

Comparative Analysis of Machine Learning Algorithms for Enhanced Clinical Prediction of Fetal Health Status

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Abstract— The Child and Maternal deaths during pregnancy are one of the major catastrophes occurring globally. Reduction of child mortality is a tragic issue in several of the United Nations Sustainable Development Goals and is a key indicator of human progress. This research aims to assess the efficacy of Machine Learning algorithms, including K-Nearest Neighbor (KNN), Support Vector Machines (SVM's), Random Forest (RF) and Gradient Boosting (GB) in accurately predicting fetal health status by making use of Cardiotocograms (CTGs) technology. By comparing these algorithms, we seek to enhance CTG technology's ability to monitor the clinical parameters of a fetus such as baseline value, fetal movements, uterine contractions and reduce the risk of child and maternal mortality. This study underscores the importance of leveraging advanced computational methods to bridge gaps in healthcare thereby addressing critical healthcare challenges and ultimately striving towards more equitable maternal and child health outcomes globally. The proposed research has been tested with 2113 records obtained from Kaggle and has been successful in predicting the best algorithm with an accuracy of 96.926%.

Index Terms— Machine Learning, Exploratory Data Analysis, Cardiotocograms Technology, Fetal Classification, Fetal Health MonitoringU.

I. INTRODUCTION

In the current global economic landscape, the significant challenge of child and maternity mortality rates persists. Vital monitoring of fetal health is imperative to mitigate the risk of maternal and fetal fatalities. Leveraging machine learning algorithms, our research endeavours to propose a highly effective and efficient solution, aiming to decrease child and maternal mortality rates through regular fetal health assessments. Detecting fetal health issues early on can empower communities to access essential prenatal care. Prioritizing prenatal factors that impact fetal brain development holds the potential to enhance socioeconomic prospects for individuals.

Cardiotocography (CTG) is a vital technology that enables the concurrent collection of data from multiple monitoring methods, encompassing fetal movements, maternal uterine contraction pressure, and fetal heart signals. This comprehensive data is crucial for evaluating the health status of the fetus.

Analysis of CTG data allows for the proactive identification and mitigation of potential risks to the fetus. The clinical CTG examination provides valuable insights into the well-being of the developing baby.

The integration of advanced machine learning and artificial intelligence techniques with the health sector has facilitated the automation of predictive analysis in various medical domains, driven by the extensive adoption of these powerful technologies in recent years. In the United States, there is a significant concern regarding the fetal mortality rate. Without the utilization of Machine Learning (ML) algorithms for prediction, the fetal mortality rate stands at around 5.6 deaths per 1,000 births. Incorporating ML algorithms in fetal health monitoring can significantly reduce the number of fetal scans required in high-risk pregnancies. Leveraging ML-based analysis of CTG data, clinicians can identify high-risk cases that require intense monitoring.

In countries like the Dominican Republic, Egypt, and Brazil, the prevalence of caesarean sections has surpassed 55%, signifying a concerning trend. This underscores the imperative for more precise and effective methodologies, including machine learning (ML) algorithms, for scrutinizing cardiotocography (CTG) data and projecting fetal outcomes. ML models hold the potential to pinpoint key contributors to the demand for caesarean sections, such as fetal distress, prolonged labor, and placental abruption. This, in turn, could empower healthcare professionals to render more evidence-based decisions, potentially curbing the incidence of unnecessary surgeries and elevating both maternal and fetal prospects.

A study revealed that the use of ML algorithms can decrease the risk of fetal mortality by 30%. This is attributed to the capability of ML algorithms to analyse extensive data and identify patterns that may signal potential risks, empowering healthcare professionals to take proactive measures to mitigate these risks. Furthermore, ML algorithms can aid in minimizing unnecessary medical interventions, thereby contributing to a decrease in fetal mortality rates. A case study revealed that Brazil has achieved notable progress in lowering its fetal mortality rate through the application of ML algorithms for analysing infant mortality rates. The SHAP framework of interpretable machine learning played a crucial role in pinpointing the factors influencing Brazil's infant mortality rates. By the efficient and proper use of ML algorithms, the country successfully detected high-risk pregnancies and implemented targeted interventions, leading to a considerable decrease in fetal mortality rates.

The utilization of CTG technology has brought a massive transformation in the domain of fetal monitoring, delivering a non-intrusive and effective method for evaluating patterns of fetal heart rate and uterine contractions. Through the analysis of CTG data, healthcare professionals are able to pinpoint abnormal patterns indicative of fetal distress or other complications, thus empowering them to take timely measures to ensure optimal outcomes for both the mother and baby.

The primary aim of this research is to employ diverse machine learning methodologies for the efficient identification of prenatal health issues. The objective is to establish the foundation for a predictive machine learning system using CTG data to evaluate fetal health, potentially serving as a decision support system. The study's findings indicate that ML algorithms can offer substantial enhancements in the precision of fetal health classification. Fetal health classification plays a pivotal role in the realm of obstetrics and fetal monitoring, allowing healthcare professionals to evaluate the well-being of the fetus throughout pregnancy and childbirth. Through the examination of various factors pertaining to fetal health including heart rate patterns, accelerations, decelerations, and uterine contractions, informed decisions can be made by medical experts to ensure a secure and successful delivery.

The significance of fetal classification resides in its capacity to identify potential risks and complications that may emerge during pregnancy and childbirth. This facilitates healthcare professionals in implementing proactive measures to mitigate these risks, consequently reducing the likelihood of adverse outcomes such as fetal distress, birth asphyxia, and even mortality. Furthermore, precise fetal classification can also contribute to the reduction of unnecessary medical interventions, thereby yielding a notable impact on healthcare costs and resource allocation. Our study conducts an analysis of the fetal health dataset, encompassing parameters such as baseline value, accelerations, fetal movement, and uterine contractions. The primary objective is to categorize fetal health into three distinct classes: Normal, Suspect, and Pathological. Machine learning algorithms are used to discern relationships and associations among these parameters and fetal health outcomes, thereby facilitating precise classification and early identification of complications. A Normal classification is characterized by consistent baseline values and regular fetal movement, while Suspect and Pathological classifications are linked to mild and severe decelerations, respectively.

This classification system has the potential to alleviate the burden on healthcare professionals, allowing them to concentrate on high-risk cases and deliver individualized care to their patients. Our research underscores the potential of machine learning algorithms in transforming the healthcare sector by enabling early identification of fetal complications, enhancing fetal monitoring, and advancing educational resources to support decision-

making. The utilization of Machine Learning technologies shows promising potential in reducing maternal and fetal mortality rates and addressing pregnancy-related complications. The integration of machine learning algorithms into CTG data has bolstered the precision and dependability of fetal classification, establishing it as an indispensable asset in contemporary obstetric care.

A. Data Preprocessing and Processing Methodology

The dataset utilized in our research was obtained from Kaggle and comprised 2126 value-based data points, some of which were duplicates. During dataset processing, we identified 13 duplicate values. After removing these, we were left with 2113 data points spread across 22 columns. To preprocess the data, Exploratory Data Analysis (EDA) was employed to categorize the data into three groups: Normal, Suspect, and Pathological. The Fig 1.2 showcases the fetal data distribution in 3 categories. Additionally, a correlation matrix for the fetal features was plotted, and a comprehensive visualization for all the features was observed to facilitate further data processing. Feature selection techniques, specifically using SelectKBest to rank the features based on their correlation with the target variable, were then applied for data processing. Subsequently, the dataset was split into training and test data sets, and our model was developed.

II. ML IN FETAL HEALTH CARE

Machine learning (ML) has seen a growing application in the field of fetal healthcare with the aim of enhancing the outcomes for both the mother and the fetus. Through the analysis of extensive datasets, ML algorithms have the capability to forecast perinatal disorders, identify fetal diseases, and recognize high-risk pregnancies. Additionally, ML is instrumental in the creation of personalized fetal medicine, where care is tailored to individual fetuses, taking into account their distinct characteristics and requirements. For example, ML algorithms can examine fetal heart rate patterns to predict the likelihood of stillbirth or neonatal complications. Moreover, ML-powered chatbots and virtual assistants are playing a significant role in offering personalized guidance and support to expectant mothers, aiding them in managing their health and making well-informed decisions regarding their care. By harnessing ML in the realm of fetal healthcare, healthcare providers can augment patient outcomes, curtail healthcare expenses, and elevate the overall quality of care provided to pregnant women and their offspring.

III. RELATED WORKS

The figures depicted in Fig 1 and Fig 2 illustrate the categorization of research papers according to their publication year and the specific algorithms utilized for reference in our study and Fig 3 shows the different authors perspective.

Dr. Louis G. Keith, a renowned expert in maternal-fetal medicine, once said, "The fetus is a remarkable patient, and its care requires a deep understanding of its unique physiology and needs." A comprehensive examination of numerous recent studies pertaining to the classification of fetal health is undertaken by delving into various procedures and methodologies proposed by scholars. This section entails a meticulous review of the approaches, techniques, and algorithms employed in several relevant research works pertinent to the current study. The Fig 3 shows a clear description of the research works comprising our observations and remarks.

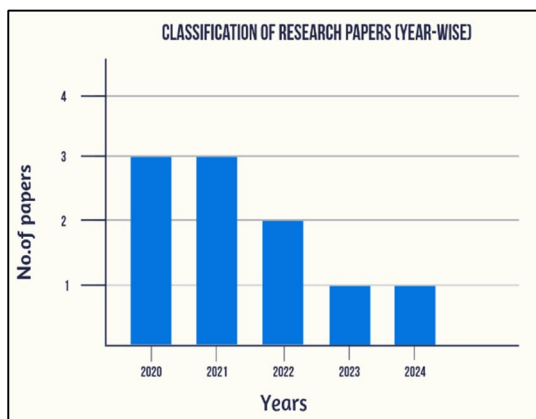


Figure 1: Classification of Research Papers (Year-Wise)

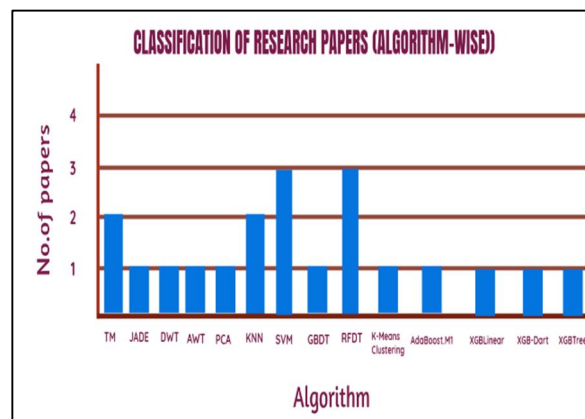


Figure 2: Classification of Research Papers (Algorithm-Wise)

Reference	Objective	Used Algorithm	Loopholes	Remarks
Kseniya V. Filipenko. [1], 2021	To develop an algorithm for detecting fetal activity from signals obtained using an accelerometer system for long-term monitoring.	Threshold method	The algorithm may not perform well in cases of intense maternal movement which can lead to false positives or false negatives.	The average accuracy of 87.50% has been recorded. Further improvements are needed to increase the algorithm's accuracy.
Surya K. [2], 2020	To develop a hierarchical probabilistic approach for fetal arrhythmia detection using Joint Approximation Diagonal Eigen (JADE) algorithm and Naive Bayesian classifier.	JADE Algorithm	Separation of fetal ECG from maternal ECG becomes difficult if the maternal ECG is strong.	The proposed study used a relatively small dataset and the descriptions of the JADE algorithm and feature extraction process could be clearer.
Yurwei Zhang. [3], 2022	To extract fetal heart rate from abdominal electrocardiography recordings using a non-invasive method.	DWT, AWT	The method may not perform well in cases where the fetal ECG signal is weak or noisy.	The proposed method performs best detecting fetal QRS complexes with high sensitivity and positive predictive value.
Wenhui Yu. [4], 2023	To develop an intelligent fetal health assessment model using machine learning algorithms.	PCA, KNN, GBDT, SVM	The model may not perform well with noisy or missing data and its performance is affected by the quality of CTG data.	The proposed study has achieved a higher accuracy of 99.3%. Further improvements can be made to deploy the algorithm in real-time.
Yulia O. Bobrova. [5], 2021	To develop an algorithm for detecting alarming fetal conditions using accelerometers and gyroscopes for recording fetal motor activity.	Threshold method	The algorithm may not accurately detect fetal movements in cases where the mother's activity is high, and the signal-to-noise ratio is low.	Further improvement can be done to make the algorithm efficient in presence of active movement.
John Mark Bautista. [6], 2022	To develop a remote prenatal care system using machine learning algorithms to predict high-risk pregnancies.	RFDT, KNN, SVM	Imbalanced dataset with less positives would drop the performance of the algorithms.	Requires further research to improve the reliability of the system.
Rahul Agrawal. [7], 2021	To identify abnormalities in the fetal brain during pregnancy using an unsupervised learning algorithm.	K-means clustering algorithm	The system has a limitation in terms of accuracy (83.76%).	System's accuracy can be enhanced to effectively detect fetal conditions.
Yalamanchili Salini. [8], 2024	To enhance diagnostic precision and facilitate timely interventions for fetal health classification.	RFDT, KNN, SVM	The study uses the relatively small size of the dataset.	Further improvements can be made by diversifying the dataset to make the algorithms work more effectively.
Syed Ali Abbas. [9], 2020	To classify birth data using bagging and boosting classification algorithms.	AdaBoost.M1, XGBLinear, XGB-Dart, XGBTree	The study could have considered the inclusion of most recent data.	The proposed study yields better accuracy, f1 score and Recall.
Quiel Andrew I. Quiwa. [10], 2020	To develop a system for remote prenatal care using telemedicine and machine learning.	RFDT	The number of data samples used in the study was relatively small with very fewer positive cases.	Further research with larger and more balanced datasets is needed to improve the accuracy and reliability of the system.

Figure 3: Comparison of various papers

IV. COMPARISON AND CONTRAST ANALYSIS

Upon examining and analyzing the aforementioned research publications, some observations regarding methodology and mobility conditions were made.

A. Methodology

Several ML algorithms were used to demonstrate the effectiveness of the model in predicting the best performing algorithm in terms of accuracy, recall and precision.

B. Mobility Conditions

To ensure that the algorithms work as intended in real-world applications, the algorithms are being tested and trained in two distinct scenarios i.e., stationary and mobile.

V. OPEN CHALLENGES AND ISSUES

Our research encompasses the utilization of four algorithms, specifically KNN, SVM, Random Forest, and Gradient Boosting. Fig 4 displays the process flow of our study. Nevertheless, this approach entails certain limitations and hurdles, which are clearly elaborated in this section. The flowchart presented below outlines the data processing sequence utilized in our study. In our study, the K-Best method was employed for feature selection in order to extract the optimal parameters.

It's worth noting that there may exist alternative feature selection techniques that could potentially further enhance the model's performance. The dataset employed in this project exhibits an imbalance, characterized by a higher frequency of instances associated with 'Normal' fetal health as compared to 'Suspect' or 'Pathological' cases. This imbalance has the potential to impact the model's accuracy in predicting minority classes. However, through the implementation of Cross-Validation, Hyperparameter Tuning, and Standardization Techniques, effective management of the 'Suspect' and 'Pathological' data has been achieved. Techniques such as oversampling, under sampling, and the generation of synthetic samples (e.g., using SMOTE) could be explored to address this issue.

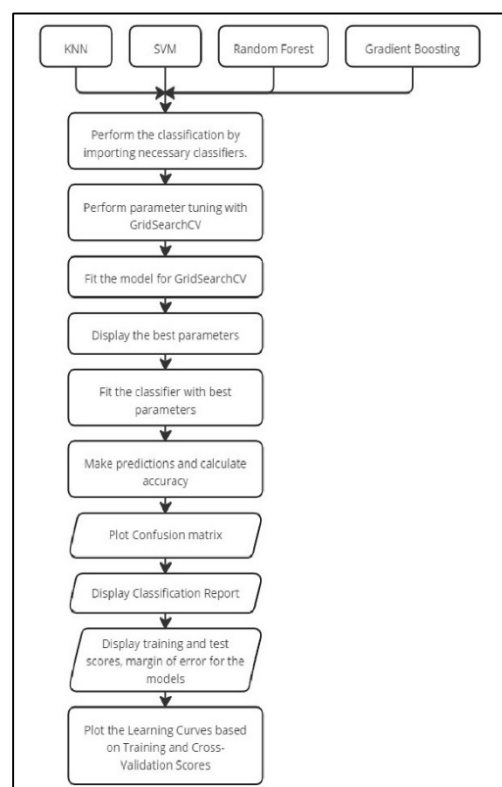


Figure 4: Process Flow of Study

While the project has utilized GridSearchCV for hyperparameter tuning, it has been observed that this approach hinders the execution process due to the size of the data and the volume of parallel jobs performed. It is imperative to explore alternative tuning strategies that could potentially bolster the model's performance. Moreover, the project's reliance on accuracy as the primary metric for model assessment warrants consideration of other evaluation metrics such as precision, recall, F1-score, and AUC-ROC for a more comprehensive comprehension of the model's performance.

VI. CONCLUSION

In our research, by comparison of training and testing data models, we have determined that among the 4 proposed algorithms, the Gradient Boosting algorithm yields the most favourable outcomes for fetal healthcare. This algorithm demonstrates high accuracy, with a training score of 0.999408, a test score of 0.969267, and an error margin of 0.030141. Conversely, the K-Nearest Neighbors model exhibits the lowest success rate. The graph Fig 5 below displays the accuracy obtained from each algorithm after training and testing the model.

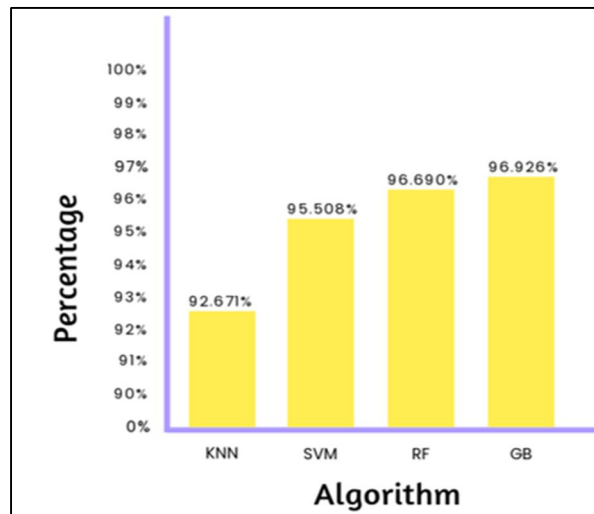


Figure 5

Future advancements of this study can focus on integrating multimodal data sources, such as fetal electrocardiogram (fECG) and ultrasound imaging, to create a more comprehensive fetal health monitoring system that can effectively detect fetal distress. Deep learning techniques can also be applied to analyze complex patterns in fetal heart rate and movement data, leading to improved detection of fetal abnormalities.

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