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Review on Machine Learning-Driven Cervical Cancer Prediction System

Ms. Jaspreetkaur Siledar[1], Ms. Ashwini N. Swami[2]
[1]PG Scholar, [2]Project Guide, Department of Computer Science & Engineering Deogiri Institute of Engineering and Management Studies, Chatrapati Sambhajinagar, India

Abstract- Cervical cancer ranks as one of the most common causes of death for women throughout the globe, with its highest impact found in developing nations which lack access to both routine screening and prompt diagnostic services. The conventional diagnostic methods which include Pap smears and colposcopy face challenges because they require extended durations to conduct and their implementation incurs substantial expenses and includes the possibility of human mistakes. This research introduces a machine learning-based predictive system which enables early detection of cervical cancer through analysis of patient demographic information and their medical background and laboratory examination results. The system employs data preprocessing methods together with feature extraction techniques and selection methods to address the challenges of missing data and noisy information and uneven class distribution. The researchers built and tested multiple supervised learning algorithms which included Logistic Regression Decision Tree K-Nearest Neighbors Support Vector Machine Random Forest Gradient Boosting AdaBoost and XGBoost using accuracy and precision and recall and F1-score metrics. The platform functions through Python, which establishes a simple decision support system that doctors can use to make medical decisions. The system automates prediction work while enhancing diagnostic precision, which helps doctors to identify patients early and decreases their load, while it aids in decreasing worldwide cervical cancer cases, especially in areas with limited medical facilities.

Keywords— Cervical Cancer Detection, Machine Learning (ML), Predictive Modeling, Data Preprocessing, Healthcare Decision Support System etc.

I. INTRODUCTION

Cervical cancer is one of the most common and preventable malignancies affecting women worldwide, yet it remains a leading cause of cancer-related mortality, particularly in low- and middle-income countries. Despite advances in vaccination and screening programs, a significant number of cases are still diagnosed at advanced stages due to limited access to healthcare facilities, lack of awareness, and inadequate screening coverage [1]. Early detection of cervical cancer and its precancerous stages is crucial, as timely diagnosis significantly improves survival rates and reduces treatment complexity and cost [2].

Conventional screening methods such as Papanicolaou (Pap) smear testing, human papillomavirus (HPV) testing, colposcopy, and biopsy have been widely used for decades. While these techniques have contributed to a reduction in cervical cancer incidence in developed regions, they present several limitations. These methods are labor-intensive, time-consuming, and heavily dependent on expert interpretation, which introduces subjectivity and inter-observer variability [3]. In high-volume screening environments, diagnostic accuracy may be affected by fatigue and workload, increasing the risk of false-negative and false-positive results [4]. Furthermore, the requirement for specialized infrastructure and trained professionals makes these approaches less feasible in resource-constrained settings [5].

In recent years, artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), has emerged as a promising solution to address these challenges. ML techniques enable automated analysis of large and complex medical datasets by identifying hidden patterns and correlations that may not be evident through traditional analysis [6]. Deep learning models, especially convolutional neural networks (CNNs), have demonstrated remarkable success in medical image analysis, including Pap smear cytology, colposcopy images, and histopathological slides [7]. Several studies report that AI-assisted systems can achieve diagnostic accuracy comparable to or higher than experienced clinicians under controlled conditions [8].

Beyond image-based screening, machine learning has also been applied to structured datasets containing patient demographic information, behavioral risk factors, clinical history, and laboratory test results. Traditional ML algorithms such as Logistic Regression, Support Vector Machines, Random Forests, and gradient boosting methods have shown reliable performance in predicting cervical cancer risk while offering better interpretability than deep neural networks [9].

Ensemble learning techniques further enhance predictive robustness by combining multiple classifiers, thereby reducing variance and improving sensitivity for minority positive cases [10].

Recent research trends emphasize the integration of multimodal data sources to improve early detection and personalized risk assessment. Combining imaging data with clinical parameters, genomic information, and biomarker profiles has shown potential to capture the complex biological mechanisms underlying cervical carcinogenesis [11]. Additionally, explainable artificial intelligence (XAI) techniques are increasingly being explored to provide transparency in model predictions, which is essential for clinician trust and acceptance in medical practice [12].

Despite significant progress, several challenges limit the widespread clinical adoption of AI-based cervical cancer detection systems. Many studies rely on small, retrospective, or single-center datasets, restricting the generalizability of developed models across diverse populations [13]. Class imbalance, inconsistent evaluation metrics, and lack of external validation are commonly reported issues that affect reliability [14]. Moreover, deep learning models are often criticized for their black-box nature, raising concerns regarding accountability, ethical considerations, and regulatory compliance [15].

Given these limitations, a comprehensive review of existing machine learning and deep learning methodologies is essential to understand current research trends, evaluate methodological strengths and weaknesses, and identify gaps that require further investigation. This review paper systematically analyzes AI-driven approaches for cervical cancer detection, focusing on data types, algorithms, evaluation strategies, and clinical applicability. By synthesizing findings from recent literature, this study aims to provide a structured overview of the state of the art and guide future research toward developing robust, interpretable, and scalable AI-assisted cervical cancer screening systems.

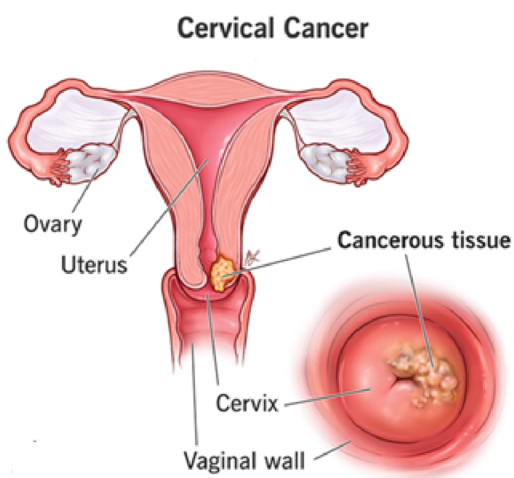

Figure 1. Cervical Cancer Causes

II. PROBLEM IDENTIFICATION

Cervical cancer continues to be one of the main causes of death for women in developing nations because these countries lack proper methods to screen for the disease and medical personnel take too long to identify it. The standard diagnostic techniques which include Pap smears and colposcopy together with biopsies require significant time and human effort while their results suffer from the potential for mistakes which hinders their capacity to identify diseases at an early stage. The current machine learning models which exist for cervical cancer prediction purposes use datasets that are both small and unbalanced and incomplete which results in their reduced ability to deliver accurate results for different patient groups. Most researchers do not study multimodal data which combines patient demographic information with laboratory results and imaging data and genomic data because this approach has proven to improve prediction accuracy.

The ML model explainability together with their model interpretability needs to receive proper attention because the current state of affairs decreases healthcare professional trust in the models which results in lower model usage. The current research does not adequately address three critical challenges which include assessing cost-effectiveness and assessing usability in low-resource environments and understanding regulatory compliance requirements for real-world implementation.

The healthcare system requires a decision support system based on machine learning technology which has proven capacity to deliver accurate results while maintaining user-friendly design for its function of detecting diseases at an early stage and providing prompt medical treatment which leads to better health results for patients.

III. LITERATURE SURVEY

A. Literature Review

Vázquez B. et al. (2025), This paper shows how researcher apply machine learning and deep learning models to diagnose and predict and treat cervical cancer. The research identifies essential model types which include CNNs and ensemble methods and classical ML but faces obstacles because of reduced dataset availability and difficulties explaining results and connecting to medical practice. The authors demonstrate real-world application gaps which exist because of regulatory restrictions and missing long-term study evidence. The researchers suggest future research should concentrate on developing clinical trials which study multiple data types and create interpretable methods that oncology professionals can use.

Ming Fang et al. (2024), This review systematically provide a complete survey of deep learning methods which researchers use to analyze cervical cytology images by applying classification techniques and segmentation methods. The study shows that DL methods enable organizations to decrease their manual workload while decreasing human error, but system performance depends on the total amount of high-quality labeled datasets. The research shows three main problems which include overfitting problems and class imbalance issues and the inability to apply results across different datasets. The research study shows that there has been insufficient research which combines image data with information from patients who do not have visual data.

Peng Xue et. al. (2025), The research paper presents the creation of a deep learning system which scientists developed specifically for analyzing liquid-based cytology (LBC) slides which hospitals use to conduct cervical cancer screenings. The model reached exceptional accuracy and strong dependability which makes it suitable for deciding which samples should undergo additional examination. The authors propose this solution as a method to connect laboratory-based cytology with machine learning-supported screening that medical professionals use in actual healthcare environments which lead to efficient automated systems that need minimal human intervention.

Lei Liu et. al. (2024), The researchers conducted a meta-analysis which examined data from 77 studies that tested AI support for cervical cytology and colposcopy procedures. The study showed that AI technology achieved an overall accuracy rate of approximately 94 percent while its sensitivity rate reached 95 percent and its specificity rate reached 94 percent during Pap smear tests. The study discovered that performance levels showed different results when compared between developed countries and developing countries. The review demonstrates that AI shows potential for advancement yet warns about dataset differences and reporting standards which require clinical trials that keep observers unaware of study elements.

Rubina Baber et. al. (2025), The article examines how traditional screening methods which include Pap smear and HPV testing can work together with machine learning classifiers to enhance detection accuracy and risk assessment. The article examines how researchers extract features from laboratory findings and demographic information and examination results. The authors demonstrate that machine learning implementation with standard screening procedures leads to decreased false results while custom screening times get established. The researchers request that researchers conduct extensive validation studies which require actual testing to determine effects and economic viability and user acceptance in medical environments.

Lizhen She et. al. (2025), The meta-analysis examined 16 studies that included approximately 2514 patients to evaluate AI imaging models which detect lymphovascular space invasion in cervical cancer patients. The system achieved a total sensitivity of approximately 84 percent and a total specificity of approximately 78 percent while internal testing produced an area under the curve score of 0.87. The external validation results showed a slight decline in performance with sensitivity reaching 79 percent and specificity reaching 76 percent and AUC falling to 84 percent. The results demonstrated that deep learning models and PET/CT imaging systems achieved better performance than MRI in certain evaluation areas. The review demonstrates high potential but requires additional external validation tests and future studies.

Yuechen Zhao et. al. (2025), The review analysed AI-based systems for cervical cytology testing and colposcopy procedures. The research demonstrates high diagnostic precision through its combined test results. The Pap test shows 94 percent sensitivity and 94 percent specificity while other cytology assessments and colposcopy tests show similar results. AI systems proved more effective than human colposcopists at identifying LSIL+ and HSIL+ precancerous lesions. The research shows that AI systems can achieve reliable performance across both developed and developing countries while different studies need standardized methods and independent testing to advance the field.

Onuiri, E. E. et. al. (2024), The study examines biomarker-driven systems which estimate cervical cancer recurrence risk. The research shows that ML models work effectively when combined with these demographic and clinical prognostic factors aswell as genetic and molecular biomarker panels. The study outcomes show moderate to good predictive power but exhibit substantial performance disparities among different research studies. The research identifies three main challenges which include limited participant numbers and missing external validation and variable tracking of participants after treatment. The study recommends the development of standardized biomarker panels together with multicenter research projects which will enhance the applicability of prognostic models across different patient groups.

Qin Wen et al. (2025), The review evaluates existing research about how gut microbiota and cervical cancer and vaginal microbiota interact with each other. The research shows that cancer-related cervical neoplasia has specific microbial dysbiosis patterns which lead to decreased microbial diversity and increased presence of certain bacterial taxa. The research evidence indicates that microbiome profiles can function as non-invasive biomarkers which help determine risk levels. The authors explain that numerous studies use cross-sectional designs and have small sample sizes while their research methods show variation which creates problems for maintaining uniformity.

Chu-Qian Jiang et. al. (2025), The study evaluates AI's ability to diagnose lymph node metastasis through imaging studies which use MRI and PET/CT and CT to examine patients with cervical cancer. The internal AI models reached a diagnostic sensitivity of approximately 0.83 which surpassed the performance of radiologists who achieved a sensitivity of about 0.54 and the models produced an AUC value of approximately 0.87 while radiologists achieved only 0.65. The AI system showed a diagnostic accuracy which matched radiologists at approximately 0.79. The results showed that different imaging modalities produced different results because PET/CT offered slightly better detection rates while MRI/CT showed acceptable results with different performance levels. The research demonstrates the potential of AI to assist in staging process yet it requires further testing through prospective trials and development of standardized imaging protocols.

B. Literature Summary

- Machine learning (ML) and deep learning (DL) methods have been extensively studied for detecting cervical cancer through Pap-smear and colposcopy and pathology images.
- The performance of CNN-based models exceeds that of conventional classifiers but their efficiency depends on extensive labeled datasets which are rarely available.
- The combination of data preprocessing and imbalance-handling methods including SMOTE and ensemble learning results in enhanced model performance and improved recall of minority positive cases.
- The use of Explainable AI (XAI) methods which include Grad-CAM and saliency maps establishes better understanding of the system thereby increasing trust from clinicians.
- The prediction accuracy improves through multi-modal data integration which includes demographics and lab tests and imaging and genomics data but data integration and missing values present difficulties.
- Lightweight models enable edge deployment which makes point-of-care screening available in low-resource environments.
- Federated learning enables organizations to train models while maintaining user privacy between different institutions.
- The combination of feature engineering and deep learning through hybrid models enables better performance on limited data sets.
- AI adoption increases when clinical studies show that the technology provides triage support instead of making final diagnosis decisions.
- The integration of emerging biomarkers shows potential for early personalized detection but needs validation from multiple disciplines together with affordable implementation methods.

C. Research Gap

The existing models depend on small or unbalanced datasets which prevent them from accurately demonstrating their ability to perform across different population groups. The prediction accuracy of models decreases when multimodal data which includes demographics and imaging and lab tests and genomics data is not integrated for analysis. Clinicians find it difficult to adopt many ML models because these systems do not provide understandable details about their decision-making processes. The research on how to use technology in low-resource environments remains limited because of the need to study both cost-effectiveness and user-friendliness aspects of actual world applications.

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Previous studies used evaluation metrics that measured accuracy but they failed to include sensitivity and recall and subgroup bias which created a risk of generating unfair predictions.

The data privacy and security issues remain unresolved because of inadequate solutions which particularly affect multi-institutional research partnerships. There exists a shortage of edge-deployable point-of-care screening solutions which require minimal resources.

Researchers need to investigate how existing clinical integration barriers which include regulatory compliance and medico-legal issues and workflow alignment can impede their research progress. The research studies lack a uniform approach to implement reliable frameworks for cross-validation and feature selection and hyperparameter optimization. The development of reliable cervical cancer prediction systems which can operate in clinical settings requires researchers to address existing gaps in knowledge.

IV. RESEARCH METHODOLOGY

A. *Criteria for selecting this study:*

- Cervical cancer continues to be a significant global health problem which particularly affects developing countries that lack proper screening facilities.
- The high mortality rates which occur because people receive their diagnoses too late demonstrate that we need to establish early detection systems which rely on scientific evidence.
- Machine learning enables accurate predictions and classifications through analysis of patient demographic information and their medical history.
- The UCI Repository provides a public dataset which researchers can use to train their models through its well-organized structure.
- The study aims to achieve better diagnostic results while minimizing human mistakes through the implementation of automated systems.
- Selection criteria requires that solutions must be accessible to users and remain within budget while they can expand their services to cover all medical facilities.
- The project aims to create a decision-support system which clinicians can trust because it provides clear explanations and demonstrates high performance standards.
- The study supports WHO's objective to use artificial intelligence technology for faster detection and treatment of cancer through its research activities.

B. *Method of analysis:*

The UCI Machine Learning Repository provided the dataset which contains 858 records and 36 attributes. The data preprocessing process involved five steps which included cleaning missing values, removing outliers, normalizing data, and applying Principal Component Analysis (PCA) for dimensionality reduction. The team conducted feature selection to find the most important attributes which would help develop a precise model. The research used eight machine learning algorithms which included Logistic Regression, Decision Tree, Random Forest, Support Vector Machine, KNN, AdaBoost, Gradient Boosting, and XGBoost.

The researchers used cross-validation to train and test each model because it helps prevent overfitting while improving model performance on new data. The evaluation of performance used standard metrics which included accuracy, precision, recall, F1-score, and ROC-AUC. The best algorithm for predictive accuracy and interpretable results was determined through comparative analysis. The project used Python libraries Pandas Scikit-learn Matplotlib and Seaborn to implement data processing and model assessment visualizations.

C. *Comparison and Analysis:*

- The examined research utilized multiple machine learning and deep learning techniques which included Logistic Regression, Random Forest, SVM, CNN, and hybrid ensemble models.
- The majority of research studies used UCI Cervical Cancer and Kaggle and hospital-based records as their data sources which enabled others to replicate their studies while maintaining open research practices.
- The researchers used data preprocessing techniques which included normalization and missing value imputation and feature scaling to enhance the quality of their data.

- The researchers used feature selection and dimensionality reduction techniques through PCA and Recursive Feature Elimination to improve both their computational efficiency and their model interpretability.
- The researchers assessed performance through accuracy and recall and F1-score and ROC-AUC metrics which enabled them to assess the model performance through multiple evaluation methods.
- The researchers used explainable AI XAI frameworks to create clinical validation tools which enabled them to understand how their models made decisions.
- The combination of traditional machine learning methods with deep learning in hybrid models produced better prediction results.
- The problem of class imbalance together with small sample sizes and overfitting constitutes a major obstacle that exists in actual medical application studies according to most research studies.

D. *Highlighting trends, advancements, and challenges*

1) *Trends:*

- Rapid integration of AI and ML in healthcare diagnostics, emphasizing predictive accuracy and early cancer detection.
- Growing use of hybrid and ensemble models that combine deep learning with classical ML for enhanced performance.
- Adoption of explainable AI (XAI) to improve transparency and clinician trust in AI-assisted diagnosis.
- Increasing reliance on multi-modal data fusion (e.g., genomics, imaging, demographics) for comprehensive risk assessment.
- Use of federated learning and privacy-preserving frameworks to safeguard sensitive patient data.

2) *Advancements:*

- Lightweight ML models optimized for low-resource or point-of-care devices.
- Enhanced feature engineering and dimensionality reduction improving interpretability and efficiency.
- Integration of cloud-based and IoT-enabled screening tools for real-time diagnostics and data sharing.

3) *Challenges:*

- Persistent data imbalance and scarcity of high-quality labeled datasets.
- Limited generalization of models across diverse populations.
- Regulatory, ethical, and interpretability issues hindering clinical deployment.
- Need for standardized datasets and cross-institutional validation to ensure robustness and clinical acceptance.

V. DISCUSSION

A. *Synthesis of findings from literature*

- Research studies show that machine learning (ML) and deep learning (DL) systems produce better results for detecting cervical cancer than standard screening techniques.
- Convolutional Neural Networks (CNNs) achieve better results than traditional machine learning models for image-based medical diagnosis whereas hybrid models that combine feature engineering with CNN embeddings display better performance on small datasets.
- The process of data preprocessing which includes handling missing values and applying normalization and class balancing through SMOTE methods, serves as a vital component that enhances both model performance and reliability.
- Grad-CAM and saliency maps function as Explainable AI (XAI) techniques that create visual representations of model decisions, which enhance clinical trust, but need further clinical validation.
- The combination of imaging data with genomic information and demographic details enables multi-modal data fusion to create more reliable predictions, which encounters obstacles associated with incomplete data and the process of data integration.
- The development of federated learning and privacy-preserving techniques enables organizations to conduct joint training activities while maintaining the protection of patient personal information.
- Research progress has achieved significant advancements, yet researchers must address three critical problems, which include dataset imbalance and model interpretability together with clinical adaptability, to solve these research issues.

B. Methodology for future research directions

An AI system uses machine learning for the testing and training stages. The model provides suggestions.

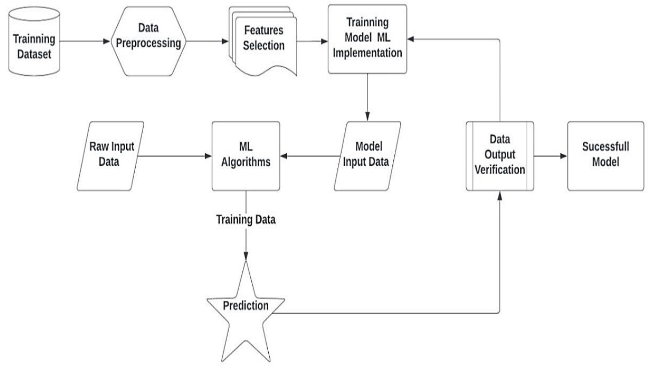

Figure 2. Predictive Analytics and Machine Learning Model

This flowchart demonstrates the complete process which starts with dataset development and ends with model testing through prediction and validation. The process starts with a training dataset, which undergoes data preprocessing to clean, normalize, and structure the data. After preprocessing, feature selection is carried out to extract the most relevant attributes, which reduces complexity and improves accuracy. The features undergo training, where ML algorithms utilize the data to discover patterns. The trained model generates model input data, which undergoes data output verification to confirm its trustworthiness and precision. The model succeeds when its results are validated.

The raw input data goes straight to ML algorithms, which produce predictions based on the trained model. The prediction step establishes a feedback mechanism, which enables ongoing system improvements. The loop mechanism maintains model performance through ongoing adaptation and precise results. The overall process demonstrates how preprocessing, feature selection, verification, and prediction work together to create effective ML models, which can be used in actual business scenarios.

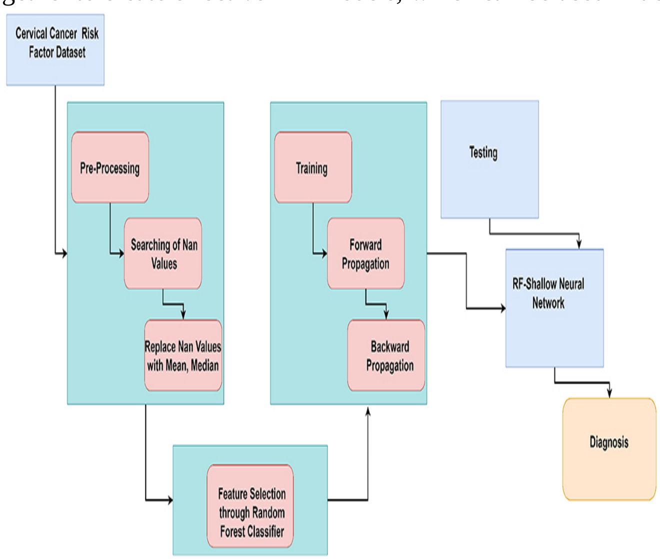

Figure 3. Machine Learning Assisted Cervical Cancer Detection

- Data Collection and Preprocessing: The research process gathers patient demographic data together with medical history records and laboratory test outcomes from trustworthy data sources. The data preprocessing stage involves three steps which include cleaning missing values and inconsistent data, normalizing attributes, and using SMOTE to balance class distribution in the dataset.
- Feature Extraction and Selection: The study establishes essential features through correlation analysis and statistical analysis which determine their impact on cervical cancer risk. The process of model development removes unnecessary features to improve model effectiveness while decreasing system resource requirements.

- Predictive Model Selection: The research evaluates eight machine learning algorithms which include Logistic Regression (LR) and Decision Tree (DT) and KNN and SVM and Random Forest (RF) and Gradient Boosting (GB) and AdaBoost and XGBoost.
- Model Training and Optimization: The selected models undergo training with training datasets while hyperparameter tuning activities take place to boost predictive performance. The process of cross-validation establishes system reliability.
- Performance Evaluation: The models undergo testing through evaluation metrics which include accuracy and precision and recall and F1-score measurements.
- Deployment: The complete model operates through a user-friendly decision support system which helps healthcare professionals with early screening practices and urgent patient treatment.

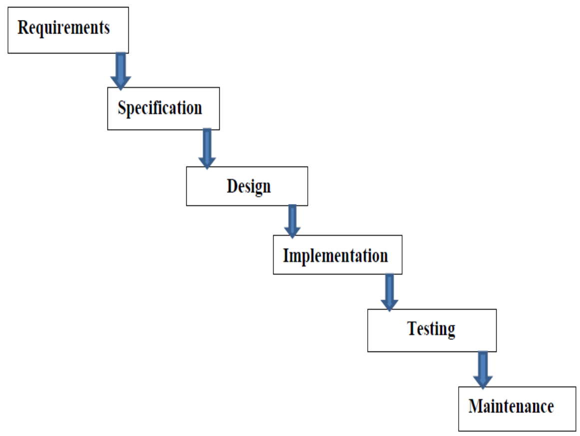

Figure 4. Waterfall Model

- Implementation: The actual programming and coding of the software takes place at this step. The result includes all library materials and application software together with user documentation and additional software product information.
- Testing: The testing process involves complete system testing which verifies whether all software requirements are met through the combination of programs and their subsequent testing. The testing process focuses on both validation and verification.
- Maintenance: The longest software development process consists of updating program features to meet customer needs while also implementing necessary external changes and fixing testing errors and improving software performance.

VI. CONCLUSION

This review highlights how machine learning (ML) and deep learning (DL) technologies can transform the early detection and diagnosis and prognosis of cervical cancer. The examined research studies prove AI-based diagnostic models can reach high accuracy levels with high sensitivity and high specificity that exceed the diagnostic capabilities of Pap smear tests and colposcopy procedures. The current situation presents multiple obstacles which need to be solved. These obstacles include data imbalance and the absence of standardized datasets and the difficulties with model interpretability and the restricted testing of models in actual clinical environments. The healthcare system needs organizations to implement proper data processing methods together with effective methods to choose most important features. They need to use explainable artificial intelligence systems. Future research needs to create systems which combine different data types. The research should develop user-friendly diagnostic tools which medical professionals can use in actual healthcare environments especially in areas with limited resources.

The healthcare system needs organizations to implement proper data processing methods together with effective methods to choose most important features. They need to use explainable artificial intelligence systems. The global medical community can achieve better cancer diagnosis results through AI-driven screening systems which also provide customized treatment options that lead to better patient outcomes and decreased death rates.

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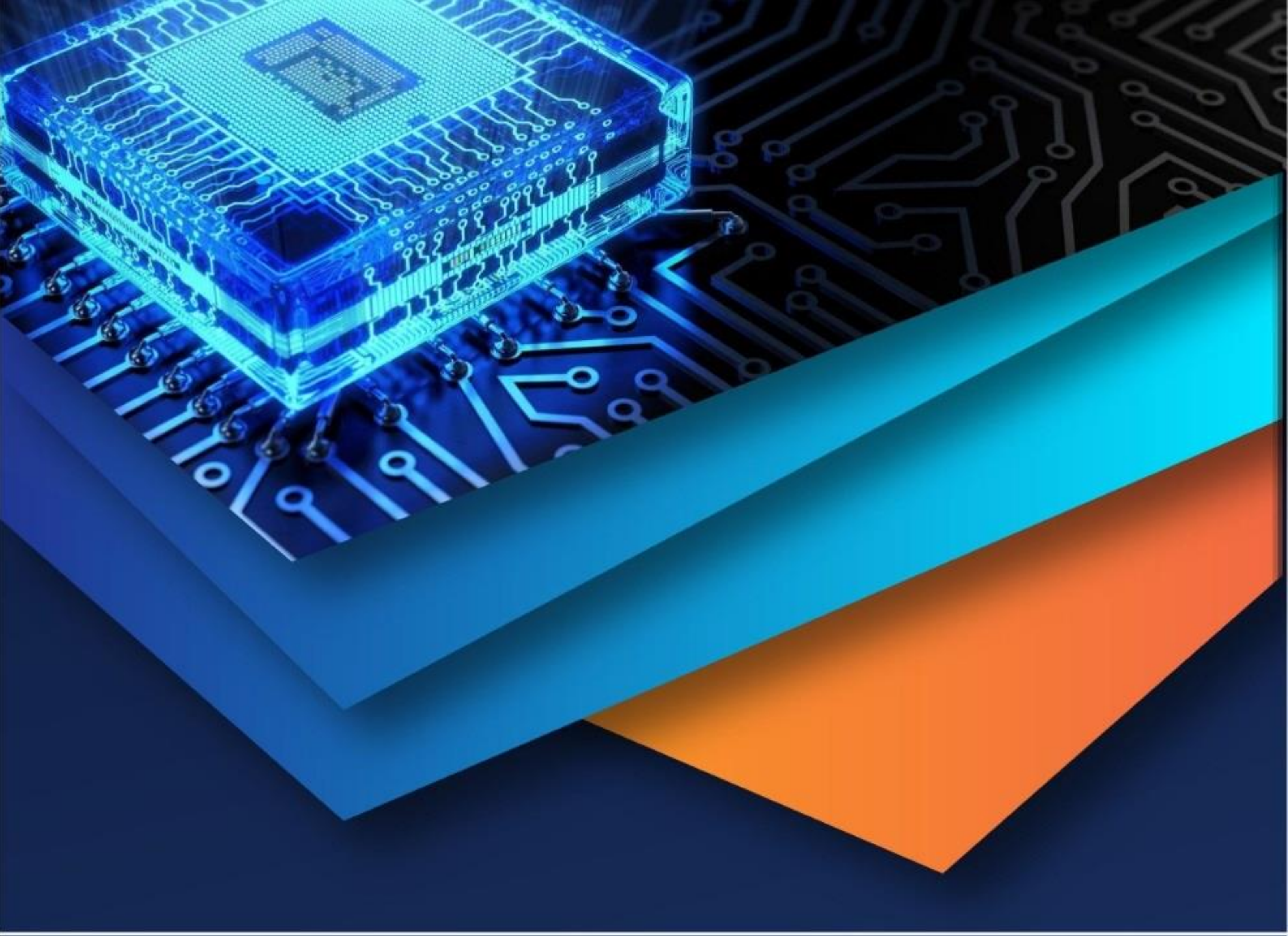

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