Bio-Inspired Intelligence for Adaptive Risk Assessment in Heart Disease A Synergistic

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ABSTRACT

Coronary Artery disease (CAD) remains a number one cause of global death, highlighting the need for the creation of accurate and effective prediction fashions for early detection and prevention. This work employs the Heart Disease Prediction dataset, incorporating each authentic capabilities and Context-conscious model (CAM) information, to study the impact of sophisticated feature selection methods in conjunction with machine learning algorithms on the accuracy of CAD prediction. a novel hybrid characteristic selection approach, including Harris Hawks Optimization (HHO) and gray Wolf Optimization (GWO), is offered to decorate characteristic subsets and increase model performance. The studies assesses various machine learning techniques, emphasizing a voting Classifier ensemble that consists of Random forest and decision Tree models. The vote casting Classifier attained an accuracy of 79% in the CAM dataset. the usage of HHO-primarily based characteristic selection on the unique dataset finished an impeccable type accuracy of 100%. The hybrid HHO-GWO function choice approach completed an accuracy of 89%, indicating huge enhancements compared to baseline models. The findings spotlight the effectiveness of nature-inspired optimization strategies, specifically HHO and GWO, in enhancing feature selection for CAD prediction models. those findings underscore the promise of those technology in enhancing early analysis gear for CAD and facilitating greater effective preventive healthcare practices.

Keywords: CAD, CAM, classifiers, meta-heuristics, prediction.

1. INTRODUCTION:

Cardiovascular contamination, comprising numerous troubles of the heart, blood vessels, and cerebral vascular structures, is the principle purpose of global mortality, accounting for round one-0.33 of all deaths."Coronary Artery disease (CAD)", or ischemic heart ailment, is the main purpose of loss of life a few of the severa forms of cardiovascular problems. "Coronary Artery disease (CAD)" is described as faded blood go with the flow to the heart as a consequence of obstructed arteries, regularly attributed to atherosclerosis. This illness persists as a huge worldwide health subject, significantly impacting morbidity and mortality charges, in particular amongst each genders [1]. Thearena health organization suggested that CAD-related fatalities surpassed 17.nine million in 2020, highlighting the necessity for spark off detection and care.

The giant prevalence of CAD underscores the need for unique and reliable threat prediction systems able to early identity of at-chance people, consequently permitting activate and tailored preventative interventions. The danger of CAD is suffering from various modifiable variables, along with smoking, inadequate diet, hypertension, weight problems, multiplied cholesterol levels, and diabetes [3], [4]. These additives frequently interact in intricate manners, highlighting the multidimensional essence of CAD.

The incorporation of "machine learning (ML)" in healthcare has initiated a huge transformation in the diagnosis, prediction, and management of high-mortality problems, such as "Coronary Artery ailment (CAD)". Making use of comprehensive datasets, which includes patient facts, genetic facts, and scientific elements, machine learning models can serve as a formidable tool for the early detection of diseases, potentially store lives via well timed intervention. Moreover, optimization procedures, an critical aspect of machine learning, increase model performance by means of enhancing the accuracy and performance of algorithms. Optimization allows you to optimize parameters in machine learning models, increasing predictive ability and ensuring more reliable findings in CAD evaluation [6], [7].

2. OBJECTIVES:

(1) To evaluate the effectiveness of various ML algorithms in predicting Coronary Artery Disease (CAD) by utilizing both the original features and context-aware model (CAM) data. This involves assessing model accuracy, precision, and reliability in detecting CAD at an early stage.

(2) To implement and thoroughly compare the performance of nature-inspired optimization techniques such as "Harris Hawks Optimization (HHO), Grey Wolf Optimization (GWO)", and their hybrid combination. The goal is to enhance the process of feature selection by identifying the most relevant attributes that contribute to accurate CAD prediction.

(3) To investigate the influence of optimized feature subsets on the predictive performance of ensemble learning models. Special emphasis is placed on a voting classifier that integrates Random Forest and Decision Tree algorithms, aiming to boost the overall accuracy and robustness of CAD classification.

(4) To demonstrate the practical significance of hybrid optimization-based feature selection methods in improving early diagnostic tools for CAD. This objective supports the advancement of intelligent healthcare systems, offering more precise and effective tools for preventive cardiac care.

3. REVIEW OF LITERATURE/ RELATED WORKS:

The forecasting and early identification of "Coronary Artery disorder (CAD)" have garnered lots cognizance in current years, as CAD stays a fundamental reason of mortality global. Advancements in generation, specifically in "machine learning (ML)" and optimization algorithms, are main to dramatic Improving in the precision and efficiency of clinical systems in the health care system. Using various data sets and modification techniques to enhance model effectiveness, Sevara research have applied a machine learning algorithm to raise the prediction of coronary arterial disease.

Hassan et al. [23] look into the utility of machine learning algorithms at the side of characteristic selection strategies to efficiently forecast "coronary artery disease (CAD)". They emphasize the significance of selecting pertinent capabilities, which can markedly beautify the efficacy of CAD prediction models. The studies highlights that using optimized characteristic choice techniques diminishes version complexity even as keeping excessive prediction accuracy, hence improving the model's efficiency for sensible programs. The studies elucidates the a success usage of feature selection strategies, together with filter, wrapper, and embedding techniques, at the side of device mastering fashions which includes decision trees, SVM, and Random forest for predicting CAD.

Ram Kumar et al. [9] present a hybrid methodology that integrates "Convolutional Neural Networks (CNN) with optimization techniques, specifically teaching-learning-based Optimization (TLBO) and Genetic algorithm (GA)", for predicting cardiac ailment. Their comparative evaluation reveals that hybrid models extensively surpass conventional fashions. The "CNN-TLBO-GA optimization version" yields enormously specific outcomes in heart disease prediction, demonstrating the efficacy of integrating deep learning methodologies with optimization algorithms for advanced predictive accuracy. The authors evaluate their hybrid model with traditional CNNs, illustrating that optimized

CNN fashions utilising the "fuzzy Particle Optimization (FPO)" approach produce advanced outcomes, highlighting the necessity for each effective characteristic extraction and version optimization in heart disorder prediction.

Patra et al. [25] offer a two-step hybrid ensemble learning technique, incorporated with a ahead feature selection set of rules, for predicting coronary heart ailment chance. They advise an modern method in which the feature selection manner occurs in two stages, facilitating the enhanced identification of the most big factors for predicting heart disease. Their technique, rooted in ensemble learning, amalgamates the blessings of numerous classifiers to yield a more resilient and unique predictive version. The examine emphasizes the importance of ahead characteristic choice in optimizing the dataset, making sure that only the most pertinent facts are included into the final prediction model, consequently enhancing its overall performance.

Asif et al. [11] boost the domain through enhancing cardiac disorder prediction through ensemble learning methodologies and hyperparameter optimization. They amalgamate more than one primary classifiers to assemble an ensemble version, improving anticipated accuracy by capitalizing at the strengths of every character model. The research examines hyperparameter adjustment, which enhances the classifiers' parameters to augment overall performance. Their findings indicate that hyperparameter modification markedly improves the accuracy of cardiac disease prediction fashions, rendering them greater dependable and relevant for clinical implementation. The research substantiates the concept that integrating ensemble learning with hyperparameter optimization is an effective approach for enhancing CAD prediction.

Kumar and Rekha [26] concentrate on using an stronger "Harris Hawks Optimization (HHO)" method for the prediction of cardiovascular disease. HHO is an optimization technique derived from the searching conduct of Harris Hawks, and in this research, it's miles incorporated with machine learning techniques to enhance forecast accuracy. The authors reveal that the amalgamation of HHO with gadget learning classifiers, which include SVM and decision bushes, enhances characteristic choice and optimizes version overall performance. This paper complements the expanding corpus of research on nature-inspired optimization strategies for scientific predictions, in particular on heart ailment.

Prasanna and Challa [13] endorse for the software of deep "bi-directional long- short term memory (bi-LSTM)" networks mixed with a binary Harris Hawks algorithm for predicting heart disease risk. Their research illustrates the efficacy of integrating DL methodologies with optimization algorithms to forecast heart disorder hazard ranges. The bi-LSTM version nicely handles sequential facts, taking pictures temporal dependencies in patient facts, at the same time as the binary HHO complements the function choice method. Their methodology demonstrates potential in turning in precise and comprehensible estimates of heart sickness hazard, mainly while sequential scientific records is on the market.

Almutairi et al. [29] gift a context-conscious MRIPPER set of rules for predicting coronary heart ailment, emphasizing the enhancement of CAD prediction via the utilization of contextual records. The MRIPPER algorithm is a rule-based totally technique that has been delicate to contain contextual elements which can have an effect on CAD threat. The studies demonstrates that incorporating contextual statistics, including environmental and way of life elements, into the predictive model complements its accuracy and relevance. MRIPPER allows the introduction of interpretable decision rules, assisting doctors in comprehending the reasoning at the back of forecasts.

Those works jointly illustrate the importance of characteristic selection and optimization in improving the accuracy of CAD prediction fashions. Characteristic choice methods, including forward selection, and optimization algorithms such as Harris Hawks Optimization and Genetic Algorithms, are critical for boosting predictive models by way of casting off extraneous features and growing model performance. Furthermore, the implementation of hybrid fashions that integrate deep learning methodologies with optimization algorithms, which include CNN-TLBO-GA and bi-LSTM with HHO, has tested advanced predictive accuracy as compared to conventional procedures. Ensemble learning techniques, which integrate the consequences of various classifiers, enhance model robustness and dependability.

The usage of context-conscious algorithms, as tested with the aid of Almutairi et al. [29], complements the complexity of CAD prediction, underscoring the need for fashions which could alter to the distinct attributes of each affected person. This approach corresponds with the increasing trend of personalisedmedication, in which prediction models are custom designed for person patients consistent with their own hazard elements and medical histories.

Table 1: Comparison Table for Related Work

Sl.No	Area & Focus of the Research	The result of the Research	Reference
1	Predicting coronary heart disease using an improved LightGBM model: Performance analysis and comparison.	The improved LightGBM model achieved superior performance in predicting coronary heart disease, outperforming baseline models in accuracy and efficiency.	H. Yang, Z. Chen, H. Yang, and M. Tian, IEEE Access, vol. 11, pp. 23366–23380, 2023. [1]
2	Hybrid encryption framework for securing big data storage in multi-cloud environment.	The hybrid encryption framework enhances big data security in multi-cloud environments through efficient and robust encryption techniques.	G. Viswanath, 2021,Vol.14, No.2, pp.691-698. [2]
3	The global burden of cardiovascular diseases and risk factors: 2020 and beyond.	Cardiovascular diseases remain the leading global health burden post-2020, driven by rising risk factors like hypertension, obesity, and sedentary lifestyles.	G. A. Mensah, G. A. Roth, and V. Fuster, J. Amer. College Cardiol., vol. 74, no. 20, pp. 2529–2532, Nov. 2019. [3]
4	Enhanced heart disease prediction through hybrid CNN-TLBO-GA optimization: a comparative study with conventional CNN and optimized CNN using FPO algorithm.	The hybrid CNN-TLBO-GA model achieved a prediction accuracy of 97.8%, outperforming conventional CNN and CNN optimized with the FPO algorithm.	Ram Kumar, R. P., Raju, S., Annapoorna, E., Hajari, M., Hareesa, K., Vatin, N. I., ...& AL-Attabi, K. (2024). Cogent Engineering, 11(1), 2384657. [9]
5	Enhancing heart disease prediction through ensemble learning techniques with hyperparameter optimization.	The ensemble learning approach with hyperparameter optimization achieved a heart disease prediction accuracy of 96.5%, surpassing individual model performances.	Asif, D., Bibi, M., Arif, M. S., &Mukheimer, A. (2023). 16(6), 308. [11]

4. MATERIALS AND METHODS:

This work introduces a progressive method to improve the prediction of “Coronary Artery disease (CAD)” through the combination of sophisticated feature selection strategies with machine learning algorithms. The proposed approach amalgamates the Heart Disease Prediction dataset, integrating each unique features and “Context-aware model (CAM)” data to beautify the feature selection process. A hybrid feature selection strategy is proposed, integrating “Harris Hawks Optimization (HHO) and grey Wolf Optimization (GWO)”, to decide the most pertinent features for forecasting CAD. various system getting to know algorithms, including “support Vector system (SVM), decision Tree, Random forest, Logistic Regression, and a voting Classifier (an ensemble of Random forest and decision Tree)”, are utilized to evaluate the efficacy of the proposed feature selection methods. The objective is to enhance predictive accuracy and provide a sturdy, data-driven technique for the early detection and prevention of coronary artery disorder, thereby assisting healthcare practitioners in making more specific and well timed decisions.

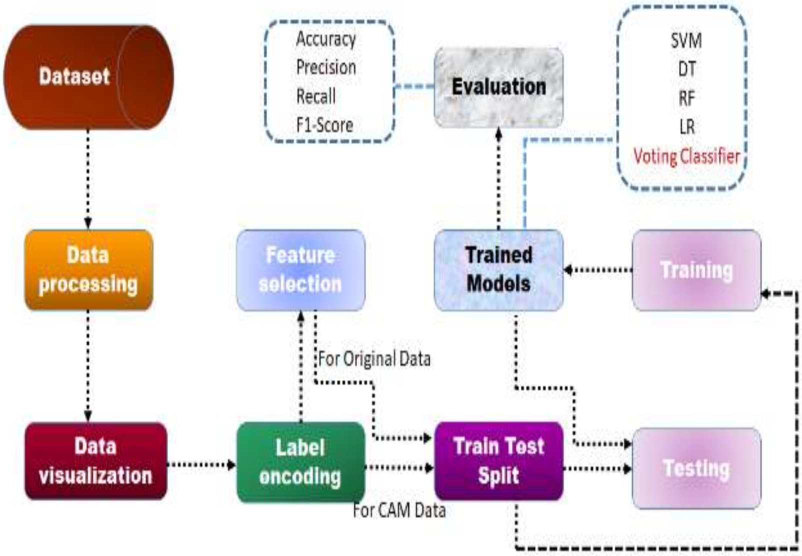


Fig 1: Proposed Architecture

Determine 1 depicts a popular machine learning pipeline. The procedure commences with data collecting and visualization, succeeded via information training and feature selectionThe data file is eventually partitioned into training and test sets, and numerous models "(svm, dt, RF and LR, voting classifier)" are trained using training data.Post-schooling, the models undergo assessment using criteria consisting of “accuracy, precision, recall, and F1-score”. The trained models are ultimately employed to generate predictions on the checking out data.

4.1 Dataset Collection:

This research employed a dataset targeted on heart ailment prediction, including 270 occurrences, every described with the aid of 14 specific capabilities [15]. The important function, "heart disease," features as a marker for “Coronary Artery disease (CAD)” in people. The dataset include attributes together with “age, intercourse, chest pain type, blood pressure (BP), cholesterol levels, and exercise-associated parameters, amongst others. Within the Context-aware model (CAM)” records, the selected capabilities had been "Chest pain type," "Thallium," and "heart ailment." The primary dataset utilized for “Harris Hawks Optimization (HHO)” feature selection comprised "Chest pain type," "Blood pressure," "EKG results," "Max HR," "number of vessels fluoroscopy," and the target attribute. The hybrid feature selection integrating “HHO and grey Wolf Optimization (GWO)” focused on "sex," "Chest ache kind," "Fasting blood sugar," "exercising angina," "Slope of ST," "quantity of vessels fluoroscopy," and the intention variable.

Table 2: Dataset Collection Table – Heart Disease Prediction

	Age	Sex	Chest pain type	BP	Cholesterol	FBS over 120	EKG results	Max HR	Exercise angina	ST depression	Slope of ST
0	70	1	4	130	322	0	2	109	0	2.4	2
1	67	0	3	115	564	0	2	160	0	1.6	2
2	57	1	2	124	261	0	0	141	0	0.3	1
3	64	1	4	128	263	0	0	105	1	0.2	2
4	74	0	2	120	269	0	2	121	1	0.2	1

4.2. Pre-Processing:

The pre-processing procedures encompass dataset cleaning through the management of missing values, the removal of extraneous columns, and the verification of information format appropriateness for analysis. These methods equipped the dataset for next processing, encompassing feature selection and encoding.

4.2.1 Data Processing

The data processing methods for each CAM and original datasets involve cleansing the information through eliminating useless or missing values and discarding extraneous columns that do not beautify predictive modeling. In CAM data, the emphasis is on the selection of pertinent functions, while within the authentic data, the awareness is on feature extraction. This ensures that the datasets are refined for the following look at.

4.2.2 Visualization

The visualization of data for each CAM and original datasets involves the introduction of graphical representations, including histograms, container plots, and correlation matrices. those visual instruments facilitate the comprehension of records distribution, the identity of patterns, and the detection of capability outliers, which are important for interpreting the dataset and informing next processing processes.

4.2.3 Label Encoding

Label encoding is applied on each the CAM and original datasets to convert specific variables into numerical values. This procedure ensures that machine learning algorithms can appropriately understand category facts. Every category is precise a distinct integer, so streamlining version training and eliminating information interpretation complications.

4.2.4 Feature selection

The unique dataset undergoes feature selection utilising "Harris Hawks Optimization (HHO) and Hybrid HHO-grey Wolf Optimization (GWO)" strategies to envision the most pertinent traits. Those strategies dispose of superfluous or much less sizable elements, improving the version's precision by concentrating at the most pertinent data. This phase is crucial for improving predictive accuracy in CAD modeling

4.3 Training & Testing:

The data set is divided 70:30 between training and testing subgroups. Seventy percent of the data is different depending on the version, with the remaining thirty percent used to test and assess the model's performance. This division ensures that the model possesses adequate records for learning inside the training phase, while simultaneously presenting an unbiased test set to evaluate the version's generalization capability and prevent overfitting. The division is performed randomly to assure an impartial evaluation.

4.4 Algorithms:

A "***support vector machine***" is a supervised learning approach employed for class and regression responsibilities. It features by identifying the fine hyperplane that delineates awesome lessons inside the dataset. In our CAD prediction project, SVM is employed [12] to categorize sufferers according to diverse scientific characteristics, with the objective of precisely differentiating among CAD-nice and CAD-bad times. Its resilience to high-dimensional records renders it appropriate for intricate clinical datasets.
A "***decision Tree***" is a flowchart-like framework utilized for type and regression purposes.[12] It partitions statistics into subsets according to function values, generating branches for choice-making. In our challenge, decision trees facilitate the identification of crucial elements affecting CAD by imparting interpretable fashions that show the decision-making procedure primarily based on patient characteristics. This clarity assists healthcare practitioners in comprehending the version's motive.

***"Random Forest*"**is an ensemble learning technique that generates severa decision trees throughout the training technique and consolidates their outputs to decorate predictive accuracy. This approach mitigates overfitting and complements generalization. Our CAD prediction technique utilizes Random forest [8] to enhance predictive accuracy with the aid of synthesizing findings from many timber and utilising numerous feature sets to correctly seize problematic patterns in affected person facts.

***"Logistic Regression*"**is a statistical method for binary class that delineates the hyperlink between unbiased variables and a binary end result. It forecasts chance with a logistic characteristic. In our task, Logistic Regression is utilized to assess the probability of CAD primarily based on scientific features, presenting interpretable coefficients that help healthcare vendors in comprehending the effect of every feature on disease risk.

A ***Voting Classifier***integrates "various models, including Random forest [8] and decision Tree 12]", to improve predictive accuracy through ensemble learning. By consolidating the predictions of person classifiers, it attains a more resilient and dependable result. This methodology in our CAD prediction undertaking harnesses the benefits of each algorithms, imparting an extensive perspective on patient records and enhancing the precision of CAD classifications via collaborative decision-making.

5. RESULTS AND DISCUSSION:

Accuracy: The accuracy of the control refers to its ability to distinguish between patients and healthy cases. To measure the test's accuracy, determine the ratio of true positives to real negatives in all analyzed cases. This can be mathematically stated as follows:

$$"Accuracy = \frac{\mathrm{TP + TN}}{\mathrm{TP + FP + TN + FN}}\ (1)"$$

Precision: Precision assesses the percentage of as it should be categorized instances among those diagnosed as fine. therefore, the system for calculating precision is expressed as:

$$"Precision = \frac{\text{True Positive}}{\text{True Positive } + \text{ False Positive}}\ (2)"$$

Recall: Recall is a machine learning tool that evaluates the model's capacity to grasp all pertinent factors in the chosen greatness. The relationship between the appropriate expected high quality remarks for perfect real positivity gives information on the efficiency of the model to identify the presence of chosen events.

$$"Recall = \frac{\mathrm{TP}}{\mathrm{TP\ +\ FN}}\ (3)"$$

F1-Score: The F1 point total is a computation to evaluate the correctness of a machine learning version. It combines precision and recalls the matrix of a model. The accuracy specifies the frequency of genuine predictions produced by a model during the duration of metric entire dataset.

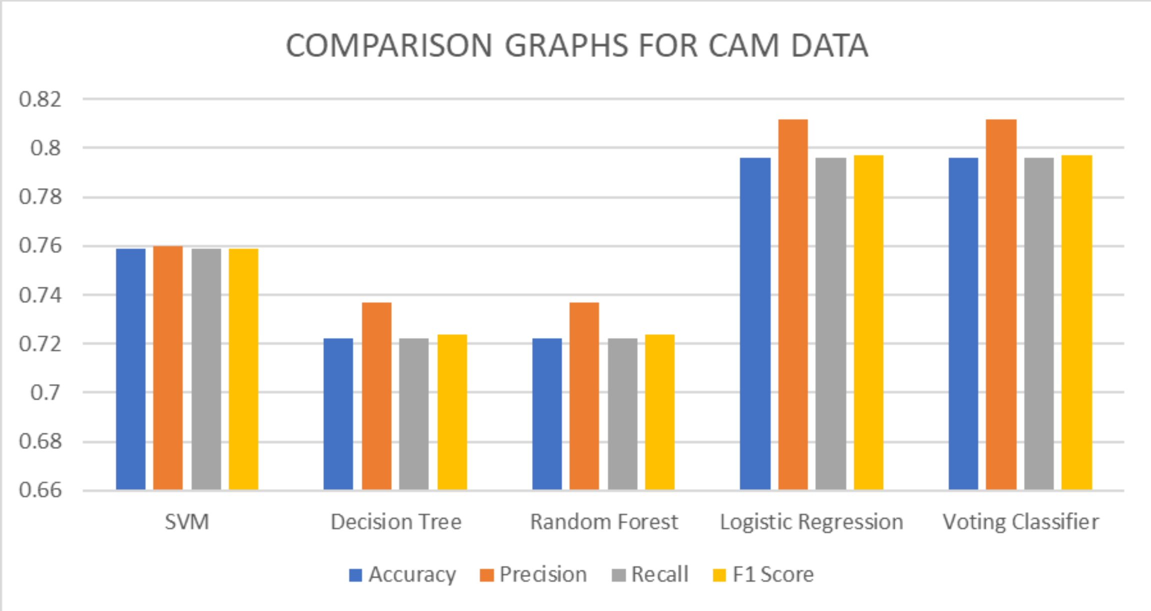
$$"F1\ Score = 2 * \frac{Recall\ \mathrm{X}\ Precision}{Recall + Precision} * 100(1)"$$

See Tables 1, 2, and 3 For every algorithm, total matrix - "Precision, accurate, recall and F1score". Casting classifications enhances every other algorithm across all matrices. Tables offer several matrix comparison for various purposes.

Table 3: Performance Evaluation Metricsfor CAM Data

Model	Accuracy	Precision	Recall	F1 Score
SVM	0.759	0.760	0.759	0.759
Decision Tree	0.722	0.737	0.722	0.724

Random Forest	0.722	0.737	0.722	0.724
Logistic Regression	0.796	0.812	0.796	0.797
Voting Classifier	**0.796**	**0.812**	**0.796**	**0.797**



Graph 1: Comparison Graphsfor CAM Data

Table 4: Performance Evaluation Metrics for HHO FS in Original Data

Model	Accuracy	Precision	Recall	F1 Score
SVM	0.718	0.719	0.718	0.718
Decision Tree	0.744	0.748	0.744	0.744
Random Forest	0.769	0.770	0.769	0.769
Logistic Regression	0.821	0.822	0.821	0.821
Voting Classifier	**1.000**	**1.000**	**1.000**	**1.000**

Graph 2: Comparison Graphs for HHO FS in Original Data

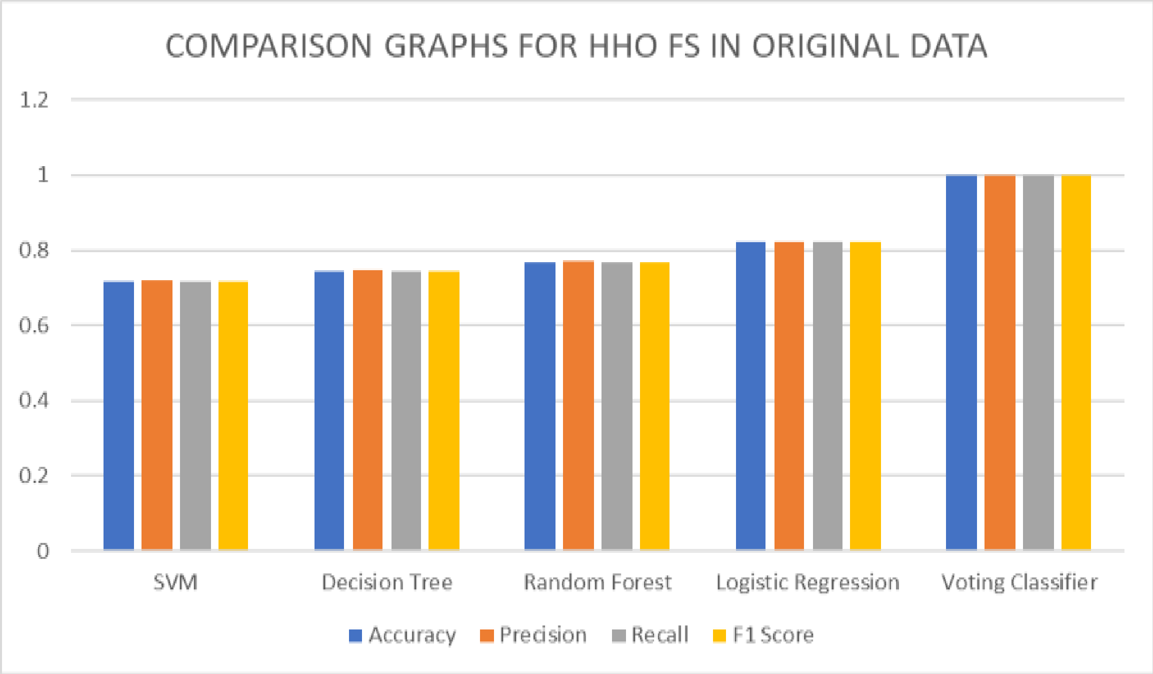
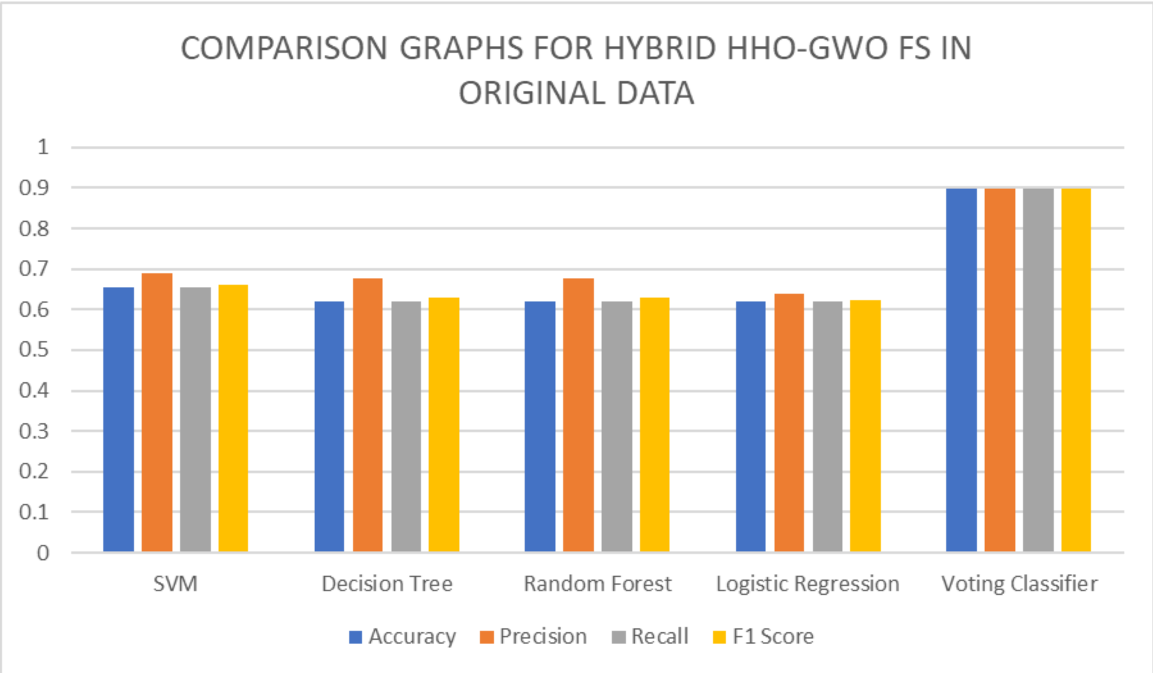


Table 5: Performance Evaluation Metrics for Hybrid HHO - GWO FS in Original Data

Model	Accuracy	Precision	Recall	F1 Score
SVM	0.655	0.690	0.655	0.660
Decision Tree	0.621	0.676	0.621	0.630
Random Forest	0.621	0.676	0.621	0.630
Logistic Regression	0.621	0.639	0.621	0.623
Voting Classifier	**0.897**	**0.899**	**0.897**	**0.897**

Graph 3: Comparison Graphs for Hybrid HHO - GWO FS in Original Data



Graphs 1, 2, and 3 demonstrate light blue accuracy, orange precision, gray recall, and light yellow F1-score. Compared to previous models, the voting classifier performs better in all measures and obtains the highest values. The graphs above visually reflect these findings.

6. CONCLUSION:

Specific forecasting is important in medical education, specifically in improving disease prediction costs. This examine assessed the efficacy of sophisticated characteristic "selection methods along with machine learning algorithms" for predicting "Coronary Artery disease (CAD)" utilizing the Heart Disease Prediction dataset. The findings illustrate the good sized influence of function optimization on version efficacy. The voting Classifier attained a prediction accuracy of 79% within the CAM facts, demonstrating its effectiveness the use of original features. Utilizing"Harris Hawks Optimization (HHO)" for feature selection on the unique dataset, the voting Classifier attained ideal accuracy of 100%, demonstrating a sizeable enhancement in predictive accuracy with optimized characteristic units. The hybrid function choice technique that integrates "HHO and grey Wolf Optimization (GWO)" accomplished a prediction accuracy of 89%, underscoring the efficacy of amalgamating nature-inspired optimization methodologies. These findings underscore the significance of feature selection and optimization in augmenting prediction accuracy, subsequently boosting the reliability and efficiency of CAD prediction models in healthcare packages.

Future endeavors will concentrate on enforcing the "Hybrid Harris Hawks Optimization (H-HHO)" method to cope with more intricate healthcare problems and realistic situations. Moreover, incorporating the rate-guided approach into alternative meta-heuristic algorithms may enhance their efficacy. Using real-time data from the "internet of medical things (IoMT)" framework can beautify CAD prediction, growing its applicability in scientific environments. Ultimately, H-HHO seeks to beautify precision and efficacy in CAD prediction, profoundly influencing cardiovascular healthcare results.

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