Performance Evaluation of Machine Learning Models to Predict Heart Attack

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Abstract. Coronary Artery Disease is the type of cardiovascular disease (CVD) that happens when the blood vessels which stream the blood toward the heart, either become tapered or blocked. Of this, the heart is incapable to push sufficient blood to encounter its requirements. This would lead to angina (chest pain). CVDs are the leading cause of mortality worldwide. According to WHO, in the year 2019 17.9 million people deceased from CVD. Machine Learning is a type of artificial intelligence that uses algorithms to help analyse large datasets more efficiently. It can be used in medical research to help process large amounts of data quickly, such as patient records or medical images. By using Machine Learning techniques and methods, scientists can automate the analysis of complex and large datasets to gain deeper insights into the data. Machine Learning is a type of technology that helps with gathering data and understanding patterns. Recently, researchers in the healthcare industry have been using Machine Learning techniques to assist with diagnosing heart-related diseases. This means that the professionals involved in the diagnosis process can use Machine Learning to help them figure out what is wrong with a patient and provide appropriate treatment. This paper evaluates different machine learning models performances. The Supervised Learning algorithms are used commonly in Machine Learning which means that the training is done using labelled data, belonging to a particular classification. Such classification methods like Random Forest, Decision Tree, K-Nearest Neighbour, XGBoost algorithm, Naïve Bayes, and Support Vector Machine will be used to assess the cardiovascular disease by Machine Learning.

Key words: cardiovascular disease, Machine Learning, heart attack, prediction.

1. Introduction

The heart is a very important organ of our body and most diseases involve the heart in some way. Heart disease refers to any condition that affects the heart and its ability to pump oxygen-rich blood to other parts of the body. There are different types of heart diseases, including coronary artery disease, congenital heart disease, and arrhythmias. Common symptoms can include chest pain, dizziness, and sweating. Risk factors for heart disease include smoking, high blood pressure, diabetes, and obesity [20]. Early monitoring and detection of heart diseases can greatly reduce the mortality rate. However, many people seek medical attention from a heart specialist only after the disease has progressed significantly [15]. Research on new therapeutic drug agents is ongoing (see for example [7]) but predicting a dangerous situation before it occurs is highly desirable.

Predictions about whether someone is likely to develop a heart disease in the future are therefore incredibly important. Unfortunately, these predictions are often not accurate, leading to premature death. To help with this problem, Artificial Intelligence is used to create algorithms that can process data in a way that is similar to processing performed by humans. Biological factors as training data for machine learning algorithms are used in order to teach a machine to recognize patterns that occur in nature. Examples of these biological factors include chest pain, angina, hypertension, age, cholesterol, blood pressure, sex, etc. By using these data, the machine learning algorithms are provided with enough information to accurately predict patterns in the real world [13]. In this paper, we are using various factors from biology, like cholesterol, blood pressure, sex, and age, as the data used in the experiments. The aim is to use these data to train machine learning algorithms, such as decision trees, linear regression, K-Nearest Neighbour classifiers (K-NN), and Support Vector Machine (SVM). We are trying to prove which algorithm can offer the best accuracy with these data sets. We shall then compare the accuracy of the four distinct machine learning algorithms, and try to determine which has the best accuracy.

2. Why machine learning

Machine learning is a type of technology that involves getting a computer to learn from datasets and use this knowledge to make decisions. It does this by following two steps. The first step is the training phase, where the computer is fed data that it can learn from. The second step is testing, where the computer uses the data it has learned from the training phase to make decisions that meet the specific requirements of the application [25].

According to [22], there are three categories of machine learning algorithms: Reinforcement Learning, Supervised Learning, and Unsupervised Learning, as shown in Figure 1.

Reinforcement Learning involves teaching the computer to achieve goals by trial and error and providing rewards for successful outcomes.

Supervised Learning uses labeled data (data belonging to known groups) to understand patterns in the data and then use them to identify and predict data groups in the future. In this paper we shall pay attention mainly, but not exclusively, to the classification methods which belong to Supervised Learning methods. They are divided into five sub-categories: Naïve Bayes classifier, Decision Trees, Support Vector Machines, Random Forest, and K–Nearest Neighbours. In this paper we shall also consider linear regression and Neural Networks, which according to [22] belong to Regression methods.

Unsupervised Learning is the process of creating new information and relationships by sorting unlabeled data into groups and categories, creating associative relationships, and using the Hidden Markov Model to predict future probabilities.

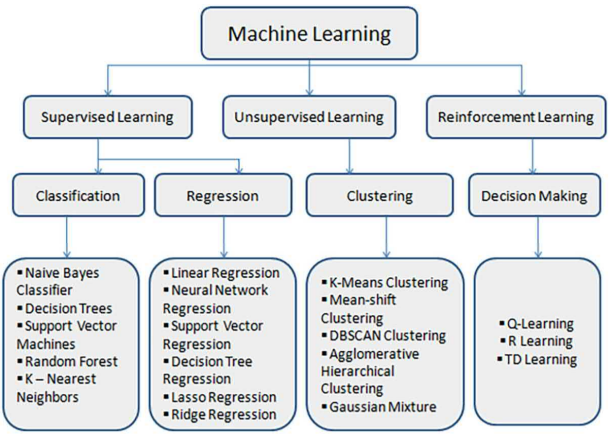


Fig. 1. Machine Learning classification. Source: [22], license: CC BY 3.0.

The machine learning methods seem to be very promising in predicting various heart diseases, which can be concluded from the literature we shall review in the next Section.

3. Literature review

Recently, different studies have been conducted to try and figure out how to predict when someone might have a heart attack. The results of these studies have been published that define proposed solutions to the prediction of Heart Attacks. This section refers to the use of machine learning algorithms, which are sets of instructions to a computer that allow it to learn from data, and about how researchers have used these algorithms to predict heart attacks. Below we have summarized and discussed a number of works to see how successful they have been.

Saw et al. [18] used data from electronic medical records, examining each element of the data and the effects it had on the results. They then created a module to demonstrate the comparison between the data before and after any changes, or *wrangling*, had been made. The authors used logistic regression for analyzing the data and finding patterns in it. Random search was used to look for the best parameters for the prediction model. The patients were classified into two groups: those who have cardiac disease, and those without cardiac disease. The Sklearn Python library (better known under the name Scikit-learn) [1] was used. The accuracy was calculated at 87%, which means that the method was able to correctly predict heart attack risk with a good level of accuracy. The authors used one machine learning algorithm and a small dataset to train and test it,

which could be seen as a disadvantage of this work. A better algorithm could produce better results [12, 24].

The study [25] by Yekkala et al. suggests a way of finding important features in data related to heart disease. It proposes a specific strategy for evaluating which features to pay attention to and then uses the random forest algorithm and rough sets to classify different types of cardiac diseases. The *Heart Disease* database [2] was used, which is a part of the University of California Irvine (UCI) repository [21], a collection of research datasets that can be used to study areas such as computer science and machine learning. This dataset contained 270 individual pieces of data, referred to as *instances*, and was cleaned up before being usedby deleting null or irrelevant instances. After that Exploratory Data Analysis (EDA) was applied the precision of this method touched 84%. The disadvantage of this work is that the parameters used were not introduced, so the algorithms are accurate and effective; however, the results can not be repeated.

Keerthika et al. [6] suggest that machine learning algorithms, such as K-NN, SVM, Logistic Regression, Decision Trees, Random Forests, and Naïve Bayes, can be used to predict heart diseases. These algorithms were applied to *Statlog (Heart)* data [19] from the UCI repository [21].. The result was that the K-NN algorithm achieved a score of 87%, which means it was successful in correctly classifying 87% of the data. The disadvantage of this approach is that it has multiple parameters so it is difficult to set their proper values. To select the values of multiple parameters the grid search or random search could be applied.

Guruprasad et al [4] used data on heart diseases from the *Statlog (Heart)* repository [19]. The data were cleaned. Finally, they used a combination of two different statistical models (a hybrid random forest and a linear model) to try to predict if someone may have heart disease. The proposed method has occurred to have a high accuracy of 92% which is an advantage. However, even though it is considered the classifier with the best accuracy, the results of the proposed method showed that it had the sensitivity of 90%, the lowest one when compared with other algorithms, which is a disadvantage.

Kim et al. [8] proposed a method called NN-FCA. It involved two steps. The first step was feature selection, which involved picking relevant data from the dataset. The second step was feature correlation, where relationships between different variables in the dataset were explored. Then, the Neural Network classification algorithm was used on the KNHANES-VI dataset [9]. This method has the advantage of providing high accuracy when predicting heart diseases. The disadvantage is that the dataset is too small to do effective correlation analysis, so traditional machine learning algorithms can provide similar performance without the added complication.

Kasbe et al. [5] proposed using a fuzzy expert system for predicting heart disease. This system consisted of three major steps: *fuzzification*, *rule base*, and *defuzzification*. The defuzzification step applied the centroid technique and the system used thirteen different input parameters and one output parameter. The dataset used was taken from

Tab. 1. Accuracy of algorithms used in the previous studies.

No.	Algorithm Name	Accuracy $\in [0, 1]$
1	Random Forest	0.94
2	Decision Tree	0.93
3	XGBoost	0.92
4	Support Vector Machine	0.90
5	K-Nearest Neighbour	0.70
6	Logistic Regression	0.69
7	Naïve Bayes	0.92

the UCI repository [19]. The benefit of this system is that it can be used easily and the people who need it can use the system by themselves, while the accuracy is 93.33%. While this system works well, it also adds complexity to the system due to the use of fuzzy logic, and the results do not significantly differ from other systems and studies done on the same dataset.

Shiva et al. [12] used a local dataset toaccurately predict heart attacks. They used a correlation matrix to determine which features were most important and then used three different algorithms: a neural network, SVM and K-NN. The neural network showed the best results, with an accuracy of 93%. The advantage of this method is that the three algorithms are all stable despite using different sizes of the dataset. The downside is that the local dataset used is not representative of the whole global population.

Preetam et al. [16] suggested a hybrid genetic neural network algorithm as a method to speed up predicting heart attacks from ECG signals. The first step before doing this was to pre-process the data, which involves getting rid of any incorrect or extra data and finding patterns in the ECG signals [3]. Then, they used the neural network and connected it to a genetic algorithm to optimize the neural network weights. The benefit of this method is that it can be used to reduce the time needed to predict heart attacks. However, it also brings complexity to the neural network.

Malavika et al. [11] proposed some traditional machine learning algorithms (like Naïve Bayes classifier, Logistic Regression, Random Forest, SVM, Decision Tree Classifier, and K-NN) to predict heart diseases. These algorithms were trained and tested on the UCI Statlog (Heart) dataset [19]. It was shown that the random forest algorithm had the best accuracy. A *pro* of using these traditional algorithms is that 91.17% accuracy was achieved, which is considered an acceptable accuracy. However, a *con* is that the dataset did not use any feature extraction techniques, which could have helped improve the results.

The accuracies achieved with the described methods can be seen Table 1, and the papers together with the databases used in them and the methods used have been gathered in Table 2.

Tab. 2. Summarized papers, datasets and algorithms.

No.	Paper	Year	Dataset	Algorithm
1	[20]	2019	Heart Disease dataset [2]	Logistic Regression
2	[25]	2018	Heart Disease dataset [2]	Random Forest, rough sets
3	[18]	2018	Author's own dataset	Logistic Regression, Naïve Bayes Classifier, Random Forest classifier
4	[6]	2022	Statlog (Heart) dataset [19]	Decision Tree, Language Model, Random Forest, Support Vector Machine,
5	[8]	2017	KNHANES-VI dataset [9]	K-NN, SVM, Logistic Regression, Decision Trees, Random Forest, Naïve Bayes
6	[5]	2017	Statlog (Heart) dataset [19]	Fuzzy Logic
7	[12]	2021	Author's own dataset	Neural Networks, K-NN, SVM
8	[16]	2020	MIT-BIH [3]	Neural Network Model
9	[11]	2020	Statlog (Heart) dataset [19]	Logistic Regression, K-NN, SVM, Naïve Bayes, Decision Tree, Random Forest

4. Methodology

Figure 2 is a visual representation of the system's methodology and illustrates the steps made to analyze patients' data. First, the patients' data are collected and important attributes are selected. Then, the data goes through a pre-processing step which involves data cleaning. The data is then put through a number of algorithms, such as Random Forest, K-Nearest Neighbour, Logistic Regression, Extreme Gradient Boost (XGBoost), and SVM, to perform the training and testing processes and to generate accuracy scores that represent the quality of classification of the heart disease patterns in the data set.

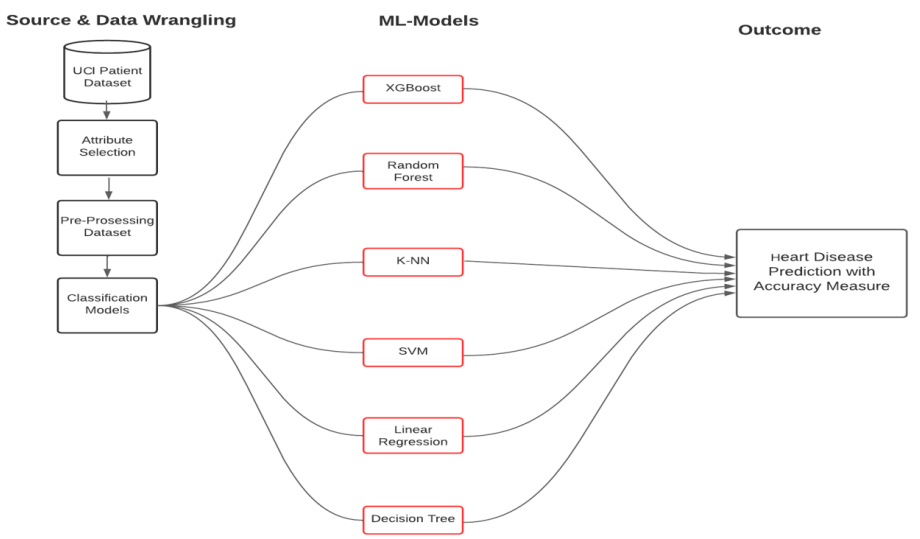
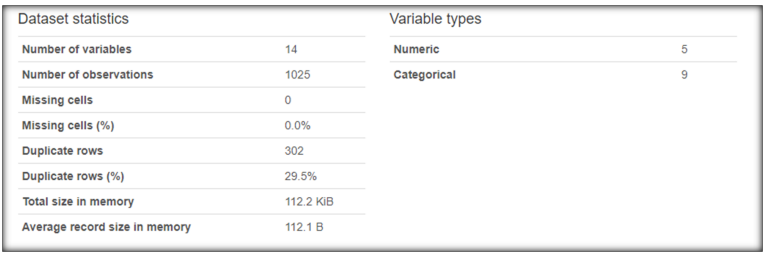


Fig. 2. Methodology used in the construction of the prediction system.



Dataset statistics	
Number of variables	14
Number of observations	1025
Missing cells	0
Missing cells (%)	0.0%
Duplicate rows	302
Duplicate rows (%)	29.5%
Total size in memory	112.2 KiB
Average record size in memory	112.1 B

Variable types	
Numeric	5
Categorical	9

Fig. 3. Overview of the dataset.

4.1. Collection of Data

The UCI repository [21] is a collection of datasets that have been compiled and evaluated by many researchers and UCI authorities. In this paper, we are using the *Statlog (Heart* disease dataset [19] from this repository. We have divided the dataset into two parts, 25% used as test data and 75% used as training data. The the training data will be used to develop the prediction mechanism and the test data will be used to test its effectiveness.

4.2. Feature Engineering

Feature Engineering is the process of choosing important characteristics, or features, of a dataset to create column variables. This means that the characteristics are used in a way that the data can be analysed. The variables will be used as the input data for the prediction system.

One of the methods of feature selection which can be applied without relation to the classification method which will later be used is the $L1$ Regularization (see for example [23]) which involves training a linear model that uses an $L1$ penalty. As a result of the process, the weights of unimportant features in the resulting model are zero. The non-zeroed features are used in the machine-learning model.

In the case of this study, there were 13 features (and one outcome, hence 14 variables) in the database. The number is not large and all the prediction models were capable of capturing this number, so all the features were used in the training and testing. The overview of the dataset and the features are shown in the next Section.

4.3. Overview of the dataset and the variables

The general overview of the dataset used is shown in Fig. 3. The variables, or features, selected for use in the analysis, together with their basic statistical characteristics, are displayed in Fig. 4. The meaning of the abbreviations used in the names of the variables are summarized in Tab. 3.

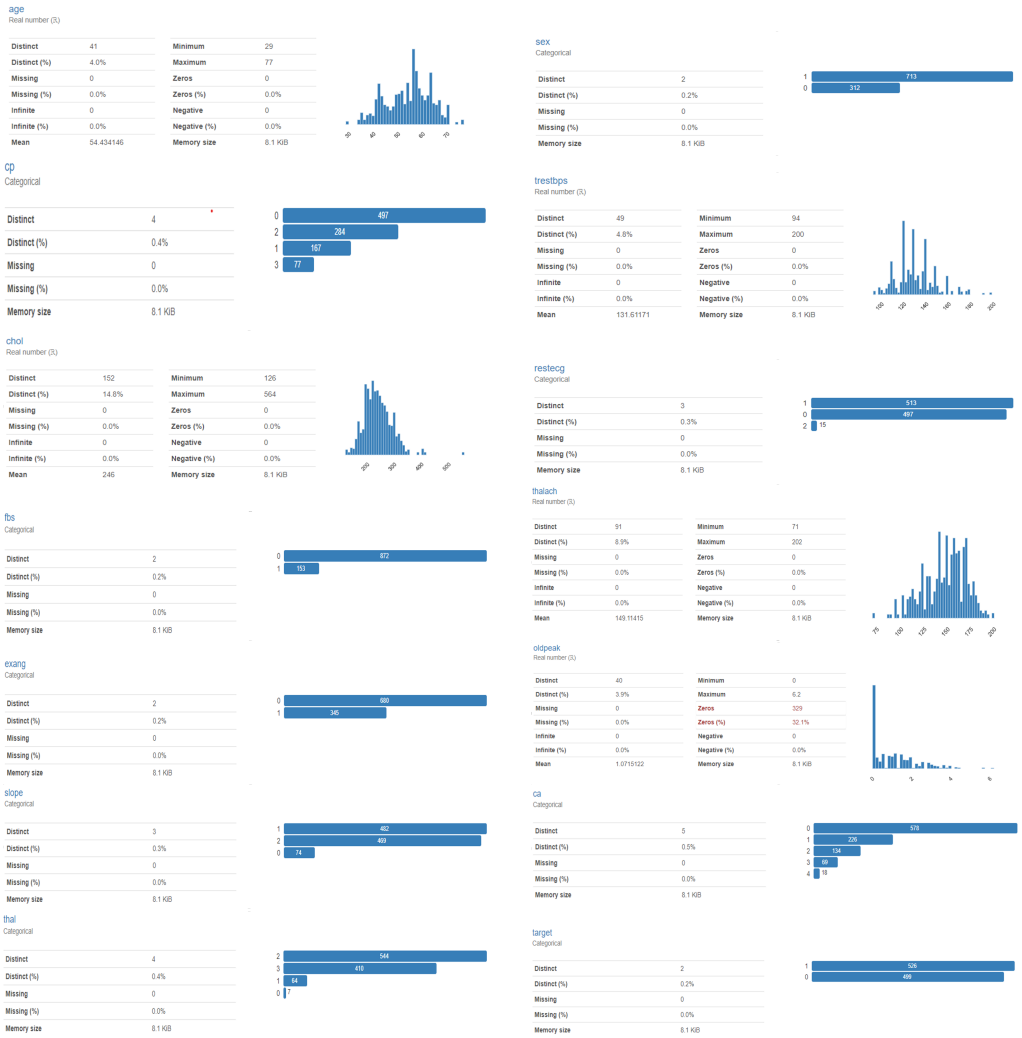


Fig. 4. Variables used in the analysis and their characteristics.

4.4. Correlation

The correlation between the features is shown in Fig. 5 using a heatmap plot. It shows how similar (over zero) or different (below zero) the characteristics of the dataset are. The heatmap was made with the Pandas Profiling tool in Visual Studio Code.

4.5. Performance of Machine Learning algorithms

In this paper several different algorithms were used to build different models which characterize themselves with various levels of accuracy. These algorithms include Random Forest, K-Nearest Neighbour, Logistic Regression, Gradient Boosting, and SVM. The measures of quality of these algorithms were checked on the testing set, to evaluate the performance of these machine learning algorithms for predicting the likelihood of heart attacks.. In the following, the results for each model are described in more detail.

Specifically, the Random Forest model achieved an AUC score of 0.9887, indicating its ability to discern patterns and make accurate predictions. Similarly, the K-Nearest Neighbour model exhibited a commendable AUC score of 0.9468, highlighting its predictive capabilities.

We also assessed the Logistic Regression model, which yielded an AUC score of 0.9391. Although slightly lower than the other models, it still demonstrated a valuable predictive capacity. Furthermore, the Extreme Gradient Boost model exhibited a strong performance, with an AUC score of 0.9774, indicating its ability to leverage boosting techniques and generate accurate predictions.

Notably, the Support Vector Machine (SVM) model stood out with an exceptional AUC score of 0.9985. This result showcases the SVM's robustness in accurately classifying individuals as either at risk or not at risk of heart attacks. The SVM model's ability to leverage kernel functions and identify complex patterns within the dataset contributes to its remarkable predictive accuracy.

Tab. 3. The meaning of the abbreviations used in the names of the variables (simplified nonmedical description).

No.	Abbrev.	Meaning	No.	Abbrev.	Meaning
1	age	age	2	sex	sex
3	cp	chest pain	4	trestbps	resting blood pressure
5	chol	cholesterol level	6	restecg	resting electrocardiographic measurement (0: normal, 1: ST-T wave abnormality, 2: left ventricular hypertrophy)
7	fbs	fasting blood sugar	8	thalach	maximum heart rate achieved
9	exang	exercise induced angina	10	oldpeak	ST depression induced by exercise relative to rest
11	slope	ST segment shift relative to exercise-induced increments in heart rate	12	ca	number of major vessels
13	thal	thalassemia	14	target	heart disease, study target

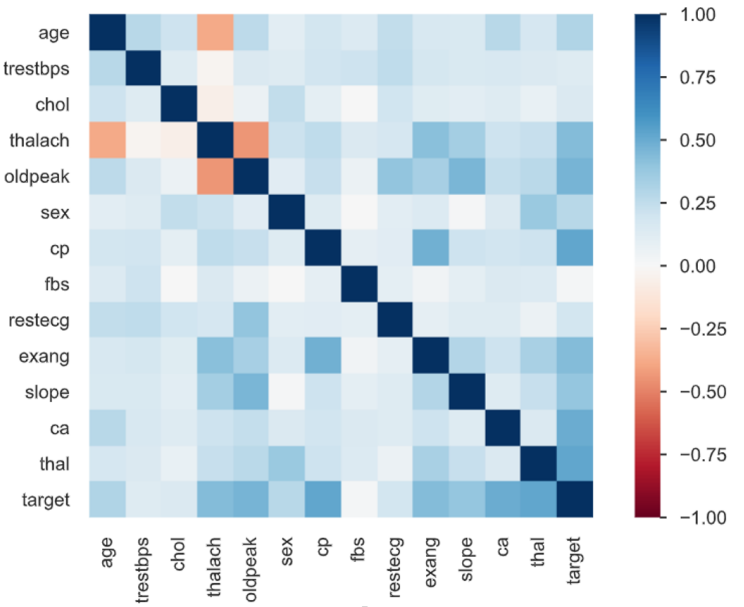


Fig. 5. Heatmap of the dataset features.

The high AUC scores obtained by these machine learning models highlight their effectiveness in predicting the likelihood of heart attacks. These findings have significant implications for early detection and prevention strategies in cardiovascular health. By incorporating these models into clinical practice, healthcare professionals can enhance risk assessment and provide personalized interventions to individuals at higher risk.

Overall, our study demonstrates the potential of machine learning algorithms, including Random Forest, K-Nearest Neighbour, Logistic Regression, Extreme Gradient Boost, and Support Vector Machine, in accurately predicting the likelihood of heart attacks. These models can assist healthcare professionals in identifying individuals who may benefit from targeted preventive measures, ultimately contributing to improved cardiovascular health outcomes.

5. Software used

In this study the Visual Studio Code environment was used as the programming platform, with its support for C++, C#, .NET and its ability to cooperate with many different types of languages and tools (such as JavaScript, Type Script, Node.js, Java, Python,

PHP, and others). In the calculations and in producing the graphs shown in this paper the NumPy and PyTorch packages [17] in Python ver. 3.10 were used.

6. Result analysis

6.1. Accuracy and other measures of performance quality

The confusion matrix is a visual representation of how well a classifier, or a model for predicting outcomes, performs on a set of test data. It compares the actual results of the model to the expected outcomes and is useful for understanding the results.

The accuracy of algorithms is calculated based on four values: true negative (TN) – the number of people without heart diseases who have been identified correctly, true positive (TP) – the number of people with heart diseases who have been identified correctly, false positive (FP) – the number of people without heart disease who have been incorrectly identified as having heart disease, and false negative (FN) – the number of people with heart disease who have been incorrectly identified as being healthy.

The general measure of decision quality taking into account the true as well the false results, and the positive and negative ones, is the accuracy:

$$\mathrm{Acc} = \frac{\mathrm{TP} + \mathrm{FN}}{\mathrm{TP} + \mathrm{FP} + \mathrm{TN} + \mathrm{FN}} \,.$$

There are at least two detailed aspects of a classifier (we shall stay with the detection of disease as an example). These are: its sensitivity – ability to classify the patients with a disease as ill, and its sensitivity – ability not to classify the healthy patients as ill.

$$\begin{aligned} \mathrm{Sens} &= \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}} \,, \\ \mathrm{Spec} &= \frac{\mathrm{TN}}{\mathrm{FP} + \mathrm{TN}} \,. \end{aligned}$$

The general performance of the system can be more accurately described by the confusion matrix containing all the four numbers, as shown in Fig. 6.

The single parameter which captures the performance of a classification system is the Area Under Curve (AUC). It is related to the Receiver Operating Characteristics (ROC) which is a curve formed by all the pairs of values of the sensitivity and specificity, for all possible thresholds in the classifier. The best value of the AUC is 1. For details please see the basic literature [10, 14].

6.1.1. Performance of Machine Learning Algorithms

To compare the accuracy scores between those received in the previous studies, summarized in Table 1, and those achieved in the present study, shown in Table 4, the results of the subsequent algorithms will be presented.

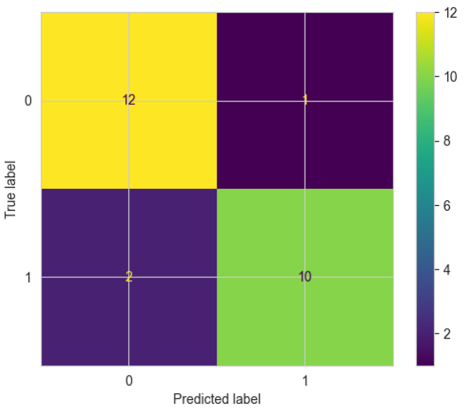


Fig. 6. Example of a confusion matrix of a trained model.

Random Forest

In Table 1 (previous studies), the Random Forest algorithm achieved an accuracy of 0.94, while in Table 4 (current study), it achieved a slightly lower accuracy of 0.93. This indicates a minor variation in the performance of the Random Forest algorithm between the previous studies and the current study.

Decision Tree

Table 1 (previous) shows a Decision Tree accuracy of 0.93, whereas Table 4 (current) reports an accuracy of 0.94. This suggests that the Decision Tree algorithm performed slightly better in the current study compared to the previous studies.

Tab. 4. Accuracy and Area Under Curve (AUC) of the methods used in this study.

No.	Model	Accuracy [%]	AUC $\in [0,1]$
1	Logistic Regression	86.34	0.939
2	Naïve Bayes	85.37	0.931
3	Random Forest	93.67	0.989
4	Extreme Gradient Boost	94.64	0.977
5	K-Nearest Neighbour	87.81	0.947
6	Decision Tree	94.64	1.000
7	Support Vector Machine	98.05	0.998

Extreme Gradient Boost)
In Table 1 (previous), XGBoost achieved accuracy of 0.92, and in Table 4 (current), XGBoost achieved an accuracy of 0.94. This indicates an improvement in the performance of the XGBoost algorithm in the current study compared to the previous studies.

Support Vector Machine
In Table 1 (previous), Support Vector Machine achieved an accuracy of 0.90, while in Table 4 (current) it achieved a higher accuracy of 0.98. This indicates a significant improvement in the performance of the Support Vector Machine algorithm in the current study compared to the previous studies.

K-Nearest Neighbour
Table 1 (previous) shows an accuracy of 0.70 for K-Nearest Neighbour, whereas Table 4 (current) reports a higher accuracy of 0.87. This suggests that the K-Nearest Neighbour algorithm performed better in the current study compared to the previous studies.

Logistic Regression
Table 1 (previous) indicates a Logistic Regression accuracy of 0.69, while Table 4 (current) reports a higher accuracy of 0.86. This indicates an improvement in the performance of the Logistic Regression algorithm in the current study compared to the previous studies.

Naïve Bayes
In Table 1 (previous), Naïve Bayes achieved an accuracy of 0.922, while in Table 4 (current) it achieved a lower accuracy of 0.85. This suggests a slight decrease in the performance of the Naïve Bayes algorithm between the previous studies and the current study.

7. Discussion of results

In our study, we evaluated the performance of several machine learning algorithms for predicting the likelihood of heart attacks, as shown in Tab. 4. The tested algorithms were: Logistic Regression, Naïve Bayes, Random Forest, Extreme Gradient Boost, K-Nearest Neighbour, Decision Tree, and Support Vector Machine. We found that SVM had the highest accuracy.

The results demonstrated the effectiveness of these models in accurately classifying individuals at risk of heart attacks. Specifically, the Random Forest model achieved an AUC score of 0.989, indicating its ability to discern patterns and make accurate predictions. Similarly, the K-Nearest Neighbour model exhibited a commendable AUC score of 0.947, highlighting its predictive capabilities.

We also assessed the Logistic Regression model, which yielded an AUC score of 0.939. Although slightly lower than the other models, it still demonstrated a valuable

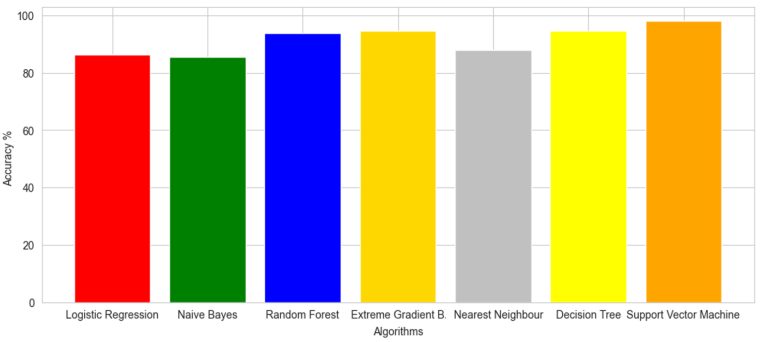


Fig. 7. Accuracy of the Machine Learning models tested in this study.

predictive capacity. Furthermore, the Extreme Gradient Boost model exhibited a strong performance, with an AUC score of 0.977, indicating its ability to leverage boosting techniques and generate accurate predictions.

Notably, the Support Vector Machine (SVM) model stood out with an exceptional AUC score of 0.998. This result showcases the SVM's robustness in accurately classifying individuals as either at risk or not at risk of heart attacks. The SVM model's ability to leverage kernel functions and identify complex patterns within the dataset contributes to its remarkable predictive accuracy.

The accuracies of the algorithms are compared graphically in Figure 7

The high AUC scores obtained by these machine learning models highlight their effectiveness in predicting the likelihood of heart attacks. These findings have significant implications for early detection and prevention strategies in cardiovascular health. By incorporating these models into clinical practice, healthcare professionals can enhance risk assessment and provide personalized interventions to individuals at higher risk. Overall, our study demonstrates the potential of machine learning algorithms, including Random Forest, K-Nearest Neighbour, Logistic Regression, Extreme Gradient Boost, and Support Vector Machine, in accurately predicting the likelihood of heart attacks. These models can assist healthcare professionals in identifying individuals who may benefit from targeted preventive measures, ultimately contributing to improved cardiovascular health outcomes.

8. Conclusion and future work

The heart is an essential part of the body. To predict cardiac issues, machine learning algorithms are needed to help treat these cardiac ailments. This research paper used seven different machine-learning algorithms to predict heart disease and found that the

Support Vector Machine algorithm was the most accurate. We compared the results of different machine learning algorithms to determine the one that is most suitable for predicting heart disease to predict whether a person has heart disease or not. In this research paper, accuracy is an important factor that is used to measure how well the algorithm works. The dataset used for the research contains 14 attributes (13 features and one target). Out of the seven machine learning algorithms tested to predict heart disease, the Support Vector Machine was found to be the most accurate prediction ability on a UCI dataset. In the future, more machine learning techniques could be used to analyse cardiac illnesses and predict them earlier. With the help of proper machine learning technologies, we can hopefully have a lower number of fatalities related to heart problems.

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