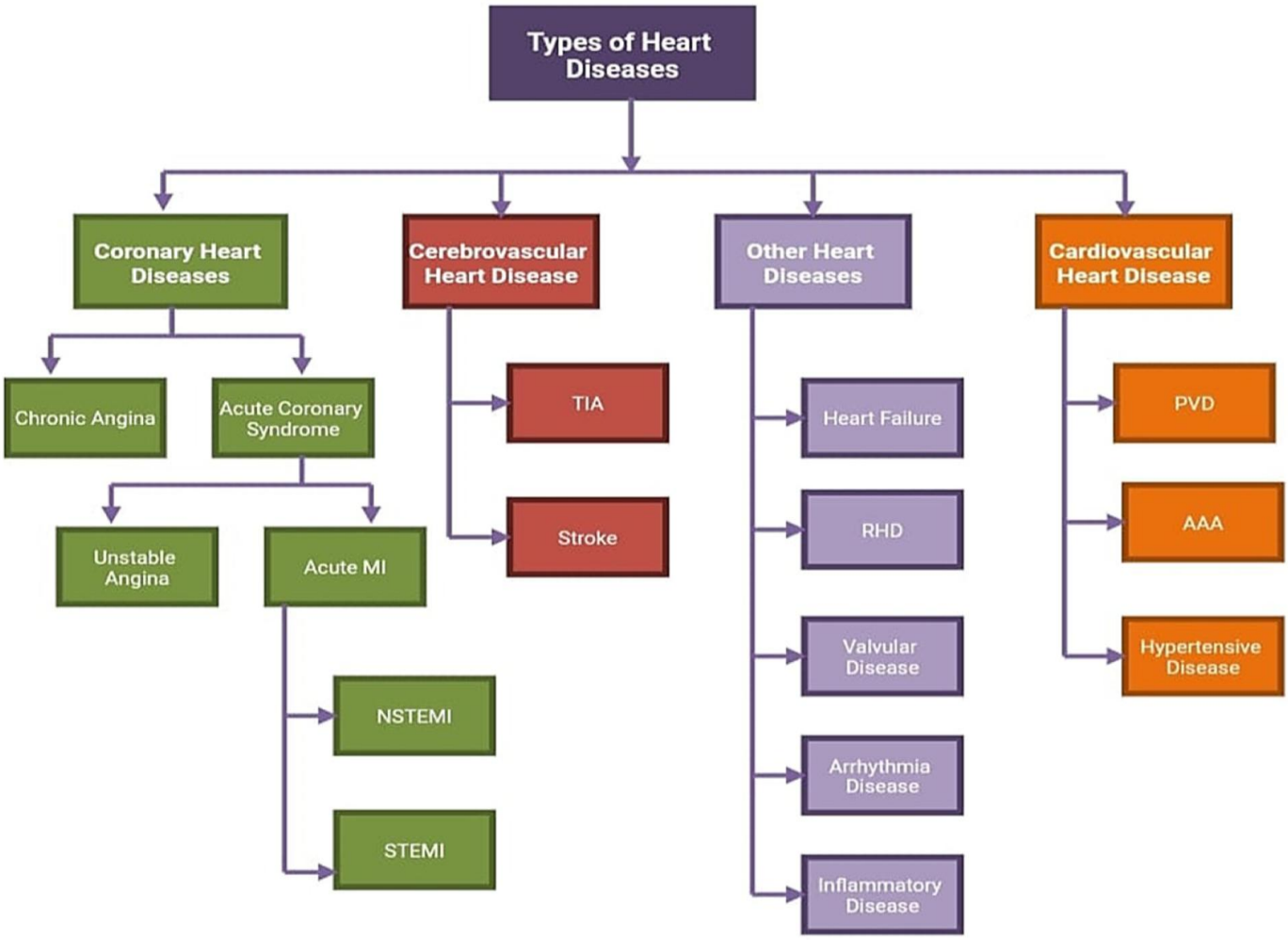

Figure 1. Generalize Heart disease prediction Approaches [37]

As shown in Table 1, predicting heart disease has a long history; however, most existing studies employ traditional machine learning (ML) models. However, some use both machine learning (ML) and deep learning models (DL). Each method has its own limitations,

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advantages, and disadvantages. To better understand the research landscape, prior studies on heart disease prediction Methods were reviewed. Table 2 provides a comprehensive review of these studies [38, 40].

Table 2. Relevant Machine Learning Models on heart disease prediction

Discription	**Key Contributions**	**Model**	**Accuracy**	**Ref**
Soft computing for heart disease	Studied use of soft computing in heart disease prediction and diagnosis	NB, DT, DF, and K-NN classifiers	KNN:90.7, DT: 80.2, RF: 84.2, NB: 88.15	[41]
ML and DL algorithms	Analyzed different heart diseases using both ML and DL methods	SVM, NB LR, DNN, DT, RF, and K-NN.	SVM:97.41, NB: 91.38, LR: 96.29, DNN: 98.15, DT: 96.42, RF: 90.46, KNN: 96.42	[42, 43]
AI for inherited heart diseases	Reviewed applications of AI models in inherited HD	KACGAN-based model	98.15, DT:	[44, 45]
ML on ECG signals	Focused on ML techniques for heart disease diagnosis from ECG data	RF	96.42, RF:	[46, 47]
ML with multiple data modalities	Summarized heart disease prediction with ML using multiple data sources	KNN	90.46, KNN:	[48, 49]
AI in cardiovascular CT	Reviewed AI-based approaches in cardiovascular CT and future implications	CNN classifiers	89.2	[50]

Analyze relevant research on predicting heart disease using machine learning (ML) and deep learning (DL) models to execute this research. Studies that applied machine learning (ML) or deep learning (DL) were excluded from the analysis. From the selected papers, we extracted details such as the year of publication, prediction techniques (ML, DL, or hybrid

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approaches), datasets used (public or self-created), and reported contributions. Studies were categorized into three groups: (i) classical machine learning (ML), (ii) deep learning (DL), and (iii) integrated approaches. Eventually, we recapitulated our findings in Tables, which provide a detailed overview of the surveyed and analyzed methods.
This table ensures that the review is wide, organized, and equitable. We applied numerous search methods to collect all appropriate literature in this review. We concentrated on keywords and subject headings related to heart disease prediction models and deep learning, using the method from earlier studies and searching only English sources. To be thorough and avoid overlap, we included both forward and backward searches. We also relied on a keyword-based strategy to keep the search both broad and targeted.

Literature Review

This subsection summarizes the research on existing work on using deep learning (DL) technology for heart disease. Table 6 comprehensively introduces the existing work of authors on deep learning for heart disease. In the field of heart disease prediction, researchers have deployed a huge array of methods with great achievements [51, 52]. This started the process of convolutional neural networks (CNNs) in categorizing individuals as fit or unfit within a Cleveland dataset [53, 54].

$$S_i^{(b,t)} = \sum_{z=1}^{E} p_{iz}^{(b)} J_z^{(b-1,t)} + \sum_{i'}^{y} x_{ii'}^{(b)} J_{i'}^{(b,t-1)} \qquad \text{Eq (6)}$$

Their model attained the impressive test accuracy of 96% and training accuracy of 97%. Especially, they integrated the clinical parameters to identify the patients' risk factors, enabling early risk prediction. In addition, they expanded on the benefits of a balanced dataset to overcome the limitations posed by traditional machine learning (ML) [55, 56].
Utilized the power of a convolutional neural network (CNN) to deal with early-stage heart disease. Their study clearly defined the dominance of a convolutional neural network (CNN) over classical methods using the Cleveland dataset and achieved the admirable accuracy of 94.78% [57, 58]. Their model passes the pre-processing and feature extraction, and also in prediction, highlighting its commendable capabilities [59, 60].

$$MCC = \frac{TP * TN - FP * FN)}{\sqrt{((TP + FP) * (TP + FN) * (TN + FP) * (TN + FN))}} \qquad \text{Eq (7)}$$

$$B_{m,n}(q+1)\left(1 - \frac{1 - X(0,1) - X(-1,1)}{1 - c_{m,n} \times f_{mn}(q)}\right) = X(0,1) \times R_{s,n} \qquad \text{Eq (8)}$$

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Table 3 provides the detailed information about an overview of deep learning (DL) approaches for heart disease prediction.

Table 3. Comparative Overview of deep learning (DL) Techniques for Heart Disease Prediction

Model	**Dataset**	**Model Precission**	**Accuracy**	**Ref**
Ensemble DL + Feature Fusion	Clinical + sensor data	98.5%	Combining wearable sensor and clinical data improved prediction	[60, 61]
Deep Neural Network (DNN)	Heart disease datasets	93.33%	Deeper network outperformed ANN and simpler models	[62, 63]
Multi-task Deep & Wide NN	Heart failure data	Superior forecasting (no % given)	Multi-tasking captured shared features Effectively	[64, 65]
CNN	Cleveland dataset	94.78%	CNN achieved strong predictive performance vs. traditional ML Models	[66, 67]
CNN	Cleveland dataset	96%	Classified “fit” vs “unfit” patients with high accuracy	[68, 69]
LSTM-DBN	Four ECG datasets	88.42%	Used time-frequency ECG signals; broader dataset coverage	[70, 71]
CNN	Cleveland dataset	94.78%	CNN achieved strong predictive performance vs. traditional ML Models	[72, 73]
CNN	Cleveland dataset	96%	Classified “fit” vs “unfit” patients with high accuracy	[74]
LSTM-DBN	Four ECG datasets	88.42%	Used time-frequency ECG signals; broader dataset coverage	[75, 76]

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Analyzed the power of flexible-5-layer deep neural network (DNN) models, attaining a high level of accuracy even with the limited dataset [77] Enhanced accuracy and sensitivity by smoothly integrating deep learning (DL) with convolutional neural networks (CNNs) employing insights from the Cleveland datasets [78, 79] Subhadra and Vikas approached diagnoses from a different perspective, proposing a multilayer perceptron (MLP) neural network precisely trained on the Cleveland dataset [80, 81] This approach offers a new viewpoint in the field of heart disease prediction, elaborating on the Breadth of using different deep learning (DL) models and techniques in this field [82] In the area of early risk prediction of heart disease, Subhadra and Vikas demonstrated how powerful a convolutional neural network (CNN) can be [83, 84].

They used the backpropagation methods along with the Cleveland dataset, and they designed a system that not only identifies the presence or absence of heart disease but also detects the severity of heart disease. This innovation outperforms the existing methods by a remarkable 9% in prediction accuracy. In another study, Illustrated a deep learning (DL) based system that applied the power of deep learning to address data gaps [85, 86]. The collected data were carefully examined for feature extraction, emphasizing the system's ability to extract meaningful insights from multifaceted data sources [87]. Due to the global burden of heart disease, this paper delves into the different techniques that can further enhance heart disease prediction. Shifted the focus to predict a person's health, proving how deep learning (DL) can gain valuable insights from the retinal fundus images [88, 89].

Cluster-based over-sampled method

A novel approach has been devised using resampling and grouping methodologies to handle unbalanced stroke data. Their model, which evaluates from wide datasets of datasets like UK Biobank and EyePACS, predicted heart disease successfully from the features of the retina [90]. Though promising, these studies also recognize the limitations, such as dataset size constraints, missing risk factors, pointing areas for further exploration and refinement. Extended deep learning techniques for heart disease prediction. This paragraph reviews various studies that utilized new technologies and deep learning–based models for predicting the risk of heart disease. Table 6 presents information on the year of publication, the methods or tools used, their limitations, and the performance results. According to Arroyo and Delima, combining genetic algorithms with artificial neural networks produced better results than applying each technique separately. The hybrid model called GA-ANN outperformed ANN, LG, DT, RF, SVM, and KNN.

$$f(x,y,w) = -\log p(y|x;w) \qquad \text{Eq (9)}$$

This work set a new standard for prediction accuracy in heart disease research. Building on this idea, developed another hybrid system. They first applied a genetic algorithm (GA) for feature selection and then utilized an ensemble deep neural network (DNN) to perform the prediction task. Their model was tested on a dataset of 900 patients with 54% features and reached 98% accuracy, which was higher than the results reported in earlier studies. Filtering was used to remove repeated entries, environmental disturbances, and data inconsistencies to

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improve the reliability of the findings [94, 95]. The system achieved an accuracy rate of 98.68%. This highlighted how combining different deep learning techniques can significantly improve prediction performance [96]. In the study a deep neural network (DNN) for predicting heart attacks using the Cleveland dataset is used, their approach addressed accuracy issues in older methods and reduced the need for heavy manual data cleaning. Their approach not only improved prediction 1accuracy but also laid the groundwork for future research in medical AI [97, 98]. In another study, developed a new DNN classifier for heart disease diagnosis. They split their dataset into training and testing groups and applied preprocessing and feature extraction to it. The model obtained a precision of 84.67% when tested on the Cleveland dataset [99, 100]. Table 4 outlines the existing literature on integrated deep learning–based approaches for heart disease prediction [99, 100].

$$B = \{B_1, B_2, \ldots, B_k, \ldots, B_l\} \quad \text{Eq (10)}$$

Integration of Deep Learning Techniques in Heart Disease Prediction

This section reviews studies where deep learning (DL) was combined with other methods to predict heart disease (HDP). It also highlights the year of publication, the methods or tools applied, limitations, and key findings. Khan created a system that links devices, small computers, and low-power radio devices [101]. Shafi and his colleagues used a type of computer program called CNN and some devices that people can wear on their bodies to try to guess if someone has heart disease. Some researchers also tried methods and techniques inspired by nature. Deepika and Balaji developed a method that helps patients feel more confident in the early detection system, encouraging them to lead healthier, more independent lives gracefully and in sync, like dragonflies gliding together. They demonstrated that it can assist heart disease prediction.

$$E_c = \frac{1}{K} \times \sum_{g=1}^{k} J_v^{b,t} - k_v \quad \text{Eq (11)}$$

A new system using swarm-ANN, which takes advantage of group intelligence and flexibility. Huang and colleagues built a multi-label learning model. This model used expert knowledge about how long a disease lasts to make predictions [102]. WoM- based bidirectional LSTM (BiLSTM) deep classifier. They mentioned that including knowledge from a particular field by experts helps improve machine learning models. In another research, Sharma and his group created a model to predict heart disease using deep learning (DL) and a large amount of data. This system demonstrates how using big datasets and advanced machine learning techniques can make disease predictions more accurate and faster.

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Table 4. Overview of Prior Research on Integrated Deep Learning Models for Heart Disease Prediction

Approach	**Key Findings**	**Dataset**	**Ref**
DT, LR, SVM, ANN	DT ≈14% better than others	Imbalanced data	[103]
DT, NB, KNN, ANN, Bagging	KNN accuracy	Limited comparison	[104]
RF, LR, KNN, SVM, DT, DL	DL best (94%)	Small dataset	[105]
CNNs, GA, SVM	Multimodal ECG+PCG better than single	Small sample	[106]
DT, RF, SVM, ANN, KNN	ANN best, open-source code	Needs larger data	[107]
CNN + wearables	Very high accuracy (98.7%)	Deployment issues	[108]
CNN, RNN, DL	Dragonfly algo promising	Needs validation	[109]
C-BiLSTM	High accuracy, less complex	Biased	[110]
BDLSTM	Fast predictions	Poor interpretability	[111]
IoT + LSTM	IoT-improved detection	Still experimental	[110]

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1D CNN, DNN	Better than statistical models	Needs generalization	[112]
IoT + AES + DL	Improved privacy/security	Complex to apply	[113]

They used the ensemble deep dynamic algorithm (EDDA) on the Cleveland dataset. By combining it with a linear regression model and a deep Boltzmann machine (DBM), they addressed numerous prediction challenges and improved accuracy, along with other key performance measures. Worked on early disease prediction and classification using the PHYSIONET dataset. Their method involved signal processing, wavelet-based techniques.

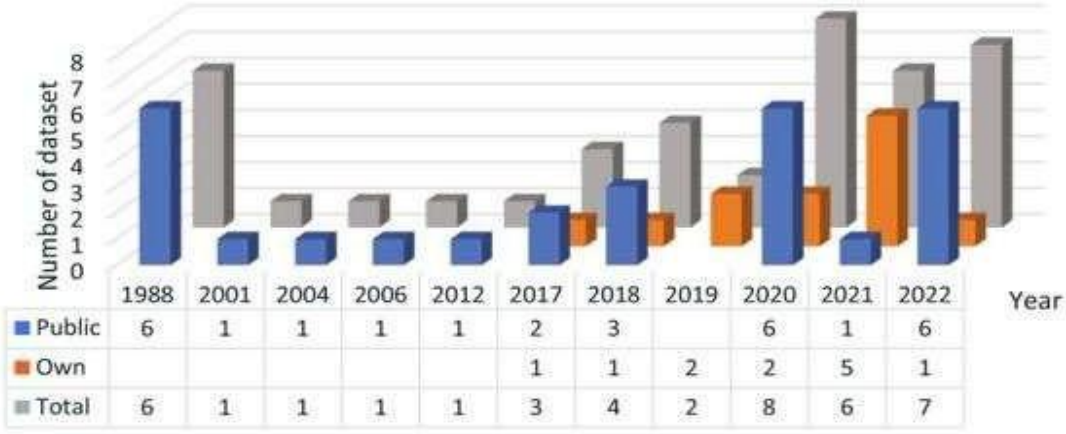

Figure 2. Statistics of existing datasets vs. public year

$$B_{m,n}(q+1)(1-\frac{1-X(0,1)-X(-1,1)}{1-c_{m,n}\times f_{mn}(q)}) = X(0,1)\times R_{s,n} \quad \text{Eq (12)}$$

The classifier contains i to represent random units of b-layer units and y to represent the total b-layer units.

$$S_i^{(b,t)} = \sum_{z=1}^{E} p_{iz}^{(b)} J_z^{(b-1,t)} + \sum_{i'}^{y} x_{ii'}^{(b)} J_{i'}^{(b,t-1)} \quad \text{Eq (13)}$$

Segmentation and a regressive learning-based neural network (RLBNN) for feature detection. Their model performed better than traditional methods, opening new ways for early disease prediction. Dami and Yahaghizadeh focused on predicting arterial events over time [114]. They used ECG recordings with time-frequency analysis and trained an LSTM-

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DBN model on four datasets. Their approach achieved high results: 85.54% specificity, 85.13% sensitivity, and 88.42% accuracy. Ali and their members use another method to improve heart disease prediction by using deep learning with feature mixing [115]. They used patient data from medical tests and wearable sensor devices. The quality and accuracy of the information got better when they incorporated frequency response functions (Fintos), this enables the model to make more accurate predictions. During this, Wearable technology was utilized in a novel and innovative way. Sarmah created a wearable sensor device that can measure heart age, stress levels, and cholesterol levels [116, 117].

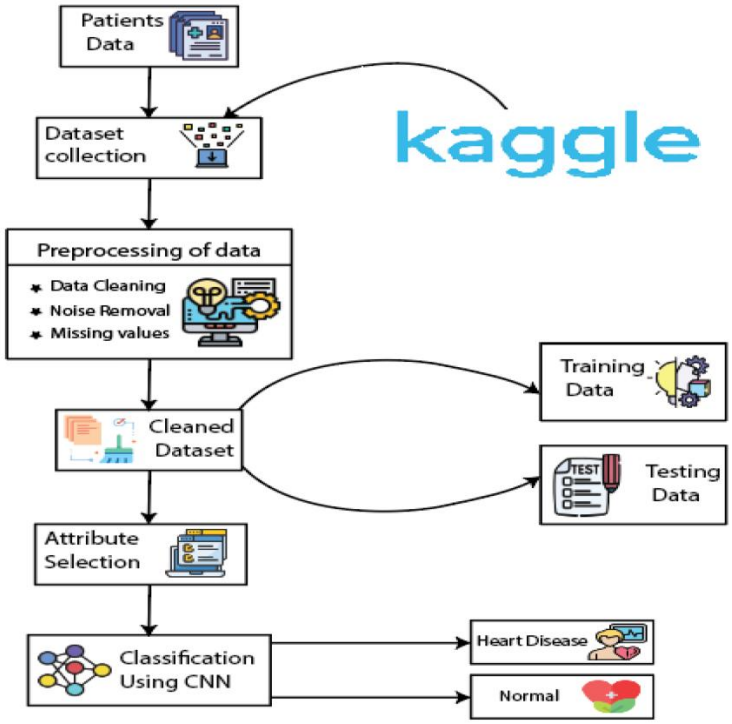

Figure 3. Generic Framework for Heart Disease Prediction Processing Datasets [118]

To keep the patient's data safe, the system used modern IoT methods such as secure data sharing, safe login, data protection, and easy-to-manage data handling. Their team introduced a new x2-DNN model, keeping in mind possible issues like overfitting and underfitting [118, 119]. Their model performed better than existing ANN and DNN models and achieved an impressive 93.33% accuracy. Wang and his team developed a new neural network architecture called the Multitask Deep and Wide Neural Network (MT-DWNN) [120, 121].

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$$P(w) = \sqrt{\frac{t}{f(w)}} + \frac{t}{f(w)},$$

Eq (14)

$$f(w) = \frac{count_w}{totalno.oftokens},$$

Eq (15)

This model was designed to predict possible complications and to determine the factors that have the most impact on patient outcomes. The results showed that for heart patients, MT-DWNN performed much better than traditional methods. This advanced model can help doctors improve patient care and treatment outcomes [122, 123]. Prediction. Deep Learning has wide applications in healthcare. Recent research has focused on finding better ways to predict heart disease using different methods. Research shows that each method has its own benefits and possible strengths. Found that the decision tree model was better than other techniques at predicting heart disease. It was 14% more accurate than the usual methods. This study used real patient data, which shows there is still a lot that can be improved in both the data and the prediction methods. They emphasized that the selection of an appropriate method is crucial and that it should be adjusted carefully for each dataset and situation tested machine learning, deep learning, and a combination of both. Their goal was to find which approach was the most accurate, reliable, and sensitive [124, 125]. They found that the best results were obtained using a method that picked the most important data points and removed incorrect data. This shows that combining more than one method can give better results than using just one. Heart electrical signals (ECG) and heart sound signals (PCG). They used a computer model to identify deep patterns in both types of data, then selected the most useful information, and finally classified patients' conditions. It showed that the multiple data make a more accurate result for heart disease predictions [126]. Researcher explored the application of various machine learning (ML) algorithms to predict heart disease (HD). The study compared Decision Tree (DT), The study used Random Forest (RF), Support Vector Machine (SVM), Artificial Neural Network (ANN), and K-Nearest Neighbor (KNN) models with the Cleveland dataset. The results showed that the ANN performed best, with an accuracy of 93.03%. To make their research more transparent, they shared their code on GitHub to let other researchers see it and work with it valvular heart diseases [127, 128]. worked on predicting chronic kidney disease using an integrated approach that combined Machine Learning (ML) and Deep Learning (DL) methods to give accurate and opportune diagnoses. Their model handled imbalanced data well and gave accurate predictions. The model is modular, meaning new algorithms and techniques can be added in the future, allowing for further improvements in chronic kidney disease prediction. In heart disease prediction [129]. Different Machine Learning (ML) methods and artificial neural networks

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(ANNs). Employed open-access datasets, which were partitioned into training and testing sets. Their analysis revealed that the Cleveland dataset is one of the most commonly employed datasets in heart disease research. such as those by Sujatha and Mahalakshmi. Random Forest (RF) worked best with 95.60% accuracy [130]. A deep neural network (DNN) model using Talos fine-tuning and trained it on real patient records. Talos performed better than other optimizers and achieved 90.78% accuracy, proving it can help make heart disease predictions more dependable. The studies used various datasets and were carefully done to improve prediction models for future research [131]. Chicco and his team built a complete system that joined distinct methods, like Fuzzy Logic (FL) with models like Decision Trees (DT), Support Vector Machines (SVM), and Artificial Neural Networks (ANN), being tested, and Adaboost. The Accomplishment of this system came from using feature reduction and feature selection methods, like LASSO and MRMR [40]. After that, Zeleznik and his team created a model known as the Hybrid Random Forest with Linear Model (HRFLM) approach. This method used a feature selection technique along with a Random Forest (RF) model to enhance the model's ability to predict outcomes. The model worked well at finding the most important features for predicting heart disease and had an accuracy of 88.7% [132]. Neural Networks with Decision Trees (DT) to develop a special hybrid system. This system performed better than older methods and showed higher accuracy in classifying heart disease. All these studies represent major progress in heart disease prediction and help in building systems that are both accurate and efficient. According to Straw and Wu, common supervised learning techniques—including Random Forest (RF), Decision Tree (DT), and ensemble approaches—are essential in predictive modelling and are very useful in analyzing medical data. These algorithms play an important role in diagnosing different types of heart diseases [133]. Introduced a new method that combined multi-layer neural networks employing a hierarchical, component-based learning framework. This enhanced heart disease prediction because it understood the complex relationships between different risk factors more effectively. It also gave better results than traditional methods. Furthermore, Das and his colleagues used important risk-related features that were derived using time-series analysis of patient data. Then they applied a rough set technique to study the relationships between those features. Their research showed that this method can predict heart disease effectively and plays an important role in healthcare analytics [134]. The analysis found that the most commonly used dataset is the Cleveland dataset, which comes from the UCI Repository. Even though this dataset has 76 features, most of the models used only 14 of them, such as age, gender, chest pain type, blood pressure, ECG results, maximum heart rate, blood sugar, and the number of major blood vessels. In terms of popularity, the Statlog (Heart) dataset came in second, and the Hungarian dataset was third [135]. The developers of heart disease prediction have used various languages. Python is one of the preferred programming languages, with 75% of the researchers describing it as a favorite programming language, as described in figure 8. A number of them are probably MATLAB, 9%, R, 8%, Java, 7%, and Knowledge representation language SWRL (Semantic Web Rule Language), 1%. each is also significant in the case of device +DL and IoT +DL. All other strategies are less frequently utilized: 6%, 6%, 4%. The paper provides a succinct overview of the Deep Learning (DL), Enhanced

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Transfer Deep Learning (ETDL), and Integrated DL approaches. To improve prediction results, bigger and more varied datasets are needed. Algorithms need to be validated by integrating multiple risk elements within very large cohorts [136, 137]. API or cloud-based datasets can be hosted for research purposes, since cloud computing efficiently handles large volumes of patient records IoT devices enable the real-time recording of key clinical indicators. Collaboration with physicians is equally important to collect meaningful data for model improvements. Enhancing predictive accuracy by subjecting models to multi-facility datasets is most likely to be more effective [42]. Nevertheless, validation remains a problem, though lab test results are some of the most valuable for evaluating prediction accuracy [138,139]. More general medical records may enhance the accuracy of some prediction models, for instance, for cardiac CT scans. Finally, researchers suggest using real-world datasets instead of just theoretical ones for simulations.

Models more efficient when working with datasets that have a lot of missing information, their feature selection methods should be changed, this will enhance the results of the model as a whole. Pairwise classification with extra features has also been proposed for increased accuracy. In order to improve the efficiency of models that take datasets with substantial missing values, their feature selection strategies should be altered. It has been proposed in studies [140, 141]. Implementing ensemble classifiers with extra features provides better models for predicting the staging and severity of a given condition, thus enhancing the results of the model as a whole. Pairwise classification with extra features has also been proposed for increased accuracy. Managing a big number of features in combination with medical data records is a task that is known to be difficult, and thus, a dedicated technique for feature reduction is needed. It is also crucial to develop a better technique that features feature elimination, missing data imputation, noise handling, and more, to boost the accuracy of a model's predictions [142, 143].

Method and Materials

The primary objective of this study is to develop a computerized framework for predicting the probability of heart disease, thereby providing valuable decision-support tools for healthcare professionals and improving patient outcomes. To achieve this goal, a range of machine learning algorithms was applied to a structured dataset, and the corresponding results are comprehensively analyzed in this report. The proposed methodology is further enhanced through rigorous data preprocessing, encompassing data cleaning, elimination of non-contributory variables, and incorporation of additional clinical parameters such as Mean Arterial Pressure (MAP) and Body Mass Index (BMI). Following preprocessing, the dataset is partitioned based on gender to enable more nuanced analysis, and k-modes clustering is employed to uncover latent patterns within subpopulations. The refined dataset is then utilized to train predictive models capable of producing robust and reliable diagnostic outcomes. This improved methodological framework is expected to substantially enhance predictive precision and overall model efficacy, as demonstrated in the subsequent sections of this study.

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Proposed Enhanced Heart disease prediction Model

This study seeks to develop a robust and comprehensive framework for precise heart disease prediction through the integration of advanced machine learning paradigms, feature selection mechanisms, and dimensionality reduction techniques. By leveraging sophisticated algorithms, the proposed model effectively uncovers and interprets complex, nonlinear relationships embedded within clinical data. The incorporation of ensemble deep learning architectures and innovative feature fusion strategies enables the system to deliver accurate and timely diagnostic predictions, providing healthcare professionals with an intelligent decision-support tool to improve diagnostic accuracy and patient outcomes.

The hybrid predictive framework is structured into three principal phases: data acquisition, preprocessing, and classification—each serving a crucial function in optimizing model performance. During the preprocessing phase, meticulous procedures are implemented to ensure data integrity and enhance computational efficiency. These include the imputation of missing values, accomplished through the ML-HDPM approach, which accurately estimates incomplete data entries. In addition, an extensive feature selection process is employed to identify the most discriminative attributes relevant to heart disease prediction. This process leverages a hybrid optimization strategy that synergistically combines the Genetic Algorithm (GA) and Recursive Feature Elimination Method (RFEM), thereby enabling the extraction of salient features that significantly contribute to predictive precision and model robustness.

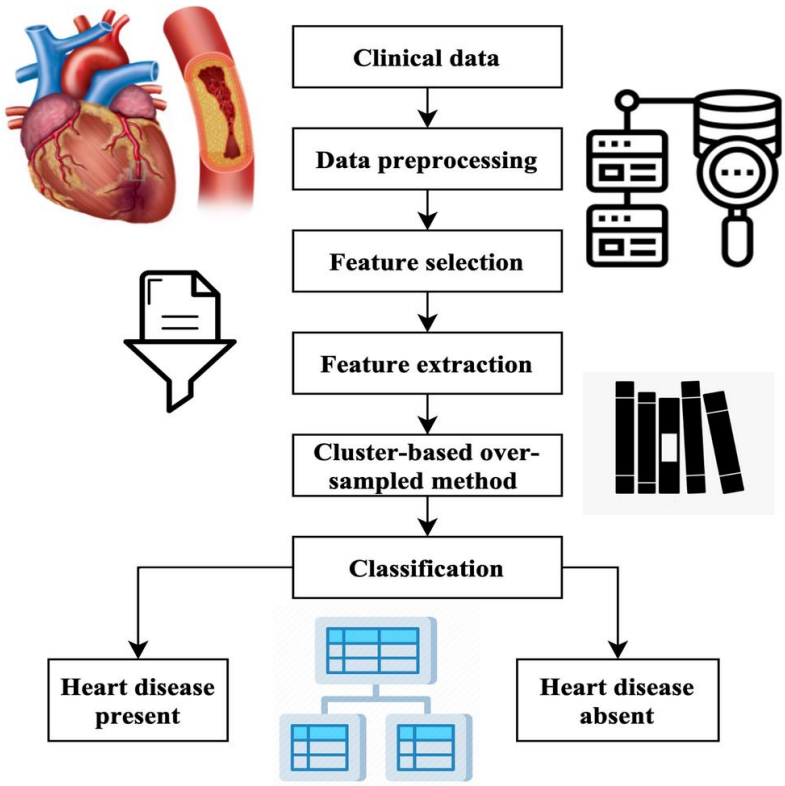

Figure 4. Proposed Framework for Heart Disease Prediction Approaches

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The experimental framework of this study was systematically designed to evaluate model performance under varying conditions through three distinct testing scenarios: (1) utilizing the complete dataset without applying any data reduction techniques, (2) employing a reduced dataset derived from a representative subset of the original data, and (3) implementing a modified bee algorithm on the reduced dataset.

Evaluation of the Enhanced Heart Disease Prediction Model

The modified bee algorithm, an enhanced adaptation of the conventional bee optimization method, was specifically engineered to improve performance by iteratively exploring and fine-tuning model parameters. All experiments were conducted on a computational setup equipped with an Intel i5 processor and 3 GB of RAM, using MATLAB version 9.2 as the primary development environment. In each scenario, the dataset was systematically partitioned for training and testing in accordance with the experimental design. To ensure methodological rigor and mitigate overfitting, k-fold cross-validation was employed, wherein the dataset was divided into k mutually exclusive subsets. Each subset was sequentially used as a validation set while the remaining subsets were utilized for training. This process was repeated k times, and the mean performance metrics were computed to provide a robust and unbiased evaluation of the model's predictive capability across diverse conditions.

$$d_{AHD}(X,Y) = (\frac{1}{X}\sum_{x\varepsilon X}\frac{min}{y\varepsilon Y}d(x,y) + \frac{1}{Y}\sum_{y\varepsilon Y}\frac{min}{\epsilon Xd}d(x,y))/2 \quad \text{Eq (16)}$$

$$d_{AHD}(2,31) = (\frac{1}{2}\sum_{x\varepsilon X}\frac{min}{y\varepsilon Y}d(2,31) + \frac{1}{31}\sum_{y\varepsilon Y}\frac{min}{\epsilon Xd}d(2,31))/2 \quad \text{Eq (17)}$$

$$d_{AHD}(4,41) = (\frac{1}{4}\sum_{x\varepsilon X}\frac{min}{y\varepsilon Y}d(4,41) + \frac{1}{41}\sum_{y\varepsilon Y}\frac{min}{\epsilon Xd}d(4,41))/2 \quad \text{Eq (18)}$$

$$d_{AHD}(2,n) = (\frac{1}{2}\sum_{x\varepsilon X}\frac{min}{y\varepsilon Y}d(2,n) + \frac{1}{n}\sum_{y\varepsilon Y}\frac{min}{\epsilon Xd}d(2,n))/2 \quad \text{Eq (19)}$$

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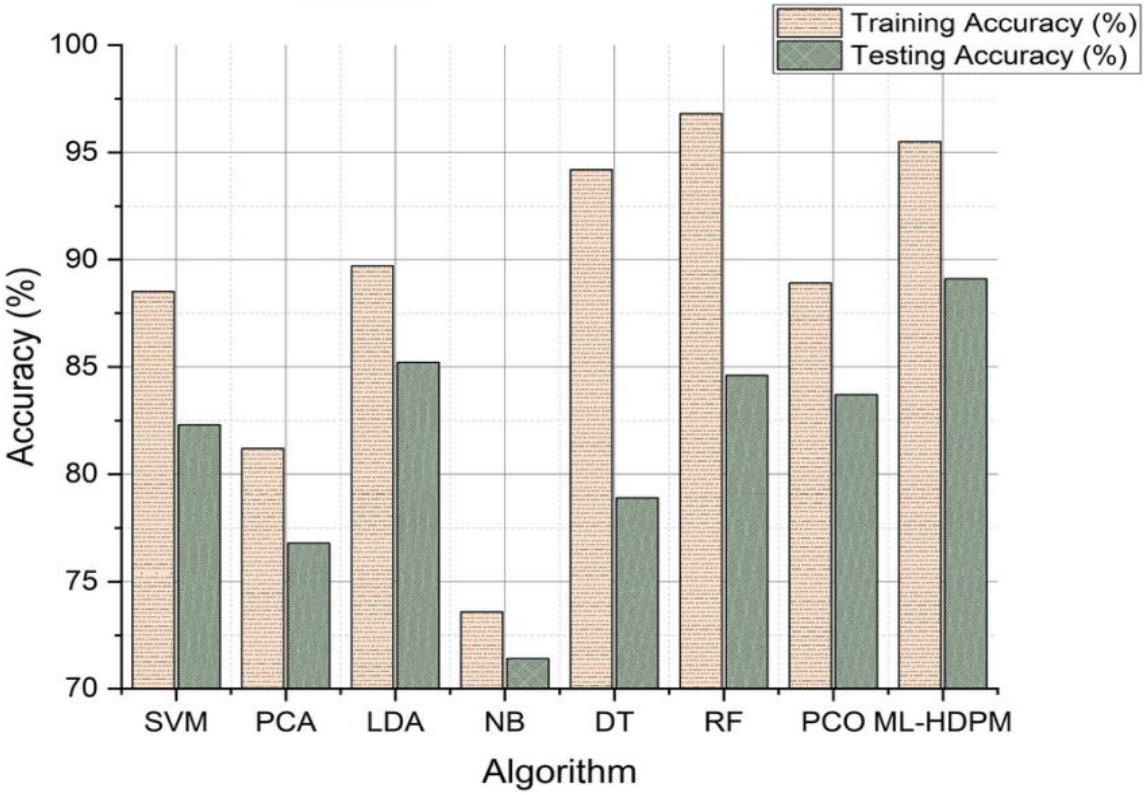

Figure 5. Accuracy analysis of predicting heart disease

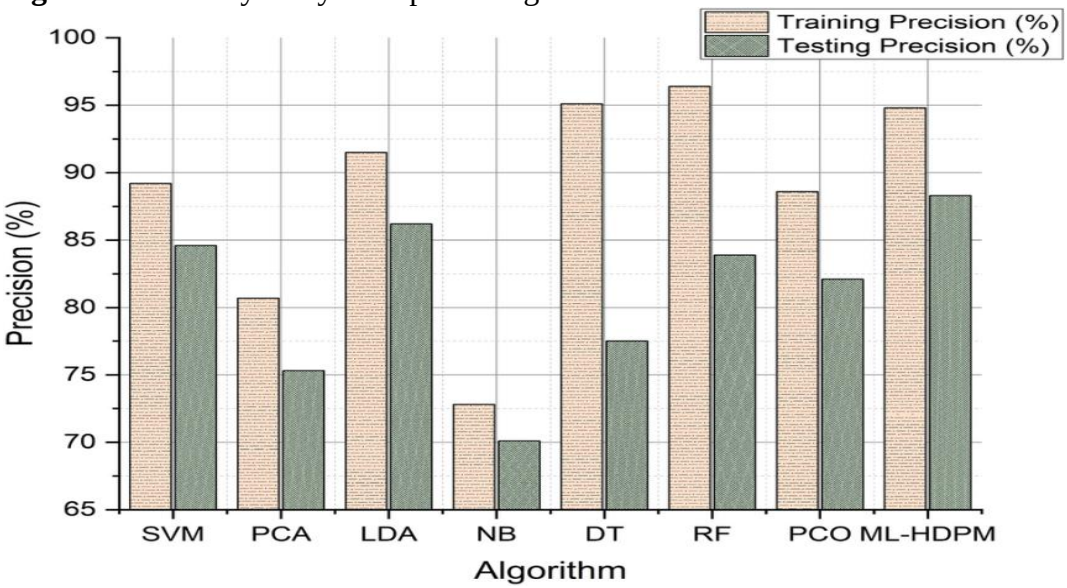

Figure 6. Precision analysis of predicting heart disease.

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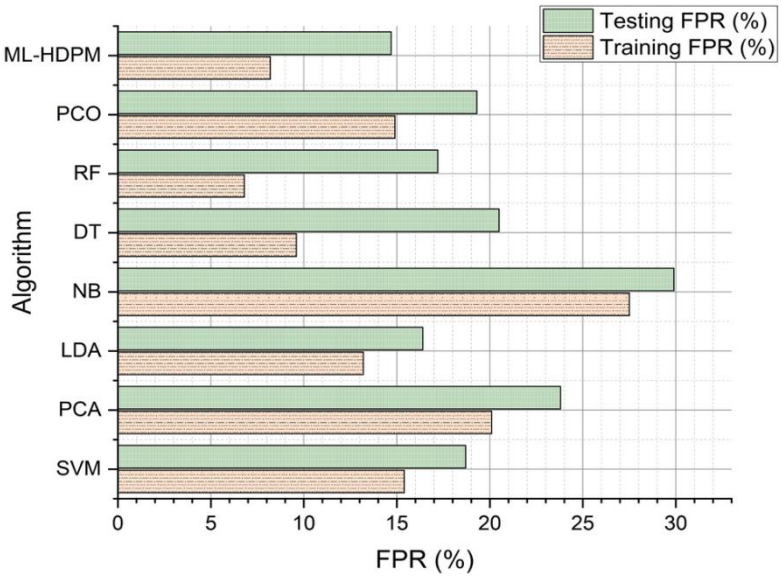

Figure 7. False positive rate analysis of predicting heart disease

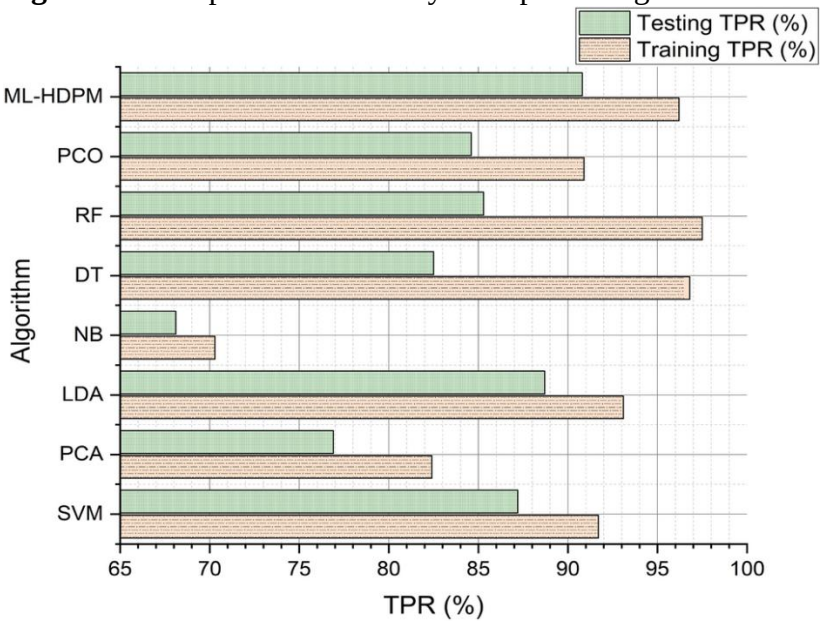

Figure 8. True positive rate analysis of predicting heart disease

The ML-HDPM approach exhibits superior performance in terms of F-score, achieving 91.5% during training and 89.6% during testing, surpassing all comparative algorithms as shown in Figure 10. This outstanding performance is attributed to the comprehensive design of the model, which effectively integrates feature selection, data balancing, and deep learning optimization techniques. By capturing significant patterns within heart disease datasets, ML-HDPM attains an optimal balance between precision and recall, resulting in consistently higher F-scores. These results emphasize the model's strong predictive

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capability and its potential to enhance diagnostic accuracy and improve overall patient care outcomes.

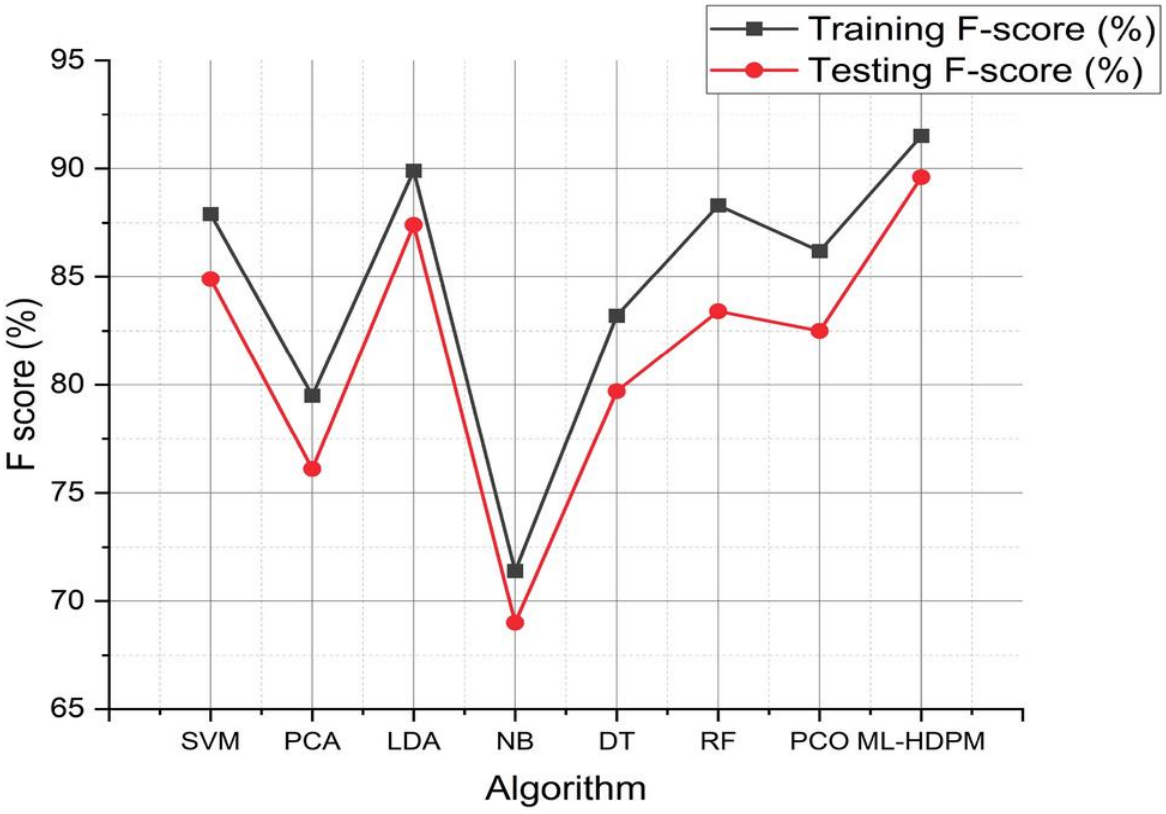

Figure 9. F score analysis of predicting heart disease.

The simulation results underscore the robustness and predictive efficacy of the proposed Machine Learning Hybrid Deep Predictive Model (ML-HDPM) in forecasting heart disease outcomes. Achieving training and testing accuracies of 95.5% and 89.1%, respectively, the ML-HDPM demonstrates superior performance relative to competing algorithms. This enhanced capability is further validated by consistent accuracy measures of 94.8% (training) and 88.3% (testing), as illustrated in Figure 11, confirming the model's generalizability across diverse datasets. Furthermore, the ML-HDPM achieves a marked reduction in false positive rates (FPR)—8.2% during training and 14.7% during testing—indicating its proficiency in minimizing misclassification errors and enhancing overall predictive precision. In parallel, the model attains notably higher true positive rates (TPR) of 96.2% (training) and 90.8% (testing), reflecting its capacity to correctly identify heart disease cases with high reliability. Collectively, these results affirm ML-HDPM's substantial potential as a robust predictive tool for accurate and reliable heart disease diagnosis.

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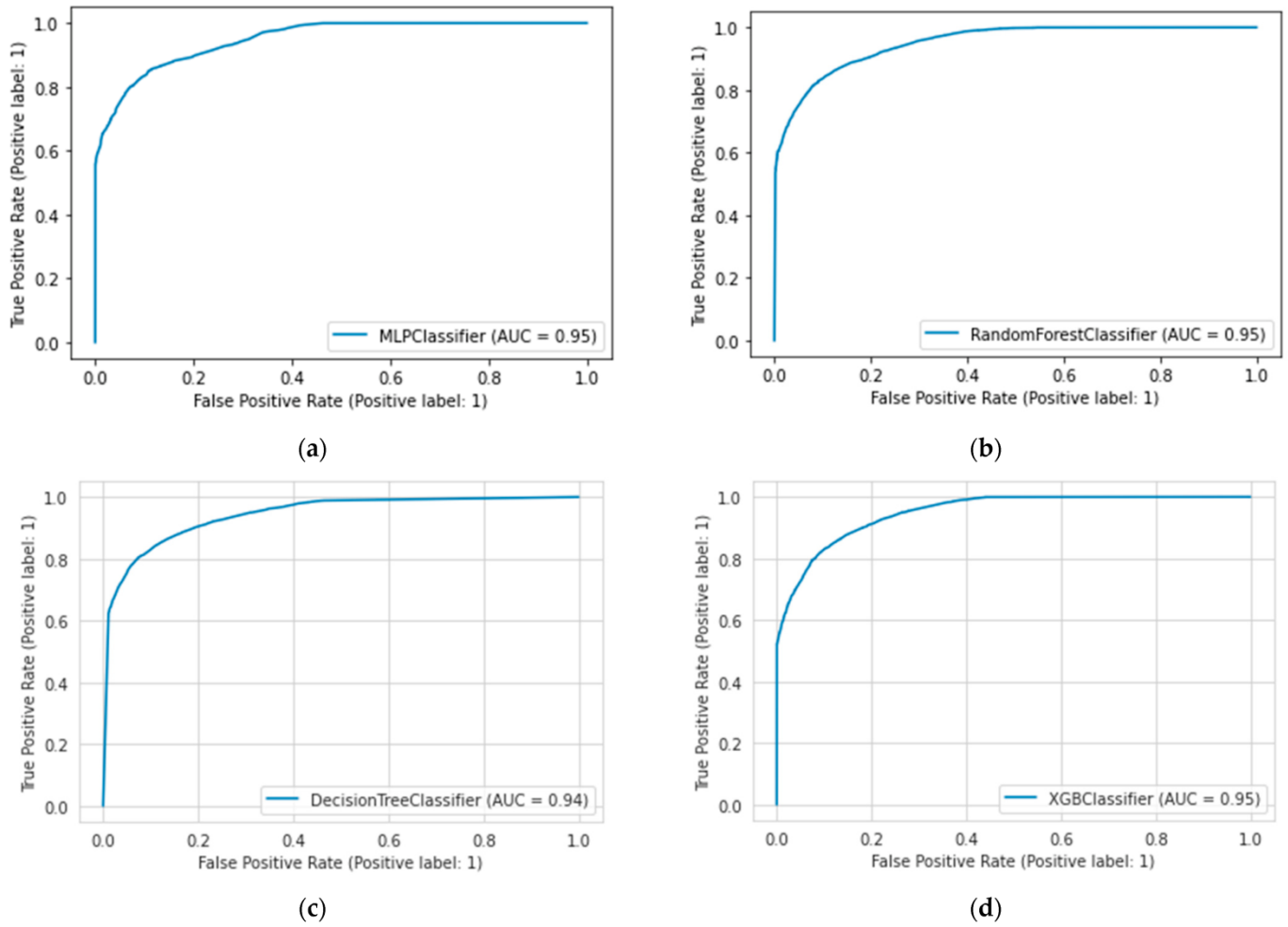

Figure 10. ROC–area under curve of (a) MLP, proposed Machine Learning Hybrid Deep Predictive Model (b) RF, (c) DT, and (d) XGB

TABLE 5: Comparative Analysis Proposed Model Using Multiple Classifiers based on UCI ML Dataset

Classifier	Model	Computation Time	JC	Dice Score	Sensitivity	Accuracy	Specificity	Precision	F-Score
NBB	3-Layer CNN	K = 30	0.74442	0.7442	0.6486	0.6415	0.6437	0.7442	0.6483
E-CNN	U-Net	K = 30	0.64333	0.6433	0.6486	0.5245	0.6485	0.6433	0.6485
SVM	VGG19	K = 30	0.143	0.8444	0.6485	0.7442	0.7442	0.7442	0.6486

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			2						
RNN	InceptionV3	$K = 30$	0.212	0.5245	0.6485	0.6433	0.1432	0.6433	0.1432
Proposed Model	EfficientNetB4	$K = 30$	0.6222	0.7627	0.6486	0.7484	0.212	0.6433	0.212

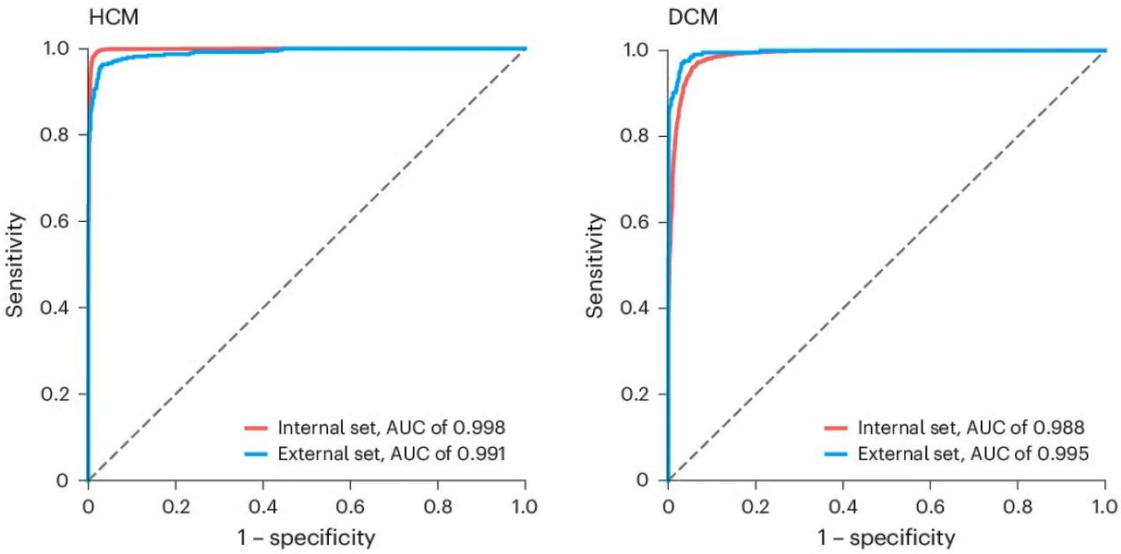

Figure 10. Sensitivity vs specificity

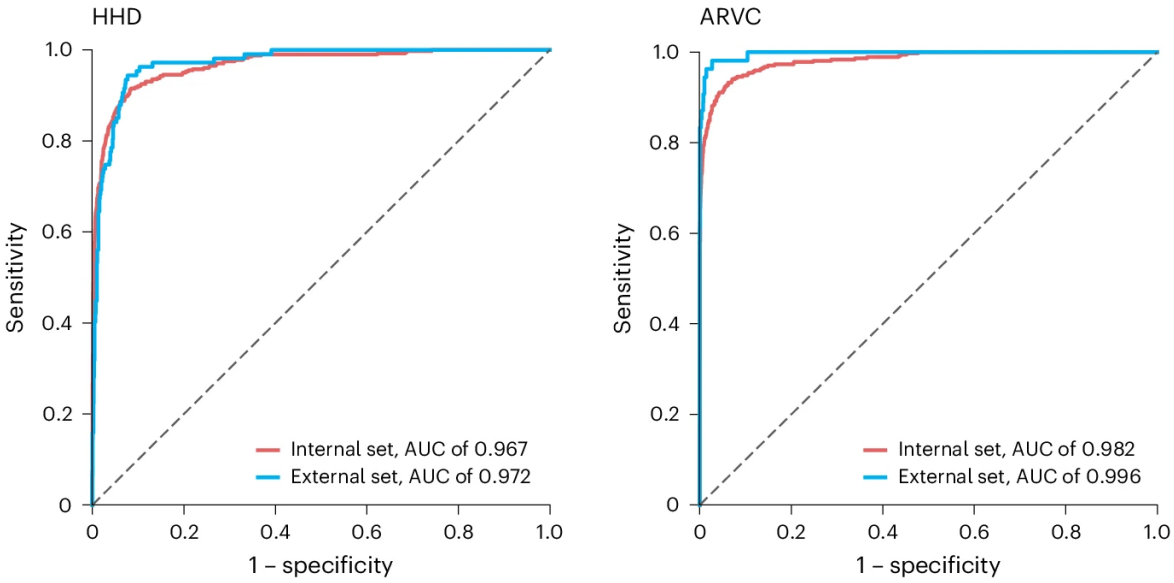

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Figure 11. Sensitivity vs specificity for HHD and ARVC

Conclusion

This article evaluates a Deep Learning (DL), Enhanced Transfer Deep Learning (ETDL), and hybrid Deep Learning approaches for forecasting heart disease prediction. The meticulous analysis shows that CNN is the leading DL-based strategy, Hybrid deep learning (DL)-based Enhanced Transfer Deep Learning Enhanced Transfer Deep Learning is the most influential Enhanced Transfer Deep Learning -based technique and the most utilized integrated paradigm in the context of DL. In recent years, there has been a growing interest in research that combines DL and other cooperative techniques. The model was trained and evaluated using the UCI Machine Learning Heart Disease dataset, and its performance was benchmarked against state-of-the-art algorithms such as Artificial Neural Networks (ANNs) and Recurrent Networks (RNs). Empirical evaluations reveal that CardioHelp achieves outstanding predictive performance, with an accuracy of 97%, an F1-score of 93.4%, and a precision improvement of 0.8% compared to existing baseline models. Furthermore, when compared with advanced hybrid architectures—including CNN-RNN, CNN-LSTM, and CNN-BLSTM—the proposed framework exhibits accuracy enhancements of 2.35%, 1.34%, and 1.95%, Predicting heart disease accurately and quickly is important but difficult. Machine learning becomes highly effective in identifying and categorizing patients. Advanced machine learning and deep learning models, like SVMs and CNNs, can forecast patients' medical histories and general well-being. It has also been found that the Python language is the most preferred one among all languages for implementing these technologies because it provides extensive libraries as well as community support. Also, the fact that most of the influential studies come from journals proves how academic this field is; mostly from giant publishers like IEEE, Springer, and Elsevier. Though the domain has moved a long way, enormous challenges still exist; importantly, big and diverse datasets are nowhere to be found. This inadequacy puts a very high limitation on how much DL- based approaches can assist in improving accuracy, robustness, and overall reliability when it comes to heart disease predictions.

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