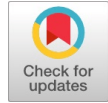


A Review, Synthesizing Frameworks, and Future Research Agenda: Use of AI & ML Models in Cardiovascular Diseases Diagnosis

Dhavalkumar Upendrabhai Patel, Suchita Patel



Abstract: Cardiovascular diseases (CVDs) continue to be a leading cause of morbidity and mortality worldwide. Early detection and accurate diagnosis of the initial phases of CVDs are crucial for effective intervention and improved patient outcomes. In recent years, advances in intelligent automation and machine learning (ML) techniques have shown promise in enhancing the accuracy and efficiency of CVD detection. This systematic review aims to comprehensively analyze and synthesize the existing literature on the application of intelligent automation and ML adaptive classifier models in the detection of the initial phase of cardiovascular disease within the realm of medical science. The review follows a rigorous systematic methodology, including comprehensive literature search, study selection, data extraction, and quality assessment. A wide range of scholarly articles from the reputed journal were searched to identify relevant studies published over a specified period. The selected studies were critically evaluated for methodological robustness and relevance to the research objective. The synthesis of findings reveals a diverse landscape of research endeavors focused on employing intelligent automation and ML adaptive classifier models for CVD detection. The review highlights the various types of ML algorithms utilized, such as neural networks, decision trees, and support vector machines, and their potential to enhance the accuracy of diagnosis by analyzing complex and heterogeneous data sources, clinical records, and omics data. Furthermore, the review discusses challenges and limitations encountered in implementing these models, including data quality, interpretability, and ethical considerations. It also underscores the need for further research, standardization, and validation to harness their full capabilities and contribute to more accurate, timely and personalized cardiovascular disease diagnosis and management.

Keywords: - Cardiovascular Diseases (CVDs), Heart Disease Prediction, Heart Disease, Machine Learning, Optimization, Initial Phases of CVDs, Machine Learning (ML) Techniques ML (Machine Learning) Adaptive Classifier Models

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I. INTRODUCTION

Data mining, a process that involves extracting valuable insights from datasets and transforming them into usable formats, holds great potential for addressing contemporary challenges in medical science. One such challenge is the early detection of cardiovascular diseases (CVDs), which continue to pose a substantial global health burden. Timely identification of the initial phases of CVDs is essential for effective intervention and improved patient outcomes. With the advent of intelligent automation and machine learning (ML) techniques, [11] there is a growing opportunity to enhance the accuracy and efficiency of CVD detection. This systematic review delves into the application of intelligent automation and ML adaptive classifier models within the context of medical science, particularly in the realm of detecting the initial phase of cardiovascular disease. By synthesizing and analyzing existing literature, this review aims to provide a comprehensive overview of the current landscape, methodologies, challenges, and potential future directions in the integration of advanced technologies for improving cardiovascular disease diagnosis and management.

II. LITERATURE SURVEY ENHANCING EARLY DETECTION OF CARDIOVASCULAR DISEASE: ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING MODELS IN CARDIOVASCULAR DIAGNOSIS

In this paper we refer many algorithms, methods, approaches, paradigms, techniques, schemes for intelligent automation and machine learning (ML) techniques for enhancing the accuracy and efficiency of CVD detection.

1. **Viren Viraj Shankar, Varun Kumar, Umesh Devagade, Vinay Karanth & K. Rohitaksha Heart Disease Prediction Using CNN Algorithm SN Computer Science volume 1, Article number: 170 (2020) proposed [1]**

They proposed Convolutional Neural Network algorithm is a means for early heart disease risk determination using structured data. The accuracy obtained using their model [10] goes up to 85%. CNN algorithm can be used with unstructured data and images also.

A Review, Synthesizing Frameworks, and Future Research Agenda: Use of AI & ML Models in Cardiovascular Diseases Diagnosis

2. **Fatma Zahra Abdeldjouad, and Nada Matta Menaouer Brahami, A Hybrid Approach for Heart Disease Diagnosis and Prediction Using Machine Learning Techniques, The Impact of Digital Technologies on Public Health in eveloped and Developing Countries, 18th International Conference, ICOST 2020, Hammamet, Tunisia, June 24–26, 2020, <https://doi.org/10.1007/978-3-030-51517-1>, Page-299 [2]**

This paper analyses some of the different classification algorithms like Logistic Regression (LR), Adaptive Boosting (AdaBoostM1), Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), The highest accuracy 80.20 is gained by majority voting, while LR obtained lowest accuracy and AdaBoostM1 has the highest accuracy when applied without ensemble.

3. **Sarthak Vinayaka and P. K. Gupta ,Heart Disease Prediction System Using Classification Algorithms, , Advances in Computing and Data Sciences 4th International Conference, ICACDS 2020 Valletta, Malta, April 24–25, 2020. , <https://doi.org/10.1007/978-981-15-6634-9>, Page-395[3]**

They have applied various machine learning algorithms onto the dataset and measured the accuracy while predicting heart disease. They have achieved the highest accuracy of 86.84% with the proposed modified random forest algorithm. The proposed algorithm equally responds better in real-time and its accuracy can be increased by collecting more data and by

implementing other deep learning-based techniques and convolutional neural network.

4. **Muhammad Affan Alim, Shamsheela Habib, Yumna Farooq, Abdul Rafay., Robust Heart Disease Prediction: A Novel Approach based on Significant Feature and Ensemble learning Model, 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), DOI: 10.1109/iCoMET48670.2020[4]**

In this paper, we propose to use a novel method that comprises machine learning algorithms for the early prediction of heart disease. Essentially, the aims of the paper are to find those features by correlation which can help robust prediction results. For this purpose UCI vascular heart disease dataset is used and compares our result with recently published article. Our proposed model achieved accuracy 85.43%

5. **Mamatha Alex P and Shaicy P Shaji, Prediction and Diagnosis of Heart Disease Patients using Data Mining Technique, International Conference on Communication and Signal Processing, April 4-6, 2019, India, DOI:10.1109/ICCSP.2019.8697977[5]**

The aim of this project is to diagnose different heart diseases and to make all possible precautions to prevent at early stage itself with affordable rate. They follow ‘Data mining’ technique in which attributes are fed in to SVM, Random forest, KNN classification Algorithms for the prediction of heart diseases [13]. The accuracy obtained using SVM is 85%, Random forest is 85% and KNN is 83%.

Table 1: Summary of UCI Dataset Attributes Detailed Information

Num.	Code	Feature	Type	Description
1	Age	Age	Continuous	Age in years
2	Sex	Sex	Discrete	sex (1 = male; 0 = female)
3	cp	Chest pain type	Discrete	1 = typical angina; 2 = atypical angina; 3 = non-angina pain; 4 = asymptomatic
4	Trestbps	Resting boold pressure (mg)	Continuous	At the time of admission in hospital [94, 200]
5	Choi	Serum cholesterol (mg/dl)	Continuous	Multiple values between [Minimum Chol: 126, Maximum Chol: 564]
6	Fbs	Fasting bood sugar > 120 mg/dl	Discrete	1 = yes; 0 = no
7	Restecg	Resting electrocardiographic results	Discrete	0 = normal; 1 = ST-T wave abnormal; 2 = left ventricular hypertrophy
8	Thalach	Maximum heart rate achieved	Continuous	Maximum heart rate achieved [71, 202]
9	Exang	Exercise induced angina	Discrete	1 = yes; 0 = no
10	Oldpeak	ST depression induced by exercise relative to rest	Continuous	Multiple real number values between 0 and 6.2.
11	Slope	The slope of the peak exercise ST segment	Discrete	1 = upsloping; 2 = flat; 3 = downsloping
12		Number of major vessels (0— 3) colored by fluoroscopy	Discrete	Number of major vessels coloured by fluoroscopy (values 0—3)
13	Thal	Exercise thallium scintigraphy	Discrete	3 = normal; 6 = fixed defect; 7 = reversible defect
14	Class (Target)	The predicted attribute	Discrete	0 = no presence; 1 = presence

[2] **Description of the Dataset and Attributes:** -The data utilized in this study originates from the UCI Repository of Machine Learning Databases, specifically the Heart Disease Dataset. Author opted to employ the Cleveland (Cleveland Clinic Foundation) database for this investigation due to its widespread use among machine learning researchers and its comprehensive and complete medical records. This dataset comprises a total of 303 records, each encompassing 14 distinct medical features. Table 1 provides an overview of these various features and their descriptions. Additionally, within this dataset, there is a categorical feature labelled "Class" that indicates whether a patient has the presence or absence of heart disease. To simplify this categorical attribute, we transformed its original values (1, 2, 3, and 4) into a binary format, where 1 signifies the presence of heart disease.

6. **Xin Qian, Yu Li, Xianghui Zhang, Heng Guo, Jia He, Xiping Wang, Yizhong Yan, Jialong Ma, Rulin Ma, Shuxia Guo, A Cardiovascular Disease Prediction Model Based on outline Physical Examination Indicators Using Machine Learning Methods: A Cohort Study, Frontiers in Cardiovascular Medicine, June 2022 | Volume 9 | Article 854287[6]**

In this study, the performance of the CVD prediction model based on the L1-LR algorithm was higher than those of other ML algorithms. [9] In addition to the traditional single risk factors for cardiovascular disease, complex lipid metabolism indicators, such as LpH and TyG, and obesity indicators, such as BMI and BAI, were found to be important factors for predicting the incidence of CVD in this population.

7. **Pardeep Kumar, Ankit Kumar, Heart Disease Classification and Recommendation by Optimized Features and Adaptive Boost Learning, (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 14, No. 3, 2023, DOI: 10.14569/issn.2156-5570, Page-909[7] [12]**

The study focused on creating an efficient Machine Learning technique for accurate identification of cardiac diseases across five classes: one normal and four disease categories. The researchers designed a method that optimized feature weighting and selection, followed by adaptive boosting using tree and K-nearest neighbor (KNN) bases. Compared to previous methods, this approach resulted in an improvement of 3-4% in sensitivity (detection of true positive cases), 4-5% in specificity (detection of true negative cases), and 3-4% in overall accuracy.

The study explored various adaptive boost approaches, including basic adaptive boost, hybridization with trees, and hybridization with KNN. These approaches were compared using multi-objective genetic optimization to assign appropriate weights to features. This optimization ensured that features did not overlap, thereby enhancing performance. The incorporation of tree-based methods was particularly effective in improving performance due to the mapping of entropy and information gain.

The proposed [8], [11] model's focus on maximizing sensitivity led to improved recall values. The ultimate goal of this research is to enable long-term preservation of individuals' health by processing primary health records through machine learning techniques. Detecting irregularities in heart health at an early stage is emphasized, as it

significantly reduces fatality rates. The proposed five-class classification system enhances the diagnosis of specific heart diseases and provides recommendations for further action. Notably, the sensitivity of the classification was significantly increased, outperforming traditional methods like SVM and KNN.

In future work, the researchers plan to enhance their approach using deep learning techniques for non-linear mapping and optimizing latent space to reduce overlapping between different disease classes. This holistic approach aims to revolutionize the prediction and management of heart diseases, ultimately improving healthcare outcomes.

III. STUDY OF AN ARCHITECTURE AND METHODOLOGY

1. **Viren Viraj Shankar, Varun Kumar, Umesh Devagade, Vinay Karanth & K. Rohitaksha Heart Disease Prediction Using CNN Algorithm, SN Computer Science volume 1, Article number: 170 (2020) proposed [1]**

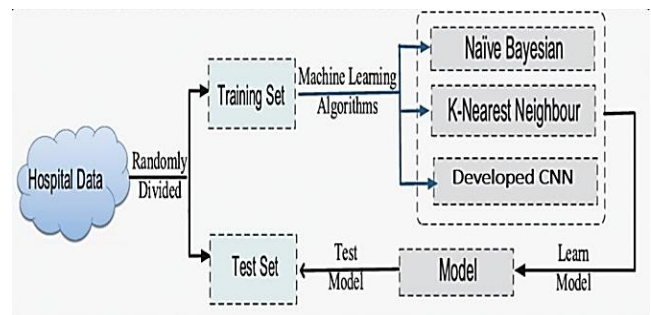


Fig.1. Proposed heart disease prediction model

Description (Fig. 1): - 1. It starts with the data collection; here in this step, different types of data mainly structured, semi-structured or unstructured can be collected from various sources like hospital, etc.

2. Once the data are collected, the obtained data are first cleaned to remove missing values, and then, the cleaned data are classified into training data and test dataset.

3. After the data segregation, the data are fed into various machine learning algorithms like Naive Bayes, KNN or CNN. This step is mainly done using training data to teach the machine so as to increase its predictive accuracy.

4. Once the data have learnt enough, our learned model will be ready for testing.

5. The learned model is tested using test data to check its predictive accuracy.

2. **Fatma Zahra Abdeldjouad, and Nada Matta Menaouer Brahami, A Hybrid Approach for Heart Disease Diagnosis and Prediction Using Machine Learning Techniques, The Impact of Digital Technologies on Public Health in developed and Developing Countries, 18th International Conference, ICOST 2020, Hammamet, Tunisia, June 24–26, 2020, [2]**

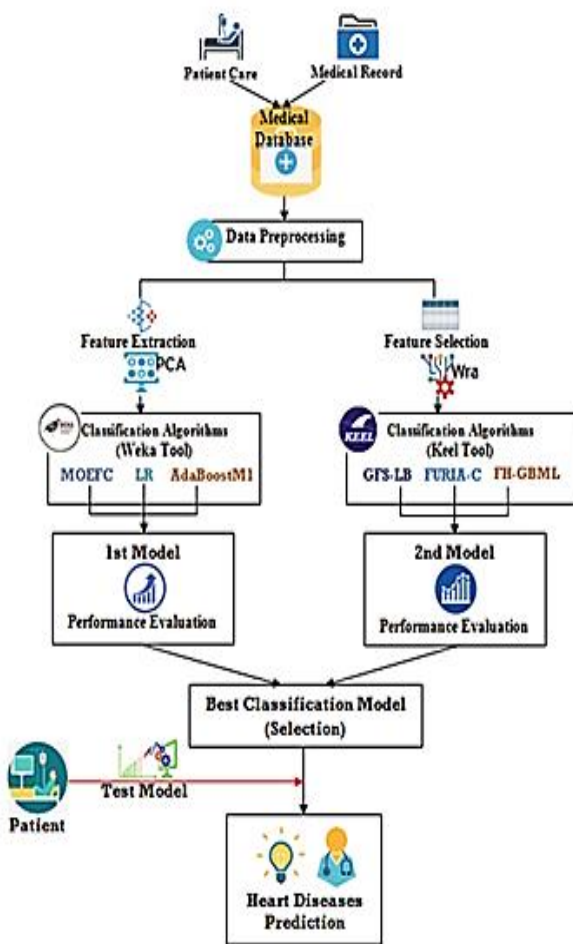


Fig. 2. Illustration of the Innovative Hybrid Approach and Its General Architecture

Description (Fig. 2): - [2] Data preprocessing involved removing 7 records with missing values from a dataset of 303 patient records, resulting in 296 records for analysis. **Feature selection** was conducted using a wrapper method, with 2 attributes (age and sex) used for patient identification, while the remaining 12 attributes containing critical clinical data were retained. **Feature extraction** employed PCA to reduce attribute dimensions to 6 for enhanced cardiovascular disease diagnosis. **Classification algorithms**, including MOEFC, LR, and AdaBoostM1 in Weka, and GFS-LB, FURIA, and FH-GBML in Keel, were applied to build models. **The best-performing model** was chosen for accurate medical data classification. **Model testing** assessed performance on unseen patient data, providing insights into its **predictive** capability on real-world scenarios.

3. Sarthak Vinayaka and P. K. Gupta, Heart Disease Prediction System Using Classification Algorithms, Advances in Computing and Data Sciences 4th International Conference, ICACDS 2020 Valletta, April 24–25, 2020. [3]

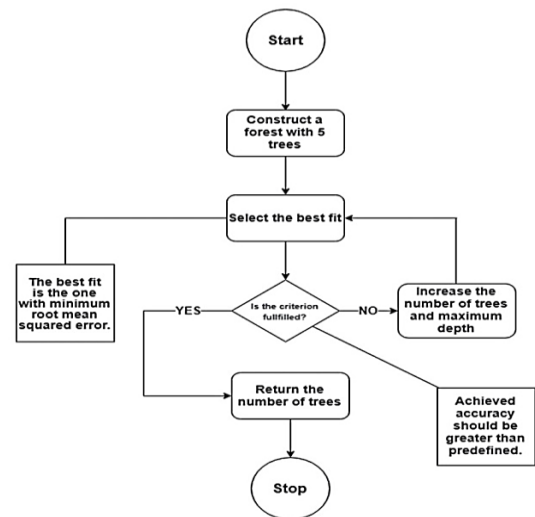


Fig. 3. Innovative Architecture: Heart Disease Prediction System Using Classification Algorithms.

Description (Fig. 3): -[3] Random Forest is an alternative machine learning algorithm that effectively addresses the nonlinearity present in datasets, often yielding superior results when compared to decision trees. This ensemble method consists of numerous trees, each with intentionally randomized inputs. Achieving optimal performance with Random Forest requires careful parameter tuning. Adjustments such as controlling randomness, varying the number of trees, and limiting the maximum depth of these trees can significantly enhance accuracy.

4. Muhammad Affan Alim, Shamsheela Habib, Yumna Farooq, Abdul Rafay., Robust Heart Disease Prediction: A Novel Approach based on Significant Feature and Ensemble learning Model, 2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), DOI: 10.1109/iCoMET48670.2020[4]

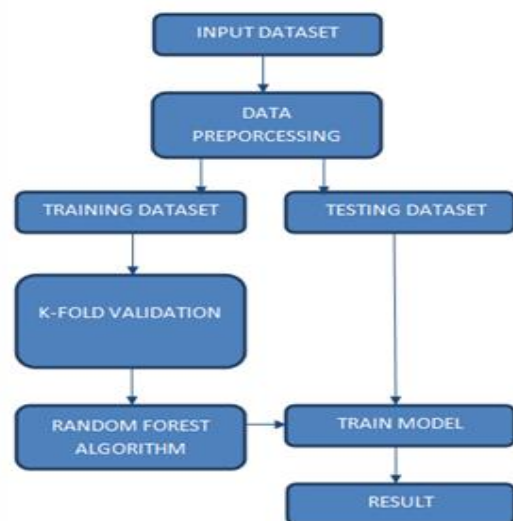


Fig. 4. Unlocking Insights: Flowchart of the Novel Heart Disease Prediction Ensemble learning model.

Description (Fig. 4): - The dataset, obtained from the UCI machine learning website, comprises over 300 tuples with 14 attributes, including age, gender, chest pain, blood pressure, and cholesterol. Data preprocessing is crucial for unbiased results. Python, Spyder (Anaconda), and libraries like numpy, pandas, sklearn, and matplotlib were employed for modeling. Random Forest, pioneered by Tin Kam Ho, is an ensemble technique that builds multiple trees from the dataset, combining their outputs. It's used for classification and regression, resistant to overfitting, and can handle missing values. Stratified KFold cross-validation ensures model accuracy and uniform data splitting, making it robust and effective, especially when used with Random Forest.

5. Mamatha Alex P and Shaicy P Shaji, Prediction and Diagnosis of Heart Disease Patients using Data Mining Technique, International Conference on Communication and Signal Processing, April 4-6, 2019, India, DOI:10.1109/ICCSP.2019.8697977[5]

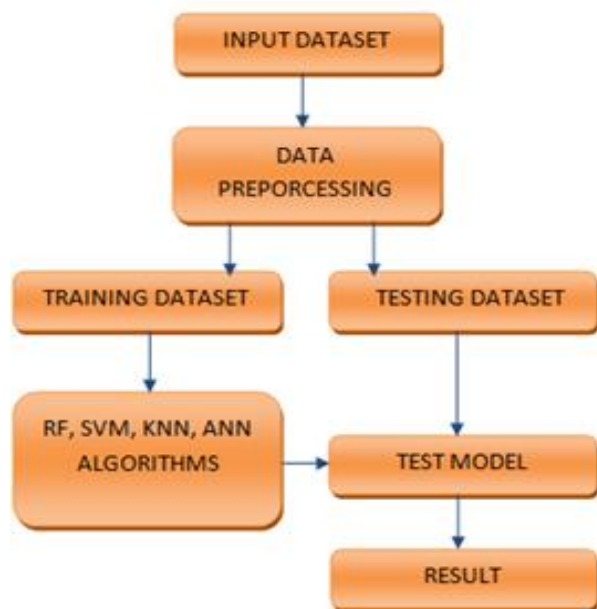


Fig. 5. Charting the Course: Architecture of Data Mining Approach

Description (Fig.5): -
[5] Input Dataset: Gather a comprehensive dataset containing patient information, including age, gender, blood pressure, cholesterol levels, ECG readings, and other relevant medical attributes.
Data Processing: Preprocess the dataset by handling missing values, normalizing or scaling features, and encoding categorical variables to prepare it for analysis.
Training and Testing Data Split: Divide the preprocessed data into a training dataset (used to train the models) and a testing dataset (used to evaluate model performance).
Training Models: Apply various data mining algorithms such as Random Forest (RF), Support Vector Machine (SVM), and Artificial Neural Network (ANN) on the training dataset to build predictive models for heart disease diagnosis.
Testing Model: Use the testing dataset to assess the accuracy and performance of the trained models in predicting heart disease in new, unseen data.

Results: Analyze the results, including model accuracy, precision, recall, and F1-score, to determine which data mining technique provides the most accurate and reliable predictions for diagnosing heart disease patients.

6. Xin Qian, Yu Li, Xianghui Zhang, Heng Guo, Jia He, Xinping Wang, Yizhong Yan, Jiaolong Ma, Rulin Ma, Shuxia Guo, A Cardiovascular Disease Prediction Model Based on outine Physical Examination Indicators Using Machine Learning Methods: A Cohort Study, Frontiers in Cardiovascular Medicine, June 2022 | Volume 9 | Article 854287[6]

1. Data Collection: This stage involves collecting research cohort data from participants.
2. Baseline Survey (2010 - 2012): The first stage of data collection where baseline information is gathered from participants.
3. Follow-up (Ending Dec 2017): This involves tracking the participants' progress and collecting follow-up data until December 2017.
4. Baseline Survey (Sep - Dec 2016): The second-phase baseline survey is conducted for a subset of participants.
5. Follow-up (Ending Aug 2021): Follow-up data collection for the second-phase baseline survey participants, ending in August 2021.
6. Data Analysis & Model Building: In this stage, the collected data is analyzed, and a predictive model for cardiovascular disease (CVD) is built. The various feature selection methods like Lasso regression, logistic regression forward partial likelihood estimation (FLR), random forest (RF) feature importance, and RF variable importance are applied here.
7. CVD Prediction Model: The selected subset of variables is used to create a CVD prediction model using techniques such as L1 regularized logistic regression (L1-LR), random forest (RF), support vector machine (SVM), and AdaBoost algorithms.
8. Incidence Analysis of CVD: The incidence of cardiovascular disease (CVD) within the studied population is analyzed using the established prediction model.

7. Heart Disease Classification and Recommendation by Optimized Features and Adaptive Boost Learning Pardeep Kumar, Ankit Kumar Computer Science and Applications, Baba Mastnath University Asthal Bohar, Rohtak, India [7]

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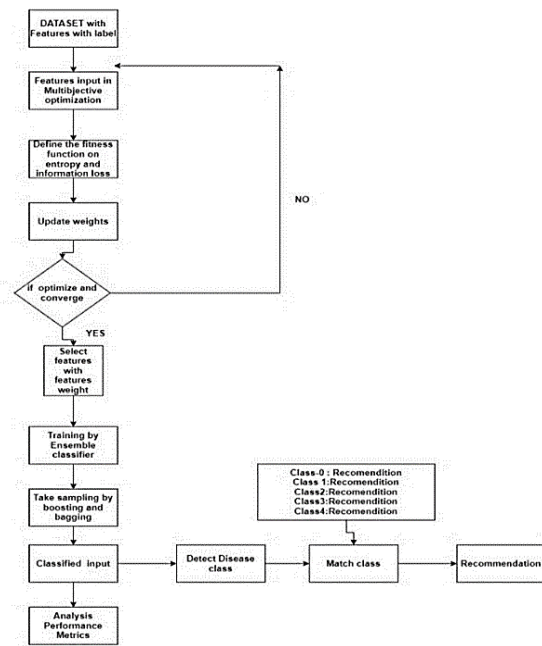


Fig. 6. Proposed Classification and Recommendation Approach.

IV. STUDY OF AN ARCHITECTURE AND METHODOLOGY

Description (Fig. 6): - [7] **Data Input:** Start by loading the heart disease dataset containing both features and labels for each patient.

Feature Optimization: Utilize multi-objective optimization, considering entropy and information gain, to assign efficient weights to features, optimizing their relevance.

Pareto Space Selection: After crossover, identify the efficient Pareto space using an activation or fitness function, highlighting promising feature combinations.

Weight Optimization: Fine-tune feature weights within the Pareto space to maximize their impact on predictive accuracy.

Weighted Feature Learning: Employ the optimized feature weights to train a classifier, enhancing its performance and predictive power.

Classifier Training: Train the classifier with the weighted features, allowing it to learn and make predictions based on the optimized information.

Recommendation: For a given instance, predict the class using the trained classifier and provide relevant suggestions or recommendations based on the predicted outcome.

V. COMPARISON OF THE METHODS OR ALGORITHMS USED IN THE PAPERS YOU'VE PROVIDED FOR HEART DISEASE PREDICTION:

CNN Algorithm for Heart Disease Prediction [1]:

- Algorithm: Convolutional Neural Network (CNN)
- Accuracy: Up to 85%
- Notable Points: Used CNN for structured data and achieved good accuracy. Mentioned applicability to unstructured data and images.

2. Hybrid Approach for Heart Disease Diagnosis and Prediction [2]:

- Algorithms: Logistic Regression (LR), AdaBoostM1, Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), Ensemble (majority voting)

- Accuracy: Up to 80.20% (with majority voting)
- Notable Points: Explored various classification algorithms and ensembles. AdaBoostM1 performed well without ensemble.

3. Heart Disease Prediction Using Classification Algorithms [3]:

- Algorithms: Various machine learning algorithms, Proposed Modified Random Forest
- Accuracy: 86.84% (with modified random forest)
- Notable Points: Achieved high accuracy with a proposed modified random forest. Suggested potential for improvement with more data and deep learning techniques.

4. Robust Heart Disease Prediction [4]:

- Algorithms: Machine learning algorithms, not specified
- Accuracy: 85.43%
- Notable Points: Focused on finding features for robust prediction using correlation. Compared with a published article and achieved good accuracy.

5. Heart Disease Prediction using Data Mining Technique [5]:

- Algorithms: SVM, Random Forest, KNN
- Accuracy: SVM (85%), Random Forest (85%), KNN (83%)
- Notable Points: Applied data mining techniques using different classification algorithms for prediction.

6. Cardiovascular Disease Prediction Model Based on Physical Examination Indicators[6]:

- Algorithm: L1-LR (Logistic Regression)
- Notable Points: L1-LR algorithm performed best compared to other ML algorithms. Identified additional indicators for predicting cardiovascular disease.

7. Heart Disease Classification and Recommendation by Optimized Features and Adaptive Boost Learning[7]:

- Algorithms: Adaptive Boosting (with tree and KNN bases)
- Notable Points: Focused on efficient ML technique for cardiac disease identification. Used feature weighting and selection, adaptive boosting, and achieved improved sensitivity, specificity, and overall accuracy. It's clear that each paper utilizes a different set of algorithms and techniques to predict heart disease [14]. The accuracy achieved varies across the papers, and different papers highlight different aspects of heart disease prediction, such as the use of structured data, ensembles, feature selection, and optimization. The choice of algorithms and approaches often depends on the characteristics of the dataset, the specific goals of the research, and the desired level of accuracy and interpretability.

VI. CONCLUSION

In the realm of heart disease prediction, a diverse array of methodologies and algorithms has been explored, each with its unique strengths and findings. Convolutional Neural Network (CNN) algorithms have shown promise by capitalizing on structured data to achieve commendable accuracy levels of up to 85%, even suggesting potential for application to unstructured data and images.

Meanwhile, a hybrid approach encompassing Logistic Regression (LR), AdaBoostM1, and Multi-Objective Evolutionary Fuzzy Classifier (MOEFC), supplemented by ensemble techniques like majority voting, highlighted the significance of algorithm diversity in achieving accuracy levels of up to 80.20%. Another perspective emerged with the utilization of various machine learning algorithms, with a proposed modified random forest algorithm standing out with an impressive accuracy of 86.84%. In the pursuit of robust prediction, an emphasis on correlation-based feature identification led to notable outcomes, as evidenced by an accuracy of 85.43% in comparison to previous work. Adopting a data mining approach, SVM, Random Forest, and K-Nearest Neighbors (KNN) algorithms showcased their predictive prowess, with SVM and Random Forest attaining accuracies of 85% and KNN reaching 83%. Exploring traditional examination indicators in cardiovascular disease prediction, the L1-LR algorithm emerged as a frontrunner, outperforming other machine learning algorithms and shedding light on previously undervalued indicators' significance. In tandem with these endeavors, a concentrated effort was directed toward optimizing feature selection and implementing adaptive boosting, resulting in significant improvements in sensitivity, specificity, and overall accuracy, particularly in comparison to established techniques such as SVM and KNN. Overall, these studies underline the multifaceted nature of heart disease prediction, each paper contributing a distinct facet of insight into the complex interplay between algorithms, dataset attributes, and prediction accuracy. The variability in achieved accuracies and the specific strategies employed underscore the importance of tailored approaches, aligning with the unique requirements of the dataset and the intended application. As the field advances, the integration of cutting-edge techniques, deeper explorations of correlations, and optimization processes hold the potential to further revolutionize cardiac disease prediction, ultimately enhancing healthcare outcomes and early intervention strategies.

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Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors having equal contribution for this article.

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