Enhanced Prediction of Diabetes Outcomes Using Machine Learning Ensemble Modeling with Hyperparameter Tuning

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Abstract. Diabetes is one of the diseases that are engraved with immense challenges to the population and the global health systems. Such factors are essential for enhancing the probability of a better prognosis to work for the advantage of the patient. This paper applies an enhancement of the machine learning technique through ensemble modeling with hyperparametric tuning for predicting diabetes outcomes. For compiling the improved and accurate prediction model, the study incorporates the merits of both the random forest and the gradient boosting models. By fine-tuning the pre-processing and tuning the hyperparameter of the model, the accuracy rate was improved to 96%. The iterative improving technique of gradient boosting and random forest's ability to deal with high-order feature interactions enabled the model improvement a lot. Besides increasing the accuracy of the prediction, the ensemble technique provides a more reliable and comprehensible model for clinical practice. This approach may also enable medical practitioners to diagnose patients at an early stage and arrange treatments to enhance the patient's quality and reduce the chance of complications for patients with diabetes. The findings here also apply the benefits of hyper-parameter optimization, thereby enhancing the outcome of a model, while the gathered outcome demonstrates the effectiveness of machine learning ensemble solutions in the medical prediction context.

Keywords: Hyperparameter Tuning, Prediction, Ensemble, Chronic Disease, Model Performance.

1 Introduction

Diabetes is a common non-communicable disease that affects millions of individuals worldwide; in addition to its complications such as neuropathy, renal failure, and cardiovascular diseases [1]. To enable those consequences to be well addressed and prevented, diabetes outcomes must be well predicted and in the shortest time [2]. Today, machine learning can be viewed as a powerful instrument in the healthcare sector with sophisticated models and algorithms that allow the evaluation of huge amounts of data to predict the development and outcome of diseases. To enhance the exactness of the prognosis of the diabetes outcome, this study examines the machine learning ensemble modeling which is a conjoining of the random forest and gradient boosting algorithms. The present work aims to achieve the best models that will yield high levels of accuracy and reliability through hyperparameter tuning [3]. When

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incorporating all these modern techniques and technologies, the efficacy of the system rises, and healthcare professionals are equipped with appropriate tools that will help them make proper decisions so that patients can receive proper management and, consequently, diabetes control.

Diabetes mellitus is a chronic condition that affects millions of people globally; statistics have it that more people are being diagnosed with the disease than before[4]. Diabetes is a disease that has its root cause in the high levels of blood glucose and a wide range of effects such as damage to a person's kidneys, nerves, and heart diseases among other illnesses that are detrimental to health [5]. The need for accurate and credible prediction models that can assist with the diagnosis and treatment of the ailment at an initial stage increases in parallel with the trend of increasing rates of diabetes. Traditional techniques that are used in diabetes outcome prediction are often based on statistical techniques that are inherently incapable of capturing the more complex scenarios of the relationship between one or many risk factors. Lending a concentrated identity as a potent substitute for conventional analytical tools, machine learning has emerged with advanced techniques for sorting through large information for patterns and linkages [6]. Out of all the machine learning methodologies, ensemble modeling has been of interest given the capability to boost up the predictive capability by integrating a variety of algorithms. In particular, when using a combination of random forest with Gradient boosting, certain possibilities have been revealed to address complex data entries with a large number of attributes. When hyperparameter optimization is used for the increasing accuracy of these models it can become an effective instrument in the war against diabetes [7].

The following are the key potential futuristic considered in the database for research are polycystic ovarian syndrome, high blood pressure, and obesity [8]. These are aging, wrong triglyceride and cholesterol concentrations, and a tendency to hyperglycemia. It is comprehensible that all these related risk factors are interdependent and mandatory to predict the outcomes of diabetes and develop effective preventive and therapeutic measures. The health care providers could more clearly identify each patient's risk and launch specific interventions to reduce the incidence and outcomes of diabetes by treating all of these factors simultaneously [9].

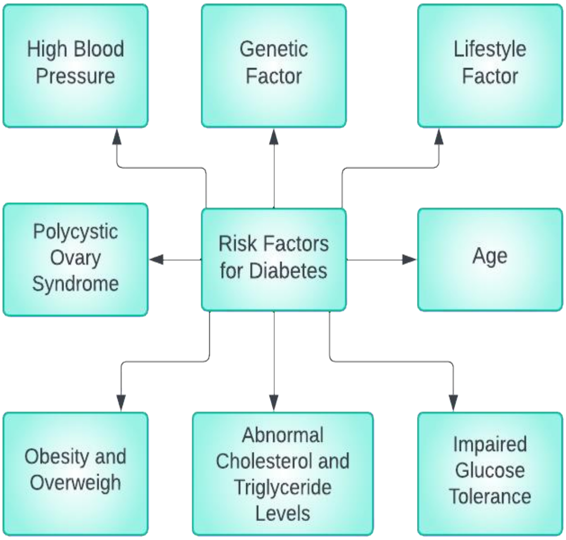

Fig. 1. Risk Factors Associated with Diabetes Disease

Fig. 1 illustrates the several risk factors that cause diabetes because diabetes is a disease that provides considerable health challenges globally and wards call for better healthcare interventions for the disease, this study seeks to enhance the prediction for diabetes outcomes by employing machine learning ensemble modeling and hyperparameter tuning. Diabetes continues to be a leading cause of both morbidity and mortality in this world and the mishaps emanating from it arise from inadequate management or lack of diagnosis. However, as a chronic, systemic disease diabetes is best classified as an illness that is characterized by a myriad of aspects and formal, mathematical-predictive models proved to be limited in terms of foreseeing the further development of the condition [11]. This could be the case because we have machine learning which can analyze large information and identify intricate patterns that would be hard to tell by other normal methods. The final use of such work is to develop a prediction instrument that can aid doctors in increasing diagnosis and bringing early treatment to implementation for healthcare professionals; ultimately, minimizing the load of issues correlated with diabetes. This incentive arises from the potential of making a huge difference in terms of patient gains and ensuring a way of delivering better plans of management for diabetic patients.

The main purpose of this research is to enhance the possibility of diabetes outcome prediction based on state-of- the-art machine learning approaches. To enhance the prediction of diabetes, Section I discussed about the brief introduction about the diabetes disease and the key factors that are responsible for it. Section II presents a comprehensive review of the current scientific literature on the application of several machine learning approaches: but focuses on the integration of the best-performing classifiers comprising random forest classifiers and gradient boosting models. Section III focuses on the methodological approach of the study and the criteria for the selection of the datasets to guarantee the variation and randomness of diabetes patients. In Section IV, all the models of the chosen ensemble are evaluated in terms of how well they interpose the various degrees of freedom of hyperparameters to improve model performance. All the research findings are then lastly concluded in Section V in which the importance of applying hybrid machine learning approaches within hospitalized patients' management and to gain more accurate findings about diabetes outcome are stressed

2 Literature Review

Employing the machine learning approaches, the authors [12] developed a model that can be employed for the predictions of the likely onset of diabetes especially among females. From the research that they conducted, it emerged how important it is to identify people with the diseases early enough to avoid deterioration and the development of related problems such as kidney and heart complications. Achieving an accuracy level of 82%, the authors applied the random forest classifier model to suggest the concept behind the method, that it can be used by physicians to diagnose diabetes in the early stages.

Daab describes difficulties that come with diabetes mellitus a metabolic condition common in humans, which is characterized by high blood sugar levels [13]. They also had to carry out some exploratory data analysis such as pre-processing, label encoding, normalizing, and cleaning the data used in the machine learning models they employed to forecast diabetes. The dataset has been balanced using synthetic minority over-sampling along with several machine learning algorithms. Moreover, to combine all the models, the authors applied the voting classifier which proved to bring the highest accuracy level, namely 96.69%.

To identify an early stage of diabetes, the authors [14] proposed to create a model for early detection of this pathology; they stressed the significance of such a diagnosis by focusing on the adverse effects of diabetes. They argued that this is the reality of the situation because too many factors depend on each other and the diagnosis procedure which ordinarily involves the administration of many tests often fails to pick diabetes when it is still in its embryonic stages. The reason for their study was to improve the accuracy of diabetes prediction by incorporating multivariate factors to reduce.

As stated by the authors [15], there is diabetic mellitus that is a chronic disease that originates from the insufficient production of insulin by the pancreas or poor uptake of the commodity by the human body. They discussed the symptoms of diabetes and how the diagnosis is done, the graduates were told how AI technology was quickly becoming less prone to human errors. This study gave a comparative analysis of the effectiveness of many machine learning algorithms such as random forest, KNN, Support Vector Machine (SVM), and decision trees concerning the diagnosis of diabetes.

The authors [16] discussed genetic and clinical variation in diabetes mellitus stressing the essentiality of early diagnostic intervention to protect the immune system and internal critical organs. They emphasized the need for efficient models based on memory and accuracy as a high recollect score in a way defines correct class identification and the lack of missed cases. To assess the performance of several machine learning algorithms, and to identify the best prediction model for the diagnosis of diabetes, they used the behavioral risk factor surveillance system (BRFSS) dataset.

The authors [17] stressed the role of early diabetes identification in improving the outcome and reducing the burden of healthcare. Techniques that were employed in their study included AdaBoost, Logistic Regression, K- Nearest Neighbors (KNN), and Naïve Bayes. The study highlighted experimental detail and comparative analysis in detail and the relative merits and demerits of each method involved in the diagnosis of diabetes were recognized. Their work contributes to the process of the constant development of new practical tools for the diagnosis of diabetes at an early stage and its treatment.

Since diabetes is among the leading causes of death, the authors [18] focused on the early prediction and detection of the disease and this admitted that this is among the most pressing healthcare challenges. To decide on the best machine learning techniques for diabetes prediction, they surveyed several articles. They found out that the techniques that have been utilized in prior research encompass the likes of Support Vector Machine, Logistic Regression, Decision Tree, Random forest, Neural Networks, and Naïve Bayes.

The authors [19] focused on the early detection of diabetes also given conditions such as; diabetes, heart diseases, and obesity just to name a few complications conveyed by the new fashionable diseases of the contemporary culture. When comparing many machine learning algorithms to each other, the authors determined that the random forest classifier was more accurate than the other approaches. The study pointed to deep and machine learning methods in the area of information security and health care, to underline that they offer greater outcomes than certain traditional approaches.

In an improved work on diabetes identification, the authors in [20] developed a new XGBoost model for identifying diabetes using the Pima Indian Diabetes dataset and a hyperparameter optimization approach called random search. The comparison implemented by the authors of the paper revealed that the optimized version of the XGBoost model outperforms six other well-known machine learning models in terms of accuracy, precision, sensitivity, and F1 score. Thus, the study reinforces the effectiveness and robustness of the XGBoost model for diabetes diagnosis and takes the field of medical diagnosis toward individualized diabetes care.

The authors [21] described diabetes mellitus as a metabolic disease that afflicts human beings due to increased blood glucose concentrations in the body as a major public health enemy. They focused on the hidden consequences of diabetes that might not be easily recognizable, including; heart problems, kidney issues, eye issues, nerve issues, and eye issues. To enhance early detection the study employed and compared naive bayes and random forest on a dataset created from PIMA samples. The authors examined the degree of accuracy of the NB and RF approaches while handling several input parameters from the PIMA dataset for the prognostication of diabetes. The study also highlighted the strengths and weaknesses of each model by assessing the suitability of the models according to the performance standards established by correctness using several performance indicators.

3 Methodology

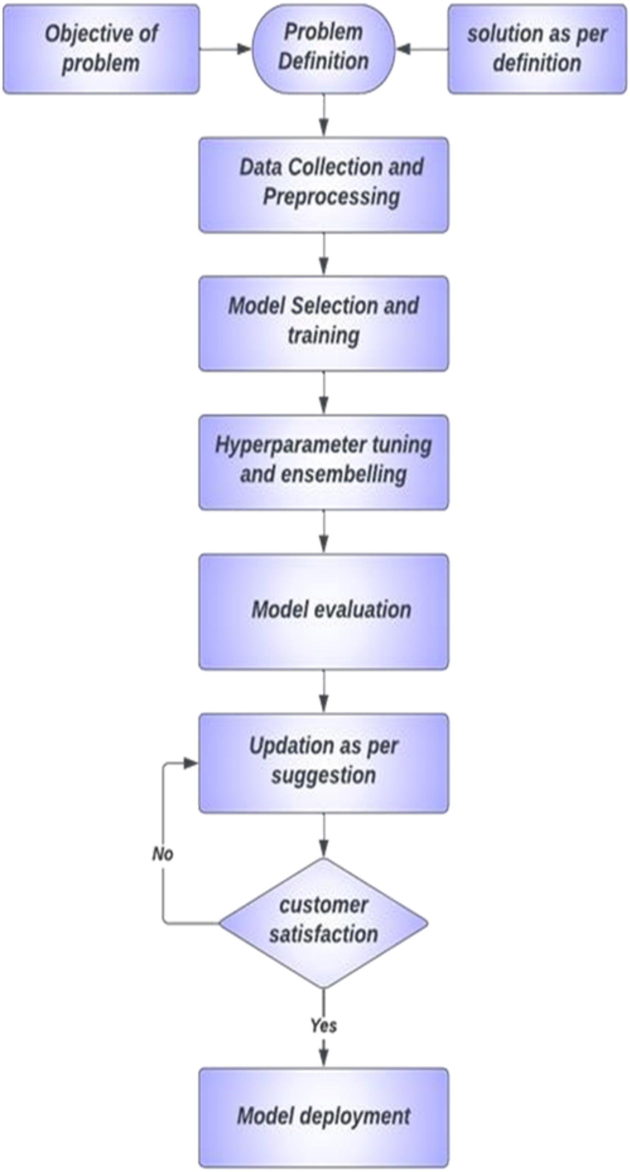

Fig. 2. Proposed Methodology

The proposed methodology suggests the various steps involved in introducing an effective model for Diabetes disease, as shown in Fig. 2, and the knowledge about the algorithms involved and tuning of the model to get better results.

3.1 Data Collection

To better predict diabetes outcome levels, the following steps should be taken: First, introduce a large dataset with a relatively highly reliable source, for example, the University of California at Irvine –Machine Learning Repository. Those are personal health records of the individuals with the values of the other variables that are important for predicting diabetes, including age, BMI, high blood pressure, blood sugar levels, and insulin levels should be included in the dataset. It is therefore important to regard the fundamental rule of ensuring that a dataset is diverse and representative to produce a robust model that is capable of affecting populations other than the one used to build the model.

3.2 Data Preprocessing

Data preparation also known as data cleansing, is also another process that follows data collection. This involves ignoring the missing values from the data through various methods like median or mean imputation. Before moving into data analysis, it is important to consider data cleaning of the collected data and that's why outliers have been identified and handled by some approaches like the Interquartile Range- based approach and the Z-score analysis approach. Facial-to- feature conversion is followed by feature creation in which the domain expertise is used along with conventional tools like Recursive Feature Elimination (RFE) to identify the most significant features based on the outcomes of diabetes. To ensure equal distribution of diabetic outcomes in both groups they then divide the data set into test and training data normally it is in the ratio of 80/20.

3.3 Model Selection

Random forest and gradient boosting are the two classification algorithms that are used for predicting the results in proposed model. Random forest is still a viable contender for diabetes outcome prediction because; it can mimic complicated feature interactions, and it can easily cope with an unbalanced dataset. While it slowly builds the weak learners, gradient boosting, on the other hand, has the flavor of building solid prediction models. The idea is that only selectively used models can be taken advantage of, and the result is a prediction system that is more accurate and reliable.

3.4 Model Hyper-parameter Tuning and Ensembling

The hyperparameters of the selected models are fine- tuned by using a grid-based search with cross-validation. The parameters that are crucial in the RandomForest model are the number of trees (n_estimators), the level of tree split (max_depth), and the number of samples split (min_samples_split). As in any other type of model, hyperparameters for the Gradient boosting model, such as the learning rate, the number of enhancing stages (n_estimators), or the depth of trees are adjusted too. After tuning, the models are combined by using a soft voting ensemble system which brings an overall increment in the prediction probability forecasts where the models are used.

3.5 Model Evaluation

To ensure that there is stability of the final model on the training data, the final ensemble model is evaluated on 10- fold cross-validation. Such measures as accuracy, precision, recall, F1-score, or even errors are calculated. The performance of the model is generalized from the training set by using unseen data to check the efficiency of the model.

3.6 Model Deployment

The purpose of simulation is to evaluate the model's effectiveness; therefore, the model must be implemented, by following its integration into a system for clinical decision-making or an equivalent system that will enable medical practitioners to make accurate predictions about the outcomes of diabetes patients. To ensure that the model works well in a practical context, it is trained again and again with a new set of data and is checked from time to time.

4 Results

4.1 Accuracy

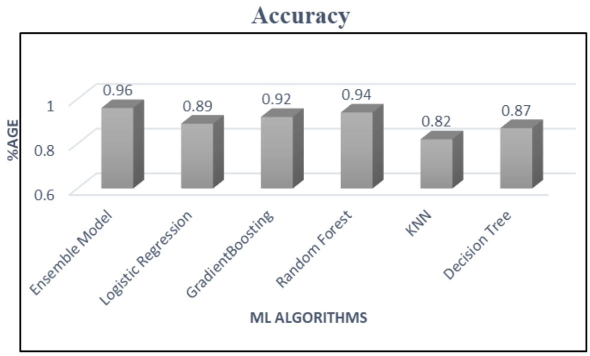

Fig. 3. Accuracy of different ML models

In the bar chart, the relative aptitude of many nested machine learning algorithms for result prediction is juxtaposed. It has to be noted that its coefficient of determination ranges from 96%, last but not least; the Ensemble Model stands out and clearly shows the benefits of combining many models for improving the predictive capabilities as shown in Fig. 3. The second is random forest with the accuracy of 94% and Gradient boosting with an 92%. The results for individual techniques include 89% for logistic regression. Nonetheless, in terms of accuracy. The Decision Tree was a little better at 87%, the lowest of all, KNN has the worst reliability score which is 82%. The graph indicates that the ensemble methods are better ranked than any separate algorithm in the aspect of accuracy and thus can be trusted with prediction jobs.

4.2 Precision

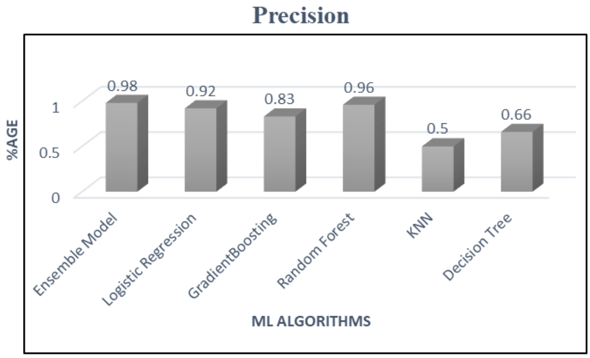

Fig. 4. Precision of different ML models

Precision refers to the rate at which true positive predictions are a fraction of all the positive predictions that were made by the model. The performance of various forms of machine learning algorithms is shown in the bar chart given in Fig. 4. It includes 98% of the ensemble model is more accurate than the Random forest which is only second best with a score of 96%. Additionally logistic regression proposed an a value of 92%. It turns out that the accuracy of gradient boosting is relatively high and stands at 83%. With 50% of KNN and decision trees has the lowest 66%. This implies that in as much as we are identifying the actual positive cases, the ensemble model together with random forest is the best and most efficient predictor model.

4.3 Recall

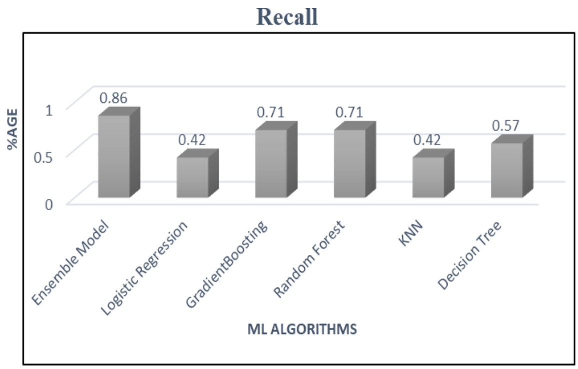

Fig. 5. Recall of different ML models

Recall is correctly predicted positive occurrences divided by all of the actual positive results existing in a dataset. It is also known as the true positive rate, or the response rate. In the bar chart shown in Fig. 5, the recall of many machine learning algorithms has been compared. With a recall of 86%, the performance of the Ensemble Model is superior to the others in the aspect of correctly detecting positive samples. 71% recall is the case of true positive both the classifiers random forest and gradient boosting perform almost equally well. Surprisingly, KNN and Logistic Regression recall is far lower at 42%, indicating that they often fail to notice a considerable amount of positive things that transpire. The Decision Tree model seems to be better than that of KNN and Logistic Regression models, but still less resistant compared to the other models proposing a value of 57%.

4.4 F1 Score

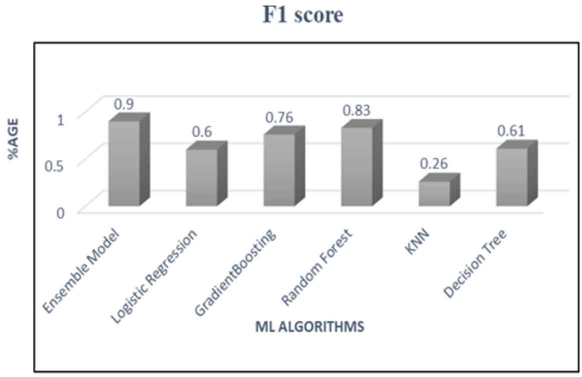

Fig. 6. F1 Score of different ML models

The F1 score measures both accuracy and recall in equal measures and is the ratio of the two combined in terms of a harmonic mean. This is in the bar chart in Fig. 6 which displays the F1 scores of most of the used machine learning algorithms to give a measure of their performance. The Ensemble Model has higher accuracy in its analysis resulting in the highest F1 score of 90%. In addition, random forest performs fairly well to give an F1 score of 83%. The third highest of the F1 scores is 76% which is quite acceptable for the Gradient boosting model. As evident from the attained F1 scores of Decision Tree and Logistic Regression models which are 61% and 60%. As can be seen from the F1 scores, KNN has the worst F1 score of 26% because of a vast disparity between its precision and recall.

4.5 Error

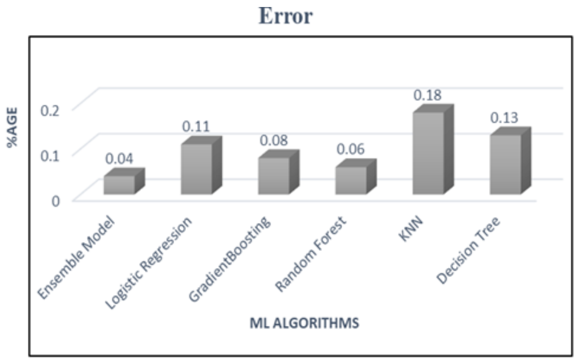

Fig. 7. Errors of different ML models

In machine learning, error is defined as the variation between actual values that are obtained from the dataset of the respective actual data results and the predicted values that are computed from the machine learning model. Coordinates of error rates of different algorithms to the corresponding bars of the bar chart are indicated in Fig. 7. Just like any other set of rules, it is not one hundred percent accurate, for it has an error margin of 4%, it is possible to observe that the proposed Ensemble Model presents the lowest error rate highlighting the model's high accuracy and predictive capability. With a little higher error rate of 6% random forest is the second but was not too bad at all. By comparing with the other methods, gradient boosting staged 8% is reasonable. In turn, lower accuracy makes Logistic Regression and Decision Trees have higher error rates of zero. 11% and 13%, respectively. At 18% KNN has the highest error rate hence making it the minimum successful model in this evaluation.

5 Conclusion and Future Scope

This study has recorded some progress in terms of accuracy and reliability in the study of using machine learning ensemble modelling with hyperparameter adjustment for improving the prediction of diabetes outcomes. The methods are able to overcome some of the limitations that the conventional predictive models possess; by integrating the random forest and gradient boosting predictive models into one by applying hyperparameter tuning. They have implemented this approach successfully to deal with complex data sets, to find out significant risk indicators and develop early intervention strategies based on individuals' risk profiles. Plans are for applying this ensemble fashion improved three days in advance for real-time information and even integrating Internet of Things health monitoring devices for future monitoring and prognosis. Also, for the purpose of testing the model's versatility in other population subgroups, the subsequent research might examine the enhancement of diverse datasets usage. The final goal would therefore be to develop an adaptive learning system that would provide a better diabetes care in the long-run, responsive to the need for new data.

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