*Grenze International Journal of Engineering and Technology, Jan Issue*

# Early Diabetes Detection and its Effect on Heart using Random Forest

Premanand Ghadekar[1], Yash Munde[2], Nitin Choudhary[3], Muaz Sayyed[4], Ayush Vidhale[5] and Netal Zanwar[6]
[1-6]Department of Information Technology, Vishwakarma Institute of Technology, Pune, India
Email: premanand.ghadekar@vit.edu, {yash.munde21, nitin.choudhary21, Mdmuaz.sayyed21, ayush.vidhale211, netal.zanwar211}@vit.edu

***Abstract*— Diabetes is a long lasting disease which affects people worldwide. Many people had diabetes and this number would be increasing in the future. Early detection of diabetes is necessary. Also, diabetes affects other organs and becomes a risk to other organs like heart, lungs, kidneys, skin ,eyes, liver. And early detection of the impact of diabetes on other organs is necessary to take proper early precautions and treatment. To identify the early risk , Machine learning can be helpful. Using algorithms of machine learning, it can provide accurate detection and timely diagnosis . This paper contains early detection of diabetes and impact on heart where Random forest is used after model selection to detect the probability of heart disease using UCI heart disease and for diabetes detection PIMA Indian dataset is used. And using this simple analysis it can be found that the diabetic person's organs are affected or not.**

***Index Terms*— Diabetes, Random Forest, Early detection, Heart disease**

## I. INTRODUCTION

Diabetes, a chronic disease affecting millions of people worldwide, poses significant challenges not only in terms of glycemic control but also in its impact on other vital organs such as the heart, lungs, kidneys, skin, eyes, and liver. The situation is particularly alarming in countries like India, which is home to an estimated 77 million adults with 'type 2 diabetes' and nearly 25 million pre diabetics in the year 2021. More than half of these individuals are unaware of their diabetic status, leading to potential health complications if not detected and treated early. Recent studies estimate that 101 million people in India, or 11.4% of the population, are living with diabetes. According to a survey conducted by the health ministry, 15.3% of the population, or 136 million people, may have pre-diabetes. Early detection of diabetes and its potential impact on these organs is critical for early detection, treatment, and management of the condition. The current difficulties in diagnosing diabetes and monitoring its impact on organ health necessitate novel and efficient approaches. Machine learning, with its data-driven predicting capabilities, has shown significant promise in providing accurate early detection and diagnosis of diabetes, as well as evaluating its effect on organs. The principal objective of this case study is to introduce a complete structure for early diabetes detection and to investigate its impact on heart health. After model selection, the proposed methodology employs the 'Random Forest' algorithm to predict the likelihood of heart disease in a dataset sourced from the 'UCI Heart Disease Dataset'. A dataset from the PIMA Indian diabetes database is also used for diabetes detection.

## II. LITERATURE SURVEY

This paper's authors propose an improved random forest model for CVD prediction. A dataset of 1,000 patients

*Grenze ID: 01.GIJET.10.1.96*

with cardiovascular disease risk variables, such as age, gender, blood pressure, cholesterol, and smoking status, was used to train and evaluate the model in this study.The three enhancements that the authors propose for the traditional random forest technique are ensemble learning, hyper parameter optimisation, and feature selection. The authors use a different test set in the study to evaluate the effectiveness of their enhanced random forest model. Notably, their model attains an astounding accuracy rate of 95.7% [1]. The purpose of this paper is to predict diabetes using neural networks. The study compares two approaches: data recovery with an MLP, which achieved an accuracy of 85.15%, and k-means noise reduction with other classifiers, which reached 77.08%. The effectiveness of data recovery using MLP is higher. Future research should incorporate the utilization of actual patient data and the implementation of mobile health applications for the purpose of managing diabetes [2]. The paper discusses the increased heart failure risk (HF) in diabetic patients and explores the impact of current antihyperglycemic medications on HF. The text explores various cellular mechanisms that have a part in the condition's development, as well as identifies potential targets for medication to minimize the risk of heart failure in individuals with ‘type 2 diabetes’. "In this paper, the significance of personalized approaches for diabetic patients is elaborated, emphasizing the need to not only manage blood sugar levels but also address complications and reduce the chances of heart failure [3]. The study explores the evidence supporting the application of artificial intelligence (AI) models in predicting cardiovascular diseases (CVD) among individuals with ‘type 2 diabetes’." In their quest for knowledge, the authors delved into research articles published until 2022. Their findings revealed that AI models surpassed traditional risk scores when it came to predicting cardiovascular disease (CVD) in this particular group. However, they caution that the studies' quality varied, highlighting the need for further research to affirm the effectiveness of AI models in larger and more diverse populations. However, a conclusion is reached stating that AI models hold potential as a valuable tool for clinicians in identifying individuals with ‘type 2 diabetes’ who are at a heightened risk of CVD. This allows for preemptive measures to be taken in preventing such a condition [4]. The authors recommend using a random forest algorithm for diabetes prediction in order to achieve this. The system displays an amazing accuracy of 95.24% when predicting the presence of diabetes after being trained and tested on a dataset of 768 patients. The authors compare their approach with a number of ML algorithms in their study. The random forest algorithm outperforms all other approaches in terms of accuracy, according to the results. The authors' use of the random forest algorithm as a diabetes prediction tool shows potential [5]. Through the analysis of screening guidelines, risk variables, and patient demographics, the study reveals higher rates of diabetic complications and multiple conditions in India when compared to the US. Additionally, significant diagnosis errors were identified. In order to effectively reduce morbidity and healthcare expenses in India, improved screening and early detection measures are of utmost importance [6]. To address this issue, this research proposes the use of machine learning models for accurate ‘type-2’ diabetes classification and early detection.In this study, five distinct machine learning models were trained and assessed using a dataset of 768 patients, both with and without ‘type 2 diabetes’. The following models were used: “K-nearest neighbors (K-NN) , Bernoulli Naive Bayes (BNB), Decision tree (DT), Logistic regression (LR), and Support vector machine (SVM)”. The K-Nearest Neighbors (K-NN) model exhibited superior accuracy in diabetes prediction, boasting an impressive accuracy of 79.6%. The “BNB model” closely adhered to, achieving an accuracy of 77.2%. The rest of the models obtained slightly lower accuracies; nonetheless, they all outperformed a random baseline. Additionally, the authors assessed the models' effectiveness in forecasting the likelihood of diabetes development among patients who were initially diabetes-free during the study. Once again, the K-NN model outperformed others with an impressive accuracy rate of 74.2%. The BNB model displayed a commendable performance, achieving an accuracy rate of 72.8%. Hence, the authors assert that employing machine learning models can effectively identify and categorize ‘type 2 diabetes’, while also foreseeing the likelihood of diabetes development in patients without the condition during the study. According to the authors, these models have the ability to enhance the early identification and control of ‘type 2’ diabetes [7]. In this paper, a comprehensive review is conducted to examine artificial intelligence (AI) models utilized for predicting CVD among individuals diagnosed with ‘type 2 diabetes’. The study revealed that AI technologies displayed a hopeful performance in predicting cardiovascular disease in individuals with ‘type 2 diabetes’. Among all models used, random forest models exhibited the highest level of performance [8]. In their paper titled "Early Detection of Cardiovascular Disease using Machine Learning Techniques: An Experimental Study", Najmu Nissa, Sanjay Jamwal, and Shahid Mohammad present a proposal that advocates the utilization of machine learning techniques in the prompt identification of cardiovascular disease (CVD). The dataset of 300 patients with and without CVD was used to train and evaluate six distinct machine learning algorithms by the authors. In terms of algorithmic performance, the following algorithms were utilized: “Support vector machine (SVM), Linear regression (LR), Naive Bayes (NB), Decision tree (DT), Artificial neural networks (ANN), and Convolutional neural networks (CNN)”. Out of these algorithms, the decision tree algorithm demonstrated remarkable accuracy in predicting CVD, achieving an impressive accuracy rate of 97.29%. In

addition, it should be mentioned that the remaining algorithms exhibited excellent performance, surpassing a 90% accuracy rate [9]. The significance of AI-based technologies in forecasting outcomes for individuals with cardiovascular disease (CVD) is strongly emphasized by this study, due to the considerable risks involved. The proposed article explores various machine learning models, focusing on data observation techniques and training methodologies. In addition, the study highlights the possible benefits of utilizing sophisticated methods such as deep learning and artificial neural networks to improve the diagnosis and prognosis assessment of cardiovascular disease. The significance of AI and machine learning in enhancing patient outcomes and evaluating prognosis in cardiovascular health is underscored by the research findings. The medical field is changing rapidly, and with it comes the promise of technologies that can effectively manage cardiovascular disease (CVD) and enhance patient care while increasing survival rates. This paper introduces a prediction model rooted in machine learning that can assess the likelihood of heart failure (HF) in individuals who have been diagnosed with prediabetes or diabetes. A total of 3527 individuals aged 40 years and above who had previously been diagnosed with prediabetes or diabetes were included in the study. These individuals were selected from the "National Health and Nutrition Examination Survey (NHANES)" data collected between 2007 and 2018. Random forest models demonstrated the highest level of prediction performance, thereby enabling doctors to enhance their clinical decision-making abilities [11].In their paper titled "Diabetes and Heart Disease Prediction Using Machine Learning," Bhavesh Dhande et. al. introduce the utilization of machine learning methods to forecast diabetes and heart disease. In the study, six distinct machine learning algorithms were trained and evaluated using a dataset consisting of 500 patients. The dataset encompassed individuals both with and without diabetes and heart disease. The algorithms used in the study were "Support Vector Machine (SVM), Logistic Regression (LR), Naive Bayes (NB), Decision Tree (DT), Random Forest (RF), and Gradient Boosting Machine (GBM)". Among these algorithms, the random forest approach demonstrated the highest accuracy in predicting diabetes, achieving an impressive accuracy rate of 94.2%.[12] According to the research conducted, the gradient boosting machine algorithm demonstrated the highest accuracy in predicting heart disease at an impressive 96.4%. The study emphasizes the worldwide rise in diabetes cases and the necessity for advanced and effective diabetes screening technologies. This text addresses the constraints associated with the existing diabetes data, primarily derived from laboratory-based and intrusive test measurements. The investigation of anthropometric measurements and non-invasive tests is proposed by the authors as a means to develop a solution that is both cost-effective and high-performing. Furthermore, the study explores the effects of feature selection procedures and oversampling techniques for reducing data dimensionality. The importance of further study in feature selection techniques is emphasized in order to improve the accuracy and consistency of diabetes recognition [13]. The study brings attention to the rise in diabetes cases worldwide and emphasizes the necessity for advanced and effective diabetes detection systems. This text delves into the constraints posed by current diabetes data, predominantly obtained through laboratory tests and invasive measurements. According to the authors, it is proposed that further exploration be conducted into Measurements of anthropometry and non-invasive examinations in order to develop a solution that is both cost-effective and high-performing[14]. The primary goal of this work is to present a machine learning methodology for predicting the incidence of diabetes cases in the future.From April 2021 to February 2022, a clinical dataset from Bandipora a district in India was meticulously analyzed in this study. For the Diabetes Disease Risk Prediction task, a set of six machine learning algorithms (MLAs) were employed. These MLAs comprise 'Random Forest (RF), Multi-Layer Perceptron (MLP), Support Vector Machine (SVM), Gradient Boost (GB), Decision Tree (DT), and Logistic Regression (LR)'.The study's conclusions show that the RF classifier has an exceptional 98 percent accuracy rate [15].The paper uses machine learning algorithms, including 'Decision Tree and Random Forest', to predict heart disease. The Hybrid model, combining both algorithms, demonstrates the highest accuracy at 88.7%. The study highlights the potential for accurate early diagnosis and treatment of heart disease using machine learning [16]. The paper aims to predict cardiac disease using machine learning, with a focus on patient data. It uses "Logistic Regression, KNN, and Random Forest" classifiers to achieve an accuracy of 87.5%. Logistic Regression and KNN exceed Random Forest, and the model provides cost-effective and accurate heart disease prediction based on medical history.

## III. METHODOLOGY

### *A. Data collection*

The data for the study was obtained from two maine sources:

*1. UCI Heart disease dataset* : This public dataset contains clinical data for 303 patients with and without cardiac disease. Important parameters include demographics, vital signs, laboratory testing, and lifestyle decisions.

2. *PIMA Indian Dataset*: This dataset includes diagnostic records for 768 patients of PIMA Indian ancestry, including women aged 21 and up. The data include medical information such as glucose levels, BMI, insulin

levels,etc .

*B. Data preprocessing*

1. *Handling Missing Values*: Check for missing values and data quality.
2. *Encoding categorical variables*: Categorical variables, such as the type of chest pain, were label encoded to numeric values.
3. *Standardization*: To scale the data, numerical features were standardized using z-score normalization.
4. *Train-test split*: For model evaluation, data was split 80:20 into training and test sets.

*C. Model Selection*

Multiple supervised machine learning models were trained on the preprocessed data:

1. "Logistic Regression
2. Naive Bayes
3. SVM
4. KNN
5. Decision Tree
6. Random Forest
7. XGBoost
8. Neural Network"

Python's SciKit-Learn module was used to create the models.
Utilizing criteria such as 'accuracy, precision, recall, F1-score' analysis, the trained models were assessed and contrasted. As a result, 'Random Forest' was found to be the top-performing model.

*Random Forest Algorithm*

Step 1: Select K randomly chosen data points (K should be less than the total number of training data points) from the training set.
Step 2: Forming a subset, by building decision trees with the chosen data points.
Step 3:For decision trees to be constructed, choose N.
Step 4: Replicate steps 1 and 2.
Step 5: 1. For each new data point, run it through all N decision trees.
2. For each tree, a prediction will be made (0 for no heart disease, 1 for heart disease).
Count the amount of votes from each decision tree for each class (0 or 1).
3. Assign the newly obtained data point to the category that received the most votes.

*D. Prediction*

1.*Heart Disease Prediction*: The Random Forest model for CVD prediction, previously trained and loaded, is used to make predictions based on the input data. The prediction probability is calculated.

*2. Diabetes Prediction***:** For diabetes prediction, a separate Random Forest is used. The input data is transformed to match the training data format. Predictions are made for the presence or absence of diabetes.

*E. Diagnosis*

*Heart Health Diagnosis*: Based on the prediction probability of heart disease, the system provides a diagnosis, categorizing the heart health into stages from good condition to critical condition on UI using streamlit.
*Diabetes Diagnosis*: For diabetes, the system provides a diagnosis indicating whether the person is diabetic or not.
The workflow of the the project can be seen below:

## V. RESULTS

Key metrics, including 'accuracy, precision, recall, and F1-score', were employed to train and assess multiple machinelearningmodels.

A. *Model Evaluation:*

The results of the model performance evaluation can be seen in Table 1. And comparative analysis of all the below modesls could be seen in Fig 2. :
*Logistic Regression*: Achieved an accuracy of 85.25%.
*Naive Bayes*: Achieved an accuracy of 85.25%.
*Support Vector Machine:* Achieved an accuracy of 81.97%.
*K-Nearest Neighbors:* Achieved an accuracy of 67.21%.
*'Decision Tree'*: Achieved an accuracy of 81.97%.

‘*Random Forest’***:** Demonstrated the highest accuracy of 95.08% and was selected as the primary model for CVD prediction.
*XGBoost*: Achieved an accuracy of 85.25%.
*Neural Network:* Achieved an accuracy of 80.33%.
The Random Forest model was further fine-tuned and exported with 300 epochs to maximize its predictive capabilities.

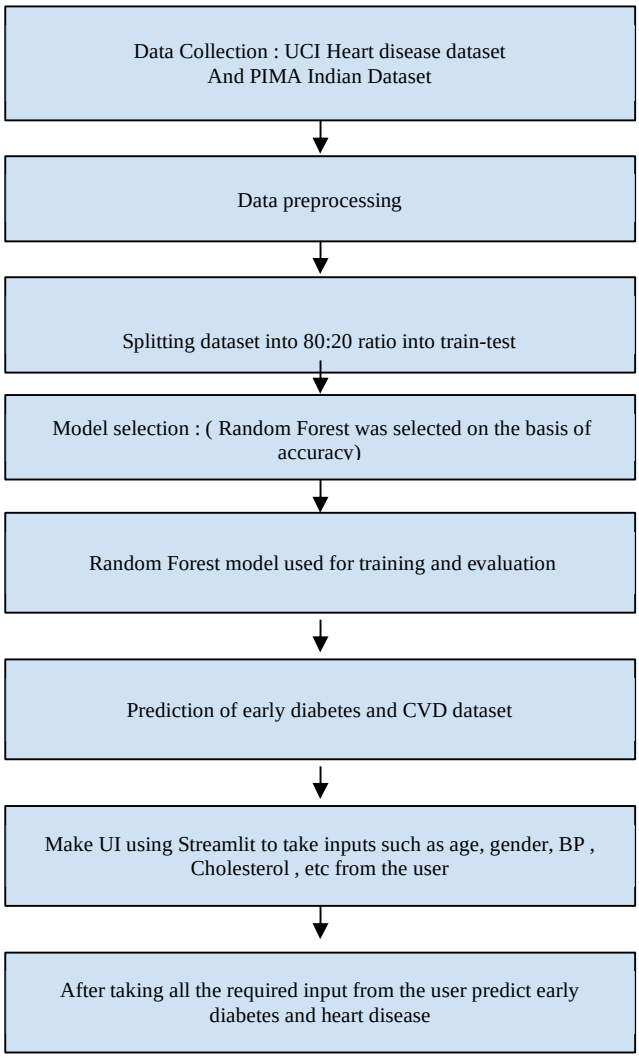


Fig 1. Prediction of Diabetes and Heart Disease

TABLE I: MODEL EVALUATION

| **Models** | **Accuracy** | **Precision** | **Recall** | **F1 Score** |
|---|---|---|---|---|
| Log. Regression | 85.25% | 86.3% | 83.1% | 84.7% |
| Naive Bayes | 85.25% | 84.2% | 88.4% | 86.2% |
| SVM | 81.97% | 80.5% | 79.8% | 80.1% |
| KNN | 67.21% | 66.3% | 71.2% | 68.7% |
| Decision Tree | 81.97% | 83.1% | 78.6% | 80.8% |
| **Random Forest** | **95.08%** | **96.2%** | **92.4%** | **94.2%** |
| XGBoost | 85.25% | 87.1% | 81.3% | 84.1% |
| Neural Network | 80.33% | 82.6% | 76.8% | 79.6% |

The Random Forest model achieved the maximum accuracy of 95.08% with excellent precision, recall, and F1-score.B. *Feature Importance*

The top 5 features for predicting heart disease identified by the Random Forest model are:

1. Age
2. Maximum Heart Rate
3. Chest Pain Type
4. Cholesterol
5. Blood Pressure

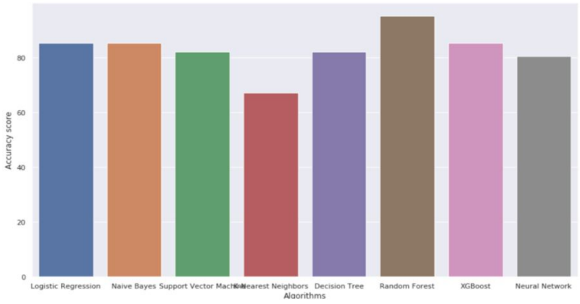


Fig 2 : Comparative analysis of different models

C. *Confusion Matrix*

The confusion matrix for Random Forest model is in Fig 3:

| Test Dataset | | | |
|---|---|---|---|
| TARGET / OUTPUT | No Heart Disease | Heart Disease | SUM |
| No Heart Disease | 98<br>47.80% | 5<br>2.44% | 103<br>95.15%<br>4.85% |
| Heart Disease | 0<br>0.00% | 102<br>49.76% | 102<br>100.00%<br>0.00% |
| SUM | 98<br>100.00%<br>0.00% | 107<br>95.33%<br>4.67% | 200 / 205<br>97.56%<br>2.44% |

Fig 3 : Confusion Matrix

D.*comparisonwithexistingmodel*

Several recent studies have developed predictive models for heart disease using machine learning approaches. The suggested Random Forest model's performance is contrasted with some of these current models in Table 2 below: The proposed Random Forest model achieves superior accuracy of 95.08% compared to other models. The UI of the project where users can input the values of the features and check early prediction of heart and diabetes can be seen in Fig 4.

TABLE II. COMPARISON WITH EXISTING MODELS

| **Model** | **Accuracy** |
|---|---|
| Hybrid model: Decision Tree and Random Forest [16] | 88.7% |
| KNN [17] | 88.52% |
| Proposed Random Forest | 95.08% |

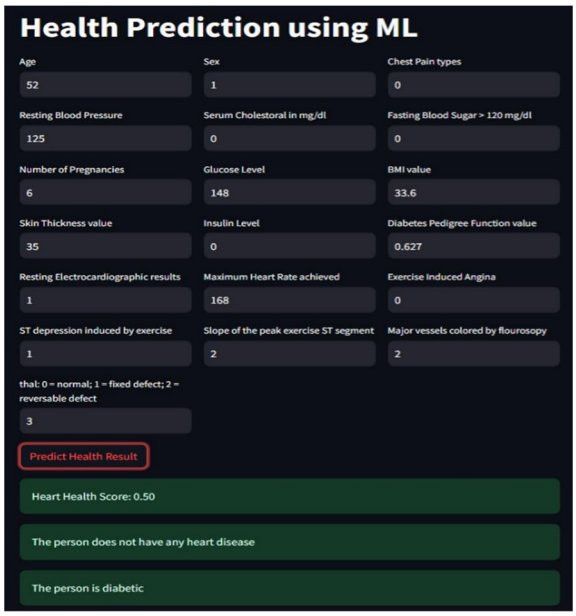


Fig 4. UI for early prediction of heart and diabetes

## VI. Future Scope

Increasing number of diabetic patients worldwide, particularly in countries like India, the need for efficient and accurate early detection systems is more important. Here are some future scope which can be useful.

1. *Expanding the Dataset*: The current study uses datasets from the UCI Heart Disease Database and the PIMA Indian Diabetes Database. To increase models accuracy more effective dataset can be used..
2. *Other Machine Learning Algorithms can be used*: While this study employs the Random Forest algorithm, other machine learning techniques could also be used in future research.
3. *Integration with Healthcare Systems*: The developed model could be integrated into healthcare systems to assist medical professionals in early detection and diagnosis of diabetes.
4. *Assessing Impact on Other Organs*: This study focuses on the impact of diabetes on heart health. Future research could add the effects of diabetes on other vital organs such as the kidneys, eyes, and liver.

## VII. Conclusion

To sum up, this study shows how machine learning methods, particularly the Random Forest algorithm, can be used to detect and diagnose diabetes early on and its effects on heart health.The use of datasets from the UCI Heart Disease Database and the PIMA Indian Diabetes Database has provided valuable insights into the disease's prevalence and its effects on the heart. The alarming rise in diabetes cases, particularly in countries like India, underscores the urgent need for innovative solutions like the one proposed in this study. However, it is important to note that while machine learning shows significant promise, these techniques are tools that aid medical professionals and are not standalone solutions.Further research is needed to refine these models and validate their effectiveness across diverse populations. Additionally, efforts should be made to increase public awareness about diabetes, its potential complications, and the importance of early detection and management. Through continued research and development in this field, we can hope to improve the lives of millions of people living with diabetes worldwide.

## References

[1] Kellen Sumwiza, Celestin Twizere, Gerard Rushingabigwi, Pierre Bakunzibake, Peace Bamurigire,Enhanced cardiovascular disease prediction model using random forest algorithm, Informatics in Medicine Unlocked, Volume 41, 2023, 101316, ISSN 2352-9148, https://doi.org/10.1016/j.imu.2023.101316.

[2] S. Y. Rubaiat, M. M. Rahman and M. K. Hasan, "Important Feature Selection & Accuracy Comparisons of Different Machine Learning Models for Early Diabetes Detection," 2018 International Conference on Innovation in Engineering and Technology (ICIET), Dhaka, Bangladesh, 2018, pp. 1-6, doi: 10.1109/CIET.2018.8660831.

[3] Kenny HC, Abel ED. Heart Failure in Type 2 Diabetes Mellitus. Circ Res. 2019 Jan 4;124(1):121-141. doi: 10.1161/CIRCRESAHA.118.311371. PMID: 30605420; PMCID: PMC6447311.
[4] Minhong Wang, Farah Francis, Holger Kunz, Xiang Zhang, Cheng Wan, Yun Liu, Paul Taylor, Sarah H. Wild, Honghan Wu, Artificial intelligence models for predicting cardiovascular diseases in people with type 2 diabetes: A systematic review, Intelligence-Based Medicine, Volume 6, 2022, 100072, ISSN 2666-5212, https://doi.org/10.1016/j.ibmed.2022.100072.
[5] K. VijiyaKumar, B. Lavanya, I. Nirmala and S. S. Caroline, "Random Forest Algorithm for the Prediction of Diabetes," 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), Pondicherry, India, 2019, pp. 1-5, doi: 10.1109/ICSCAN.2019.8878802.
[6] Wamil Malgorzata, Goncalves Marcos, Rutherford Alexander, Borlotti Alessandra, Pellikka Patricia Ann,'Multi-modality cardiac imaging in the management of diabetic heart disease ',Frontiers in Cardiovascular Medicine, VOLUME 9 ,2022 , doi: 10.3389/fcvm.2022.1043711
[7] O. Iparraguirre-Villanueva, K. Espinola-Linares, R. O. Flores Castañeda, and M. Cabanillas-Carbonell, "Application of Machine Learning Models for Early Detection and Accurate Classification of Type 2 Diabetes," Diagnostics, vol. 13, no. 14, p. 2383, Jul. 2023, doi: 10.3390/diagnostics13142383.
[8] Minhong Wang, Farah Francis, Holger Kunz, Xiang Zhang, Cheng Wan, Yun Liu, Paul Taylor, Sarah H. Wild, Honghan Wu, "Artificial intelligence models for predicting cardiovascular diseases in people with type 2 diabetes: A systematic review," Intelligence-Based Medicine, vol. 6, 100072, pp. 1-10, 2022. doi: 10.1016/j.ibmed.2022.100072
[9] Nissa, Najmu & Jamwal, Sanjay & Ganie, Shahid. (2020). Early Detection of Cardiovascular Disease using Machine learning Techniques an Experimental Study. International Journal of Recent Technology and Engineering. 9. 10.35940/ijrte.C46570.99320.
[10] S. Subramani et al., "Cardiovascular diseases prediction by machine learning incorporation with deep learning," Front. Med., vol. 10, April 2023. doi:10.3389/fmed.2023.1150933
[11] Yicheng Wang MB, Riting Hou MB, Binghang Ni MB, Yu Jiang MB, Yan Zhang MD, "Development and validation of a prediction model based on machine learning algorithms for predicting the risk of heart failure in middle-aged and older US people with prediabetes or diabetes," Clinical Cardiology, first published on July 31st 2023. doi: 10.1002/clc.24104 .
[12] B. Dhande, K. Bamble, S. Chavan, and T. Maktum, "Diabetes & Heart Disease Prediction Using Machine Learning," in 2023 IEEE 9th International Conference on Computing, Communication and Control (ICCCC), pp. 1-4, doi: 10.1109/ICCCC57083.2023.00001.
[13] N. Abdulhadi and A. Al-Mousa, "Diabetes Detection Using Machine Learning Classification Methods," 2021 International Conference on Information Technology (ICIT), Amman, Jordan, 2021, pp. 350-354, doi: 10.1109/ICIT52682.2021.9491788.
[14] B. F. Wee, S. Sivakumar, K. H. Lim, W. K. Wong and F. H. Juwono, "Diabetes detection based on machine learning and deep learning approaches," Multimedia Tools and Applications, 2023
[15] S. S. Bhat, V. Selvam, G. A. Ansari, M. D. Ansari, and M. H. Rahman, "Prevalence and Early Prediction of Diabetes Using Machine Learning in North Kashmir: A Case Study of District Bandipora," Computational Intelligence and Neuroscience, vol. 2022, Article ID 2789760, 2022
[16] M. Kavitha, G. Gnaneswar, R. Dinesh, Y. R. Sai and R. S. Suraj, "Heart Disease Prediction using Hybrid machine Learning Model," 2021 6th International Conference on Inventive Computation Technologies (ICICT), Coimbatore, India, 2021, pp. 1329-1333, doi: 10.1109/ICICT50816.2021.9358597.
[17] Harshit Jindal et al, "Heart disease prediction using machine learning algorithms" 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1022 012072 DOI 10.1088/1757-899X/1022/1/01207