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Smart Maternal Health Analyzer by AI

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Abstract: ***Maternal health difficulties are currently one of the most difficult challenges in the world. Every year, many women die during pregnancy and after childbirth, which is a primary source of infant mortality. Maternal risk factors such as the mother's chronic illness, blood pressure, mental health, diet, and other medical care during pregnancy all play important roles. Pregnant women in remote locations confront several obstacles and challenges, including a scarcity of doctors, insufficient expertise, a lack of accessible clinics, infrastructural constraints, and transportation issues. The infant's poor health is mostly due to the mother's pregnancy, rather than any additional issues that may have occurred following childbirth. Using machine learning approaches, the study has predicted the maternal health risk level in previous due to avoid uncertain birth death or any inconvenience of a new born child. A variety of pre-trained advanced machine learning techniques were utilized in the study to find out the sustainable result. ANN, Ridge Classifier, SGD, XGBoost, Cat Boost, Random Forest, XGB, Decision Tree, and more algorithms were implemented. The recommended model was created, trained, and tested on the preprocessed dataset with the help of Hyper Parameter Tuning. The Cat Boost Classifier was the most accurate machine learning system for the study with a score of 97.4%.***

Keywords: Maternal Health Risk, Machine Learning Approaches, Hyper Parameter Tuning, ANN, Ridge Classifier, AUC Score.

I. INTRODUCTION

The term "fatal maternal risk of complications" refers to a variety of issues that can have a major impact on a woman's and her children's health and occur during pregnancy, delivery, or the postnatal period. If some of these symptoms arise, the patient should seek medical attention right once to avoid death. Every year, approximately 585,000 women die around the world during childbirth, the postpartum period, or delivery, and nearly 50 million maternal and infant difficulties are reported, with approximately 300 million women affected by long-term and short-term medical issues associated with being pregnant, giving birth, and after delivery. The primary goal of this research is to predict health risk for maternal mortality in Bangladesh using machine learning techniques.

A. Background and Present State

Pregnancy health is a key measure of a country's general well-being and reflects the success of its healthcare services and regulations. Despite substantial improvement in other areas, maternal health remains a pressing concern in Bangladesh. In 2017, the World Health Organization (WHO) estimated that there were 196 maternal deaths per 100,000 live births in Bangladesh [1]. Although this figure has reduced from prior years, it underlines the necessity of ongoing efforts to guarantee healthy pregnancies and deliveries. Several factors impact the condition of maternal health in Bangladesh. Regional differences in maternal health outcomes continue, despite government attempts to improve healthcare infrastructure and services. A survey carried out by the Bangladesh Bureau of Statistics (BBS) in partnership with foreign organizations finds a large gap in maternal death rates between urban and rural areas [2]. Maternal health is a critical aspect of a woman's well-being during pregnancy, childbirth, and postpartum periods, and its impact extends beyond the individual to the broader community and society. The significant financial and human costs associated with maternal mortality underscore the importance of developing effective strategies to reduce these rates. Machine learning methods have shown promise in predicting maternal health risks by analyzing medical parameters such as maternal age, heart rate

B. Problem Statement

The research is driven by the urgent need to address the high rates of maternal mortality globally, particularly in developing countries. By utilizing machine learning methods to predict maternal health risks early, medical experts can intervene promptly to reduce complications and prevent maternal deaths. Factors such as age, blood disorders, blood pressure, blood glucose levels, body temperature, and heart rate directly impact pregnancy risks, highlighting the importance of early risk classification.

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Identifying and categorizing key risk factors through machine learning techniques can inform targeted interventions and evidence-based strategies to improve maternal health outcomes. The potential of machine learning to accurately predict risks, the significant impact of maternal deaths, and the need for tailored interventions are the primary motivations behind maternal health risk prediction research. This research aims to provide a proactive approach to maternal healthcare, enabling the early detection and management of pregnancy-related risks to ultimately reduce maternal mortality rates.

II. LITERATURE REVIEW

A. Overview

Technology has made our lives so quick and simple, and we want everything at our fingertips. In this chapter, I will address relevant research or projects, as well as comparative analysis. I employed machine learning advanced classifiers and ensemble learning methodologies in the study to extract more accurate data. Machine learning or data mining techniques are more significant for making predictions in general. Indeed, I can say that determining a woman's prenatal health risk status from medical exam records is my primary obligation. As if the patient could obtain exact information. Finally, knowing whether they are at high or low risk from the prediction system allows the patient to receive more effective treatment at the hospital.

B. Comparison Between Existing Works

Most prior studies on the prediction of maternal health risk attempted to experiment with a few pre-trained data mining algorithms. Many of them employed the minimal amount of available data and chose factors that were occasionally unrelated to the diagnosis of maternal health risk. A handful of them also worked with survey results and open-source datasets. Some writers are also skeptical about the preprocessing methods. Using Google Colab, I will combine common and popular classifiers such as Support Vector Classifier (SVC), Decision Tree, and Naive Bayes with advanced machine learning algorithms such as Stochastic Gradient Descent, Ridge Classifier, Extreme Gradient Boosting (XGBoost), and CatBoost to predict maternal health risk and obtain an accurate classifier for this study. I also used the Artificial Neural Network (ANN) in the experiment, and it worked great. More crucially, I have 1524 occurrences of local data in my dataset. The experiment collects the required variables for identifying maternal health risk. Finally, I observed that the CatBoost algorithm had the highest accuracy for forecasting maternal health risk based on various medical exam data.

C. Open Issues

In the medical profession, there is little opportunity to collect data. Due to privacy concerns, the majority of institutes do not share their patients' medical checkup records or data. I visited several mother and child centers, hospitals, and clinics to obtain medical checkup data, but many of them refused to offer the information.

Following that, I found a private clinic and diagnostic center that agreed to supply data for the purpose of my research. On the other hand, to develop a model using machine learning techniques, various obstacles may occur, such as Collect real-time medical data and Understanding machine learning techniques.

D. Summary

Conclusion In essence, the adequacy of accuracy rates evidenced in this literature review shows great promise for the ability to predict maternal health risk with machine learning models using diverse data sources. Nevertheless, numerous challenges arise: data quality and reliability, model interpretability; ethical issues; integration into clinical care. More broadly applicable models that include different populations and data in real-time are also required.

Future research is needed to tease these open issues in order for machine learning tools that can be implemented internationally to see extensive use and save more mothers' lives. In a nutshell, this strategy uses machine learning techniques to create prediction models that identify people who may already be at high risk for maternal health issues or who may already be at risk but have not yet received a diagnosis. In order to forecast the possibility or severity of maternal health issues, the study examines the viability, accuracy, and efficacy of several machine learning algorithms that can evaluate pertinent data such as medical history, environmental factors, symptoms, and potentially even genetic predisposition. The comparative part assesses how well various algorithms perform.

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III. METHODOLOGY/ REQUIREMENT ANALYSIS & DESIGN SPECIFICATION

A. Overview

The study "Maternal Health Risk Prediction Based on Health Checkup Using Machine Learning Approaches" provides an overview of the research on maternal health risk prediction. Viral infections impact millions of individuals globally, and their symptoms are frequently misdiagnosed until they become serious. Effective management and the avoidance of problems depend heavily on early detection and intervention. The clinical examination and laboratory tests that are the mainstay of traditional diagnostic approaches are not always reliable in predicting maternal health concerns or determining the severity of those risks. With the use of machine learning (ML) and artificial intelligence (AI) advancements, this research attempts to create predictive models that will help with maternal health early detection and severity evaluation. In a nutshell, this strategy uses machine learning techniques to create prediction models that identify people who may already be at high risk for maternal health issues or who may already be at risk but have not yet received a diagnosis. In order to forecast the possibility or severity of maternal health issues, the study examines the viability, accuracy, and efficacy of several machine learning algorithms that can evaluate pertinent data such as medical history, environmental factors, symptoms, and potentially even genetic predisposition. The comparative part assesses how well various algorithms perform. Informed judgments made by public health officials and healthcare experts could lead to better patient outcomes, lower healthcare costs, and early interventions. This research is utilizing machine learning approaches to construct models of maternal health risk. There is a lot of potential to improve patient care and healthcare delivery by incorporating machine learning algorithms into public health initiatives and maternal health diagnoses. This study aims to solve current issues and open the door for more precise, effective, and individualized management of maternal health by utilizing the potential of data-driven approaches.

B. Proposed Methodology/ System Diagram

There are numerous important steps in the suggested machine learning-based maternal health risk prediction method. To ensure data quality and applicability for training models, secondary datasets composed of patient data and risk level are first gathered and pre-processed. It manages missing values, categorical variable encoding, and scaling of numerical features. Subsequently, feature selection approaches are employed to ascertain the relative importance of key maternal health predictors. The preprocessed dataset is used to train several machine learning algorithms after feature selection. To optimize and prevent model performance issues, cross-validation and hyper parameter adjustment are employed.

Over-adaptation First, preprocessed datasets comprise patient medical records with variables like age, blood pressure, systolic blood pressure, medical history, and blood test results are gathered. This include encoding categorical variables, normalizing features, and cleaning the data. To find the most pertinent predictors, feature selection is then carried out utilizing statistical approaches and dimension reduction methods. Kfold cross-validation and hyper parameter tuning are used in the training and validation of several machine learning methods. A confusion matrix is used to illustrate performance, and metrics including accuracy, precision, recall, F1-score, and AUCROC are used to evaluate the models. Attribute importance scores are examined in order to comprehend the model. Patient data gathered from the closest hospital is included in the dataset used in this investigation. A wide range of clinical, diagnostic, and demographic data pertinent to the prediction of maternal health are included in the dataset. Important factors gathered for every patient's record.

C. Summary

Preprocessing, model selection, evaluation, and data collecting are all part of the methodical methodology used in this study, "Maternal Health Risk Prediction Based on Health Checkup Using Machine Learning Approaches." To ensure a thorough dataset, data will be gathered via clinician reports, patient surveys, and electronic health records. In order to improve model accuracy, preprocessing procedures include resolving missing values, standardizing data, and choosing pertinent features. For the classification challenge, eight machine learning algorithms have been chosen based on their different strengths.

To guarantee robustness and avoid over fitting, a crossvalidation technique will be used for both training and validation of each model. A number of metrics, including F1-score, recall, accuracy, and precision, will be used to assess performance. Data security and patient privacy are two ethical issues that are central to the design. The ultimate goal of this all-encompassing strategy is to create a therapeutically valuable, interpretable, and dependable model for predicting maternal health, which will enhance patient outcomes and care efficiency

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IV. IMPLEMENTATION

A. Overview

The steps done in practice to create machine learning models for dengue forecasting are covered in the implementation section. We will now reveal some machine learning algorithms that were considered for this assignment. We'll also concentrate on the preprocessing methods required to make sure the data is organized, clean, and appropriate for the algorithm of choice. This section will go into more depth about the training procedure used to create the model, namely how the model describes denguerelated patterns. Lastly. We'll talk about a few assessment criteria that we used to gauge how well the model predicted the occurrence of dengue. A road map for comprehending the technological intricacies needed in developing machine learning models for dengue forecasting is given in this overview.

B. Train Model/ Prototype Design

Predictive models are developed and validated through a number of crucial phases in the use of "Maternal Health Risk Prediction Based on Health Checkup Using Machine Learning Approaches". First, a comprehensive preprocessing is performed on the dataset, which consists of 1524 patient records with 12 characteristics. These include selecting features to improve model performance, normalization, and handling missing data. Based on initial evaluation measures and their fit for the classification problem, eight machine learning methods were chosen.

1) Train Model

Based on their suitability for the classification task and initial evaluation metrics, eight algorithms are selected: Artificial Neural Networks (ANN), Naive Bayes, Decision
Trees, Support Vector Classifier (SVC), Stochastic
Gradient Descent (SGD), Extreme Gradient Boosting, CatBoost, and the Ridge Classifier. To preserve the distribution of classes, the dataset is split into training and test sets, usually using stratified sampling approaches. Each algorithm is trained on various subsets of the training data using cross-validation techniques like cross-validation, and their performance is assessed over a number of rounds. Through training, the algorithms develop the ability to use the training data to generate predictive models that can differentiate between individuals who pose a high risk and those who do not. Standard metrics like accuracy are used to evaluate the performance of the models in order to determine how well each algorithm generalizes to new, unseen data.
To further maximize performance, each algorithm's unique hyper parameters are finetuned during the training process. By avoiding over fitting, this iterative procedure guarantees that the models reach high accuracy and robustness. The outcomes of this training phase set the stage for the validation and subsequent application of machine learning models in clinical practice, with the aim of enhancing patient care outcomes associated with maternal health risks and raising the diagnostic accuracy.

2) Prototype Design:

In order to incorporate the trained models into clinical practice, the prototype design for "Maternal Health Risk Prediction Based on Health Checkup Using Machine Learning Approaches" focuses on creating an intuitive user interface. In addition to ensuring accessibility for medical practitioners, the design seeks to optimize the patient datadriven prediction process.
User Interface: A graphical user interface (GUI) on the prototype makes it simple for medical professionals to enter patient data. Clear prompts for entering pertinent medical data, such as symptoms, medical history, and demographic data, are incorporated into the interface's straightforward design.
Data Integration: The prototype easily interfaces with standalone data input techniques or current electronic health record (EHR) systems. This guarantees that medical professionals can safely and effectively obtain patient data for forecasting needs.
Prediction Engine: Extreme Gradient Boosting (XGBoost), CatBoost, the Ridge classifier, and Decision Tree are the machine learning models that have been trained behind the interface of the prototype. These algorithms can forecast a patient's chance of experiencing maternal hazards by analyzing the data that is input.
Output and Interpretability: The prototype indicates the expected probability or classification of maternal health risk in a way that is easy for physicians to understand. Anticipations can be accompanied by visual aids for understanding and decision making, such as charts or risk level.

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C. System Testing/ Model Evaluation

To assure accuracy, dependability, and usability in clinical practice, "Maternal Health Risk Prediction Based on Health Checkup Using Machine Learning Approaches" is being implemented with thorough system testing and model validation.

Testing Framework: A thorough testing protocol is developed to assess the performance of the prototype. Unit testing of distinct parts, such as the user interface, machine learning algorithms, and data pretreatment modules, is included in this. The smooth operation of various system modules, such as the data input, prediction engine, and output visualization, is ensured via integration testing.

Performance Metrics: Common performance measures, including accuracy, are used to evaluate the efficacy of the prediction models. Based on the input data, these measures offer quantitative insights into how successfully the models classify patients into high-risk and low-risk groups.

*Cross-Validation***:** Cross-validation is one of the crossvalidation approaches used to test the robustness and generalizability of the models. Training and testing are carried out iteratively to reduce overfitting and make sure the models function effectively on data that hasn't been seen by dividing the dataset into several subsets.

*Validation Against Baselines***:** The efficacy of the machine learning models is evaluated in relation to baseline techniques or accepted clinical standards. The models' superiority in terms of accuracy and predictive capacity is supported by this comparative study.

Real-World Simulation: The performance of the prototype under various settings can be further assessed by using datasets and simulated real-world scenarios. During this testing step, the predictive models' adaptability to various patient demographics, symptom profiles, and clinical contexts is evaluated.

*Clinical Validation***:** Clinical validation of the prototype is facilitated by collaboration with healthcare experts. Physicians assess the predictions made by the prototypes against the actual outcomes of their patients, offering qualitative comments on the prototypes' usability, interpretability, and therapeutic significance. *Ethical Considerations***:** Ethical concerns of patient privacy, data security, and model openness are critical throughout the testing and evaluation phase. When it comes to the use of healthcare data, steps are taken to guarantee compliance with legal requirements and ethical norms. This implementation phase seeks to evaluate the efficacy and usability of machine learning-based maternal health risk prediction models in real-world clinical settings through extensive system testing and model evaluation. The evaluations yield valuable insights that aid in the improvement of patient care outcomes through model refinement and accuracy.

D. Summary

The steps involved in creating a machine learning model to forecast the hazards to a mother's health are described in this section. We go into detail about the machine learning algorithm that was chosen, the methods for cleaning and preparing the data before analysis, and the model-building training procedure. Furthermore, we delineate the assessment measures employed to appraise the model's efficacy in risk prediction. A general review of the technical issues of creating machine learning models for forecasting maternal health is given in this section.

V. RESULT AND ANALYSIS

A. Overview

Insightful findings about the performance of eight algorithms were obtained from this study on "Maternal Health Risk Prediction Based on Health Checkup Using

Machine Learning Approaches": Artificial Neural Networks (Accuracy and area under the receiver operating characteristic curve are two examples of suitable evaluation measures that are used to assess the performance of the model (AUC-ROC). To evaluate the effectiveness of several algorithms and choose the best technique for predicting the risk to a mother's health, comparative analysis is conducted. To guarantee the accuracy and applicability of the findings, validation methods such as external validation and sensitivity analysis are used. The study intends to create accurate and trustworthy predictive models for maternal health forecasts based on this experimental design, which would enhance patient outcomes and healthcare decision-making. According to the study Catboost outperformed the other algorithms in terms of accuracy, achieving a remarkable 97.4%. The resilience and appropriateness of Catboost for medical prediction tasks are demonstrated by their abilities to classify patients into normal and afflicted groups. XGBoost also fared well, obtaining a 96.9% accuracy rate, indicating its capacity to manage intricate variables and data structures. These findings imply that machine learning algorithms might greatly enhance the precision and effectiveness of high- and low-risk prediction, giving medical professionals useful instruments to enhance patient care plans and diagnostic procedures. Additional examination reveals the necessity of ongoing model validation and improvement for various patient populations.

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B. Experimental/ Simulation Result

In this section, eight algorithms are compared. The performance of classification comes first. The overall metrics of those models are then examined in order to gather, characterize, pinpoint probable causes, and pinpoint areas where outcomes could be improved. First, for each machine learning method under consideration, the section summarizes performance indicators like as accuracy and area under the receiver operating characteristic curve (AUC-ROC). The performance of various algorithms is then compared using comparative analysis in order to determine the best technique for predicting maternal health risk. To further demonstrate the effectiveness of the models, additional visualizations like ROC curves and confusion matrices can be offered. Discussed are the advantages and disadvantages of each method, emphasizing elements like computational efficiency, interpretability, and forecasting accuracy. Sensitivity analysis is used to evaluate the predictability of the model under various scenarios, and if external validation methods are available, they can be used to evaluate the model's performance on independent datasets. All things considered, the analyses and outcomes of the experiments offer insightful information about how well machine learning models perform when predicting maternal health risk using secondary datasets, which will guide future research and clinical decision-making procedures.

C. Summary

The outcomes of the machine learning model created for forecasting maternal health are shown in the Results and Analysis section. Here, we go over the model's performance using a few chosen assessment metrics. In order to evaluate the model's predictive accuracy for maternal health risk, accuracy measures are presented. To learn more about the advantages and disadvantages of the model, we shall examine the data in more detail. This could involve looking into what influences the model's performance, figuring out where it could be improved, or using the model's predictions to visualize the decision-making process. The performance of machine learning models created for forecasting maternal health is examined in the Results and Analysis section. We examined eight different algorithms. With an accuracy of 97.4%, Catboost was the most accurate of these algorithms, followed by XGBoost (96.9%) and ANN (96.3%). This suggests that the best model for correctly predicting the presence of risks in our dataset was catboost. Subsequent examination will go more deeply into each model's performance. We will investigate variables that might have an impact on the outcomes, like the intricacy of the data or certain traits of each program. Furthermore, we might think of visualization methods to comprehend the predictions made by each model and pinpoint possible areas for development. The purpose of this part is to give a thorough understanding of how well the models anticipate high-risk and low-risk events.

VI. IMPACT ON SOCIETY, ENVIRONMENT AND SUSTAINABILITY

A. Impact on Life

This study may have a tremendous influence on life, influencing many aspects of public health, healthcare, and personal well-being. Early discovery of maternal health risks can lead to rapid medical intervention, potentially lowering the risk of pregnancy and newborn mortality. This research might lead to improved medical processes, regulations, and recommendations for identifying and treating maternal health issues. By utilizing machine learning algorithms to predict health risks during pregnancy, this research empowers healthcare providers to intervene early, leading to better health monitoring and treatment for expectant mothers. The implementation of predictive models enhances healthcare practices, ensuring timely interventions and personalized care for pregnant women, ultimately contributing to healthier pregnancies and safer childbirth experiences. Moreover, by addressing maternal health risks proactively, this research not only benefits individual women but also has broader societal implications, such as reducing the economic burden associated with maternal mortality, improving overall community health, and promoting maternal well-being as a fundamental pillar of society. On the other hand, the study can assist improve healthcare technology, especially if it promotes the use of new advancements such as machine learning.

B. Impact on Society and Environment

The impact of maternal health risk research on the environment is significant. By understanding the environmental factors affecting maternal health, such as pollution, chemicals, and climate change, researchers can highlight the interconnectedness between environmental health and maternal well-being. This research sheds light on how environmental exposures can impact pregnancy outcomes, maternal morbidity, and mortality, emphasizing the need for policies and interventions to address these risks. Furthermore, the identification of environmental stressors like air pollution, noise, and inadequate green spaces underscores the importance of creating healthier built 28 ©Daffodil International University environments to support maternal and infant health. Ultimately, maternal health risk research not only improves healthcare practices but also advocates for sustainable environmental policies that benefit both maternal health and the well-being of communities at large.

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C. Ethical Aspects

The study ensuring the adequacy of informed consent, considering paternal involvement, balancing risks for both the mother and fetus, and promoting access to research and treatment. These ethical considerations are crucial in safeguarding the rights, autonomy, and well-being of pregnant women, especially those living with HIV, and their unborn children. Respecting the core ethical principles of Beneficence, Respect for Persons, and Justice is essential in conducting research with pregnant women to ensure their safety, understanding, and involvement in decision-making processes. Balancing the risks involved, addressing disclosure concerns, and promoting inclusivity in research participation are key ethical imperatives in maternal health risk prediction research. However, the technological involvement will occur.

D. Sustainability Plan

The predictive models are integrated into normal maternity care by forming collaborations with healthcare providers, legislators, and community organizations. Embracing digital platforms expands access to risk assessment tools and encourages continual data collecting for model modification. Furthermore, investing in capacity building and education allows healthcare practitioners to successfully use these tools. Long-term financing commitments and stakeholder participation are essential for fostering an innovative and adaptable culture in maternity healthcare practices. People must be aware of the significance of maternal health risk finding and usage of the system. Users can gain benefits from the system. Given these considerations, the system's sustainability strategy was fulfilled

E. Summary

The application of machine learning to the prediction of maternal health has profound effects on sustainability, the environment, and society. Socially, this technology helps distant populations and improves healthcare equity and accessibility. It lowers the frequency of high-risk cases, lessens the financial strain on patients and healthcare systems, and promotes a proactive attitude toward health. Reducing hospital stays and critical care helps the environment by using less resources and medical waste, which promotes sustainability. As a result of fewer hospitalizations, throwaway medical supplies are used less frequently, supporting efforts to preserve the environment. By decreasing the need for substantial physical infrastructure and travel, the adoption of digital health solutions lowers the healthcare industry's carbon footprint. Overall, including machine learning into the process of predicting the danger to a mother's health promotes an effective and sustainable conclusion that benefits the environment and society.

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VII. CONCLUSION AND FURTHER WORK

A. Conclusions

In today's world, we are all dependent on technology. We cannot survive a day without the use of technology. However, technology and appliances offer both advantages and downsides. In the world of technology, the implementation of machine learning is rather difficult. The medical and technological sectors are interdependent. Today, we observe a revolutionary technology participation in the medical business.

The proposed method predicts maternal health risks using data from patient medical checkups. To predict maternal health risk, I evaluated the effectiveness of several classifiers and boosting strategies. When comparing the accuracy of different machine learning algorithms, CatBoost performs remarkably well across a variety of criteria, whereas Naive Bayes has the lowest accuracy. Python and Google Colab were used to conduct the research. Pregnancy death can result from a significant risk of maternal health. This automated technique might be a useful tool in raising awareness of whether maternal health risks are high or low. This tool can produce the most rapid and accurate prediction results in the shortest amount of time and at no cost.

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B. Further Suggested Works

The world operated on the basis of artificial intelligence. Machine learning is part of artificial intelligence. Our daily lives provide several challenges. Machine learning may 30 ©Daffodil International University significantly improve problem-solving. Machine learning has a large variety of algorithms. The study may be expanded with new data, data mining tools, and improved machine learning algorithms. In the near future, I want to develop an Android app and webbased software that can quickly assess maternal health risks and recommend simple preventative steps to consumers.

C. Limitations/ Conflict of Interests

Despite the significant contributions of this research, several limitations must be acknowledged. The dataset used was relatively small, which may impact the generalizability of the findings. The real-life implementation was confined to a smallscale pilot project, limiting the broader applicability of the results. Specific challenges were encountered in addressing diverse maternal health issues due to limited access to comprehensive data and the complexity of these concerns. Additionally, geographical constraints and resource limitations, including time, funding, and technical infrastructure, may have affected the depth and breadth of the research. Addressing these limitations in future studies will be crucial for enhancing the validity and applicability of the findings.

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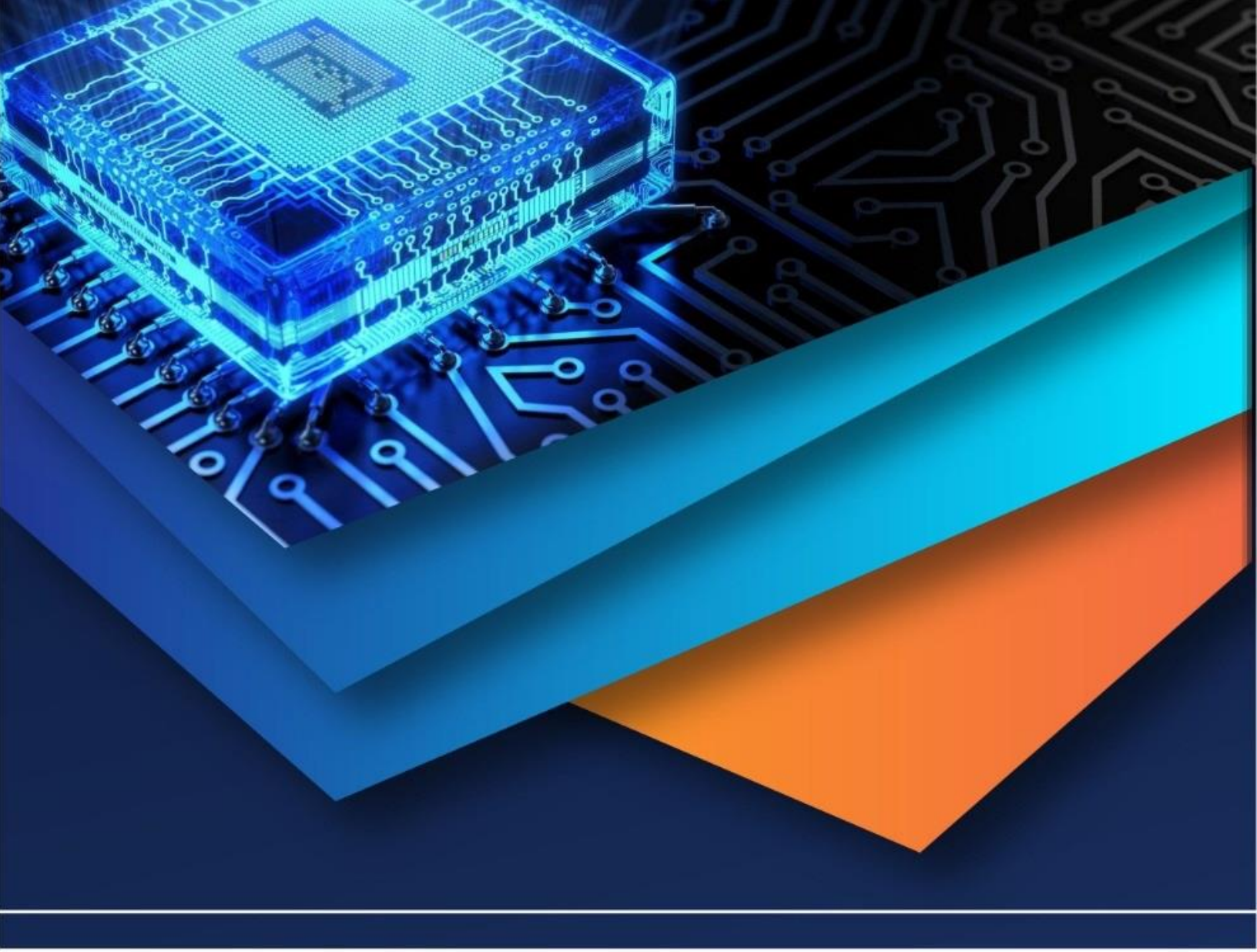

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