Involving machine learning techniques in heart disease diagnosis: a performance analysis

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ABSTRACT

Artificial intelligence is a science that is growing at a tremendous speed every day and has become an essential part of many domains, including the medical domain. Therefore, countless artificial intelligence applications can be seen in the medical domain at various levels, which are employed to enhance early diagnosis and prediction and reduce the risks associated with many diseases, including heart diseases. In this article, machine learning techniques (logistic regression, random forest, artificial neural network, support vector machines, and k-nearest neighbors) are utilized to diagnose heart disease from the Cleveland Clinic dataset got from the University of California Irvine machine learning (UCL) repository and Kaggle platform then create a comparison between the performance of these techniques. In addition, some literature related to machine learning and deep learning techniques that aim to provide reasonable solutions in monitoring, detecting, diagnosing, and predicting heart disease and how these technologies assist in making health decisions are reviewed. Ten studies are selected and summarized by the authors published between 2017 and 2022 are illustrated. After executing a series of tests, it is seen that the most profitable performance in diagnosing heart disease is the support vector machines, with a diagnostic accuracy of 96%. This article has concluded that these techniques play a significant and influential role in assisting physicians and health care workers in analyzing heart patients’ data, making health decisions, and saving patients’ lives.

Keywords: Artificial intelligence, Cleveland clinic, COVID-19, Deep learning, Heart diseases, Machine learning

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1. INTRODUCTION

Today, computers and computer systems have become a vital part of our lives [1]. Computers are employed in almost every domain [2]. In the past years, computers have been benefited from summarizing large amounts of data over time and making comments about events utilizing these data while performing calculations or transmitting data [3], [4]. Nowadays, computers can make decisions about events and know the relationship between events [5]. Also, computers can also solve issues that cannot be mathematically formulated. The most noteworthy part of computer science is artificial intelligence [6], [7]. This science is distinguished by its ability to suggest computational models of learning based on human biological neural networks [8]. In other words, several models of artificial intelligence have been suggested, which, thanks to advancements in computational technology, have allowed the growth of "intelligent" techniques that facilitate processing more data in less time, speeding up the decision-making process [9], [10]. In addition,

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this science is involved in many domains such as advanced robotics, computer vision, natural language processing, virus tracking, prediction, diagnosis, planning and optimization. The most noteworthy part of artificial intelligence is machine learning [11]–[14], which includes different types of techniques such as random forest, naïve bayes, and k-nearest neighbor. Besides, these techniques are separated into supervised, unsupervised, and semi-supervised techniques. Moreover, machine learning is characterized by analyzing and processing big data [15], [16]. Another part of artificial intelligence is deep learning [17], [18], which is widely utilized to evaluate image, video and audio data using convolutional neural networks with their various parameters. After the spread of the coronavirus disease (COVID-19) pandemic and the development of its genes, rapid solutions are needed to monitor, detect, and diagnose diseases resulting from its causes [19]; artificial intelligence proposes many options to monitor the spread of the disease, tracking the infected and studying the behavior of the virus. Artificial intelligence techniques seek to detect infection with COVID-19 through chest X-ray or computerized tomography, see Figures 1(a) and 1(b) and the ability of these techniques to diagnose and predict heart diseases by relying on a patient dataset that is collected and analyzed to make the right decision regarding the patient’s condition [20]–[23].

![Figure 1](image1.png)

Figure 1. High-definition images of a 41-year-old male patient with unilateral COVID-19 pneumonia (a) X-ray and (b) computed tomography [21]

The principal contribution of this article is to execute five machine learning techniques and study their behavior in diagnosing heart disease datasets gathered from the Kaggle platform. After that, the obtained results are compared, and the most useful and worst performances among the applied techniques are known. In addition, a summary of the ten most crucial pieces of literature published between 2017 and 2022 on the use of machine learning and deep learning techniques in the diagnosis and analysis of heart disease data and what are the results of these literature so that this article can be a reference for future use.

The rest of this work is organized: in section 2, a summary of heart diseases and pieces of literature in which artificial intelligence techniques have been applied to analyze these diseases are introduced briefly. Analysis of the performance of the involved techniques with details of the results obtained in section 3. Finally, section 4 is the conclusion of this work.

2. LITERATURE REVIEW

Heart disease is a common and harmful disease that affects humans, and it is a disease caused by a change in the blood vessels of the heart or coronary arteries [24]–[27]. These diseases may occur due to other conditions, such as changes in the lung that increase pressure on the right hemisphere and lead to high blood pressure that can strain the left hemisphere [28], [29]. Changes in the balance of hormones can also cause these diseases and inflammatory rheumatic diseases [30], [31]. There are many reasons for the occurrence of heart disease that may lead to death, and therefore it may require resorting to taking appropriate treatment, according to the patient’s condition. In general, heart disease occurs significantly with age, but it is very rare in children, young, and adults [32], [33]. Especially after the age of forty, in these age groups, heart diseases are prevalent due to atherosclerosis, i.e., ischemic heart disease [34]. In the recent period, the number of cases of heart disease has grown [35], especially ischemic heart disease, which causes death and is a widespread disease of death in all industrialized nations. This may be due to the high life expectancy of the population, and the incidence of ischemic heart disease increased for people aged 40 to 50 years, as illustrated in Figure 2 [36]. However, there are other dangerous factors, such as infection with the COVID-19 virus, which leads to an increase in the effort of the heart due to a lack of oxygen in the lungs [37], [38]. Today, artificial intelligence techniques are constantly striving to save patients’ lives and help healthcare workers make the right decision about a patient’s condition [39], [40]. Artificial intelligence has entered
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many domains, including healthcare, where its techniques are developing with the development of diseases, especially with heart diseases [41], [42]. In this section, a set of studies are reviewed in which these techniques are utilized to analyze heart diseases. Image analysis is an area in which machine learning progresses is faster and sufficient, therefore it is of great significance in cardiology, see Figure 3 [43]. In a study executed by Damen et al. [44], they suggest using machine learning techniques to analyze 4D ultrasound (4DUS) cardiac data (160,000 pixels per image with about five thousand total images) to predict left ventricular wall motility. In this work, three main features are used to build the proposed models: the projection of raw US data, smoothing spline basis across time, and parameterization of the left ventricular boundaries. They use the Monte Carlo cross-validation method to evaluate the execution of the three models. This study finds that the Monte Carlo simulation of the endocardial wall makes much closer predictions when employing Model 2 vs. Model 1 with a rate of 48.67% and employing Model 3 vs Model 2 with a rate of 83.50%. In a study conducted by Arabasadi et al. [45], they proposed a hybrid method for coronary artery disease diagnosis by improving the execution of the artificial neural network technique employing a genetic algorithm based on the Z-Alizadeh Sani dataset. This study found a diagnostic accuracy of more than 93%.

Figure 2. Old people suffering from heart disease in hospital [46]

A study instructed by Ankenbrand et al. [47] they advise using the open-source Python library (misas) for sensitivity analysis with arbitrary models and data. This application is applied in two cases in a cardiac magnetic resonance imaging study. This paper concludes that sensitivity analysis is a very sound tool for clinicians as it helps them interpret segmentation models. Also, Neural networks are used in decision-making, and this paper has got excellent results in analyzing heart images. Diagnosing heart diseases is one of the most essential tasks that the doctor performs to know the patient's condition, in a study conducted by Pan et al. [48] on the uses of machine learning techniques in diagnosing heart disease with the help of the internet of medical things. In this work, deep neural network (DNN), enhanced deep learning assisted convolutional neural network (EDCNN) techniques, neural network ensemble method (NNE), recurrent neural network (RNN), artificial neural network (ANN), and ensemble deep learning-based smart healthcare system (EDL-SHS) and are applied. The authors are able to determine the level of risk of heart disease with high adequateness, as the precision of the effects gained more than 99%. Ricciardi et al. [49], they apply machine learning techniques (random forests, multivariate logistic regression, ADA-Boost, and gradient boosting) in computed tomography (CT) analysis of heart disease in older adults with cardiovascular disease (CVD), coronary heart disease (CHD), and chronic heart failure (CHF).

Figure 3. Heart disease images analysis mechanism utilizing machine learning techniques [49]
The effects of this study depend on four classification metrics: classification by tissue type, age, feature importance, and total classification score. The effects result in the superiority of the random forest technique as it achieves the highest classification performance for all analyses, and the overall classification scores for all three conditions as they are perfect: The AUCs for CHD=0.936, for CVD=0.914, and for CHF=0.994. In a study conducted by Helwan and Ozsahin [50], artificial neural networks are employed to recognize the left ventricle and its detection in magnetic resonance imaging of the heart. Through this analysis, a backpropagation neural network is trained on instances of the left ventricle as well as samples of the non-left ventricle. A neural network trained in backpropagation has demonstrated the power of validating simulated samples with a test set. The training and test groups gain a high accuracy rate of 100% and 88%, respectively. Many platforms support the execution of image analysis of heart disease, such as TensorFlow, Pytorch, Keras, and Caffe, that can be trained and used due to their high efficiency in the implementation. Moreover, there must be a set of images reported manually and need a great deal of experience in making the appropriate adjustments in the analysis of these images. Alarsan and Younes [51] applied machine learning techniques (decision tree, random forests, gradient-boosted trees) and big data tool (Spark–Scala) to classify Electrocardiogram (ECG) signals based on ECG features to reveal a patient's condition. The databases of this analysis are more than 205,000 records of 51 patients. Therefore, to evaluate the execution of techniques by understanding arrhythmia. This analysis concluded that the best performance in binary classification is the gradient-boosted trees technique, which achieves an accuracy of more than 97%. In the multi-class classification, the most suitable performance is for the random forest technique, which has earned more than 98% accuracy. Ali et al. [52] have involved machine learning techniques (decision tree, nearest neighbor, and random forests) to diagnose early-stage heart disease by developing accurate and effective predictions based on digital patient records collected from the Kaggple platform. The performance of the techniques is compared to the accuracy of disease prediction. This analysis has found that the random forest technique has the most suitable performance, with an accuracy of 100% and a sensitivity of 100%. The authors confirm that these techniques can be used in making clinical decisions. A study by Joloudari et al. [53] developed a neural network and deep neural network techniques for diagnosing cardiac magnetic resonance imaging (CMRI) dataset. In this study, several operations are performed to improve the performance of both techniques in the diagnostic process. Through experiments, it is found that the best performance is the deep neural network technique, which achieved an accuracy of more than 99%, which is a very impressive effect. In comparison, the standard neural network technique achieved more than 92% accuracy.

3. PERFORMANCE ANALYSIS

In this section, five techniques (logistic regression, random forest, artificial neural network, support vector machines, and k-nearest neighbors) for diagnosing heart diseases and comparing performance are utilized to identify the most acceptable technique in terms of performance. This study relies on cardiology data from the UCL repository, including the Cleveland Clinic dataset. This dataset includes 76 parameters with a numerical value with 14 input attributes. Attribute information are sex, age, resting blood pressure, chest pain type, serum cholesterol, fasting blood sugar > 120 mg/dl, resting electrocardiographic results, maximum heart rate achieved, exercise induced angina, the slope of the peak exercise ST-segment, ST depression induced by exercise relative to rest, number of major vessels (0-3) colored by fluoroscopy, num is diagnosis of heart disease (angiographic disease status): value 0:< 50% diameter narrowing and value 1:> 50% diameter narrowing, and thal: 3=normal; 6=fixed defect; 7=reversible defect. Figure 4 illustrates the distribution of some variables. The total data of the Cleveland Clinic is 303, which is divided into 165 data for patients and 138 data for healthy people obtained from the Kaggple platform [54]. This work is performed utilizing Jupiter Notebook, a web-based platform for open-source application development. Moreover, it is preferable to use the Python programming language in applying machine learning techniques. The libraries Numpy, Scipy, Matplotlib, Sklearn, and Pandas are utilized during the working stages.

The logistic regression technique resulted in 23 false diagnoses and 280 proper diagnoses. The random forest technique resulted in 18 false diagnoses and 285 proper diagnoses. The artificial neural network resulted in 15 false diagnoses and 288 proper diagnoses. The support vector machines resulted in 11 false diagnoses and 292 proper diagnoses. Finally, the k-nearest neighbors resulted in 32 false diagnoses and 271 proper diagnoses. Figure 5 shows the variables distribution in univariate or multivariate forms, with a chart illustrating each input variable’s issuance. All variables are dispersed in an orderly manner, where the Univariate variable includes the analysis of only one variable. At the same time, the multivariate provides for the study of two or more variables according to the input dataset. Figure 6 illustrates the working mechanism in which heart disease data is analyzed. Table 1 demonstrates the effects obtained by utilizing the five most utilized techniques on the same dataset to measure the performance of each technique. However, this table
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Illustrates that the most useful performance technique is support vector machines, which achieved an accuracy of 96%. In contrast, the most inadequate performance is the k-nearest neighbors technique, which earned an accuracy of 89%. Moreover, artificial neural network random forest, and logistic regression techniques have good and acceptable performance in diagnosing heart disease. Figure 7 illustrates the effects of the techniques involved in the diagnosis process. Also, Table 1 illustrates the most useful technique in terms of performance. The most effective technique for diagnosing Cleveland Clinic dataset has been identified in the same table. Besides, Table 2 compares this work with previous studies that used machine learning techniques to analyze the same dataset utilized. In this scenario, four mathematical equations are relied upon to find the effects of the techniques, which are: Accuracy: indicates the overall performance of the techniques (1), Sensitivity is the ratio of heart patients to the total number of patients in the dataset and it gives a positive confirmation of the patient’s diagnosis (2), Specificity: is the diagnosis of healthy people as unhealthy (3), and Precision is the marker of a positive diagnosis made by the techniques (4). The last metric is the F1 score, which measures the probability that a positive diagnosis is correct (5).

\[
\text{Accuracy} = \frac{TP + TN}{TN + TP + FN + FP} \times 100\% \\
\text{Sensitivity} = \frac{TP}{TN + TP} \times 100\% \\
\text{Specificity} = \frac{TN}{TN + FP} \times 100\% \\
\text{Precision} = \frac{TP}{TP + FP} \times 100\% \\
F - \text{measure} = \frac{2 \times \text{precision} \times \text{sensitivity}}{\text{precision} + \text{sensitivity}}
\]

where \(TP\) is true positive, \(TN\) is true negative, \(FN\) is false negative, and \(FP\) is false positive.

Figure 4. The distribution of variables (age, sex, cp, trestbps, chol, and thalach)

Figure 5. Univariate or multivariate variables (Age, blood pressure, electrocardiography, exercise test time)
Figure 6. Mechanism of work for diagnosing heart disease dataset

Table 1. Comparison of the effects of the executed techniques

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Diagnoses Proper</th>
<th>Diagnoses False</th>
<th>Accuracy</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Precision</th>
<th>F1-score</th>
<th>Processing time (Second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistic regression</td>
<td>280</td>
<td>23</td>
<td>92%</td>
<td>94%</td>
<td>95%</td>
<td>95%</td>
<td>94%</td>
<td>412</td>
</tr>
<tr>
<td>Random forest</td>
<td>285</td>
<td>18</td>
<td>94%</td>
<td>96%</td>
<td>94%</td>
<td>95%</td>
<td>95%</td>
<td>490</td>
</tr>
<tr>
<td>Artificial neural network</td>
<td>288</td>
<td>15</td>
<td>95%</td>
<td>95%</td>
<td>95%</td>
<td>98%</td>
<td>95%</td>
<td>501</td>
</tr>
<tr>
<td>Support vector machines</td>
<td>292</td>
<td>11</td>
<td>96%</td>
<td>97%</td>
<td>92%</td>
<td>98%</td>
<td>96%</td>
<td>317</td>
</tr>
<tr>
<td>k-nearest neighbors</td>
<td>271</td>
<td>32</td>
<td>89%</td>
<td>91%</td>
<td>98%</td>
<td>94%</td>
<td>92%</td>
<td>388</td>
</tr>
</tbody>
</table>

Bold indicates that these effects are the most useful.

Figure 7. The effects of the techniques applied in the diagnosis of dataset

Table 2. Comparison between the current study and previous studies through the same dataset

<table>
<thead>
<tr>
<th>Articles</th>
<th>Dataset</th>
<th>Best Techniques</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patel et al. [55]</td>
<td>Data Cleveland Clinic dataset set</td>
<td>J48 decision tree</td>
<td>56%</td>
</tr>
<tr>
<td>Nassif et al. [56]</td>
<td></td>
<td>Naive Bayes</td>
<td>84%</td>
</tr>
<tr>
<td>Terrada et al. [57]</td>
<td></td>
<td>Artificial neural network</td>
<td>91%</td>
</tr>
<tr>
<td>Akella and Akella [58]</td>
<td></td>
<td>Artificial neural network</td>
<td>93%</td>
</tr>
<tr>
<td>This work</td>
<td></td>
<td>Support vector machines</td>
<td>96%</td>
</tr>
</tbody>
</table>
4. CONCLUSION AND FUTURE WORK

The application of machine learning techniques is a common thing for the detection and analysis of diseases due to the predictive ability of these techniques, as it is possible to achieve a prior diagnosis that helps healthcare workers to create decisions that assist save the lives of citizens. The major reason why the authors prefer heart disease is that heart disease is a risk factor in human life, which is considered one of the most dangerous diseases that gives a high mortality rate all over the world. This article applies the five most common and used techniques in analyzing and diagnosing heart diseases. All the used techniques are compared with each other in terms of accuracy, and the most acceptable and worst practice in terms of performance are determined. The artificial neural network technique has taken the most time to implement, reaching 501 seconds, which is considered the most time to implement in this work. While the support vector machines have achieved a short time in the work as it reached 317 seconds, which is the shortest time that is achieved in this work. It is concluded that the artificial neural network technique gives solutions in a long time, and this leads to the difficulty of benefiting from it in the future. Although this technique is difficult for various reasons, but its application is increasing because it gives clear and acceptable results in performance. As for the support vector machines gave the highest accuracy among the applied techniques and in less time; that is, it is considered the fastest applied technique and the most appropriate in diagnosing heart diseases. The summarized literature in this article confirmed that machine learning techniques are necessary and should be applied in the healthcare service because of their high ability to assist in decision-making. In the future, a survey will be conducted on the application of machine learning techniques in the medical field and how they are used. Also, the focus will be on implementing machine learning techniques for analyzing and diagnosing a large medical dataset to create predictions.

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