WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Machine Learning-based Automated Diagnosis for Cervical Cancer Using Pap Smear Images: A Systematic Review

Olusunde T. Grace[1], Ernest E. Onuiri[2*]

[1, 2]Department of Computer Science, School of Computing, Babcock University, Ilishan-Remo, Ogun State, Nigeria
Doi : https://doi.org/10.55248/gengpi.5.0924.2517

A B S T R A C T

This systematic review evaluates the effectiveness of machine learning-based automated diagnosis for cervical cancer using pap smear images. Cervical cancer remains one of the most prevalent cancers affecting women worldwide, with early detection being crucial in reducing mortality rates. Automating the diagnosis of cervical cancer through machine learning presents a promising solution for providing timely, accurate, and reliable diagnoses. This review systematically examines various machine learning algorithms and approaches applied to pap smear images, assessing their accuracy and efficiency. Out of 115 studies that met the eligibility criteria, the findings indicate that machine learning techniques have been successful in diagnosing cervical cancer based on pap smear images. However, a significant challenge is the limited availability of training data, particularly in developing countries where awareness and accessibility to routine cervical checks and pap smear tests are insufficient. The review highlights the need for future research to focus on increasing awareness and improving data collection to enhance machine learning models. This study adheres to PRISMA-P 2020 guidelines for systematic reviews and meta-analyses and concludes that automating cervical cancer diagnosis using pap smear images represents a crucial advancement in early detection and treatment.

Keywords: Cervical Cancer, Diagnosis, Image Processing, Machine Learning, Pap Smear Images, Systematic Review

Introduction:

Cancer is said to be abnormal cell growth in any part of the body with the ability to spread to other tissues in the body and then to other organs of the body if not properly attended to. This type of cancer shows up in the cervix first, which is the narrow end of the uterus (womb)[1]. Cervical cancer over time is a kind of cancer among women that is fast becoming well known just like breast cancer. Rated fourth among the types of cancer faced by women[2]. Yearly, over 300,000 women are affected by cervical cancer, every minute a woman is diagnosed with this time of cancer. Early detection and classification of cervical cancer cells greatly adds to successful treatments and this can be achieved using machine learning models for automation of pap smear image classification[3]. cervical cancer is one of the leading types of cancer in the world and has a high mortality rate among women, this can be prevented and cured using vaccinations and with early detection[4]. This type of cancer involves cancer cells growing in the cervix (the neck between the uterus and the vagina). The cervix is what connects the uterus to the vagina. These cells start to grow on the surface of the cervix and grow slowly over a long period. Cervical cancer develops first in the cervix tissues[5]. These cells grow gradually over a period and if not noticed could become precancerous cells. It is important to note that not all precancerous cells change or turn to cancer cells, though all cancerous cells are precancerous cells. Women who have been sexually active at an early age, women who have multiple sex partners, and women who have multiple children are at high risk of being diagnosed with cervical cancer. It is key to note that early detection is still ensuring proper diagnosis and ensure adequate treatment[6]. Common symptoms include abnormal vaginal bleeding and increased discharge, pelvic pain to mention a few. It is therefore key to ensure that changes noticed and detected are properly handled to avoid extra damage being done. There are different ways to diagnose cervical cancer some of which include: Regular Pelvic exams with Pap tests, Human Papillomavirus, testing, and Regular gynecology examinations with Pap Smear Tests. Cervical cancer is growing at a rapid rate across the globe, most especially in developed and developing countries where the impact is felt more. It is curable if it is detected early, and adequate treatments are carried out. As a result of the high cost of treatment, awareness of the diseases, and availability of highly equipped diagnosis, and screening tests, these are key reasons for the inadequate participation in screening or clinical tests to detect cervical cancer at an early stage[7]. The golden standard of diagnosing cervical cancer is the pap-smear test[8]. The automation of cervical cancer diagnosis methods proves to be reliable and time-conserving. These automated detection methods can be devised through the accurate segmentation and classification of Pap smear cell images[9].

Pap Smear Test is a type of test that collects cells from the cervix of the female, which is examined further for pre-cancer signs and other anomalies. It is a simple screening procedure for detecting cervical cancer at any stage[10]. Pap Smear images show the cell changes in the cervix and check the pre-cancer cells observed on the cervix surface to know which are prone to grow and turn into cancer cells. The most common type of cervical cancer is Squamous cell carcinoma smear test aids in the identification of cervical cells showing abnormalities in the cervix that can pass into cancer cells[6].

Using automated pap smear cervical screening is part of the effective ways for image-based cancer diagnosis tools used for the adequate categorization of the cervical is into normal and abnormal images[11].

1.1 Objectives

The primary aim of this systematic review is to assess how cervical cells can be accurately segmented for proper diagnosis, as this is crucial for effective treatment. However, the frequent presence of overlapping cancer cells in pap smear images poses a challenge to accurate segmentation. This review evaluates the effectiveness of automated cervical cancer diagnosis, which has improved early detection through machine learning algorithms trained on pap smear image features and outcomes to aid future predictions.

The specific objective of this review is to evaluate existing machine learning-based automated diagnosis systems that diagnose cervical cancer and classify the severity of the disease using pap smear images.

2. Materials and Methodologies

For this systematic review, the recommendations of the PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis protocol), and the check-list in reporting this paper were followed to carry out this research properly.

2.1 Eligibility Criteria

- Participants: females diagnosed with cervical cancer.
- Interventions: Machine learning models and algorithms used for diagnosis using classification and segmentation of pap smear images.
- Comparison: this will be between different machine learning models and algorithms reported in the nineteen reviews identified for this review.
- Outcomes: The main outcome of interest includes the level of accuracy of the model, sensitivity, precision, and recall value. The secondary outcome is the ability of the model to diagnose cervical cancer cells at any stage, beginning or advanced stage.

2.2 Setting Inclusive and Exclusive Criteria

Publications that did not focus on machine learning diagnosis for cervical cancer using pap smear images were excluded from the study, and publications that discussed general types of cancer diagnosis, treatments, or other unrelated topics to the review were excluded. Publications that were not in English or published outside the last five years (2018-2023) were excluded. Also, publications that lacked sufficient, adequate details on cervical cancer diagnosis using pap smear images, hence making it difficult to access their performance and limitations, were excluded. Studies with low sample sizes, high bias risk, and generalizability of their results were excluded as well. With this exclusion criteria, 231 articles were initially screened, and 84 articles were excluded. In the second phase of the screening which involves checking the methodologies used and the results/findings of the studies, another 121 articles were excluded because they did not meet the inclusion criteria. Fig. 1 shows the procedures used for the inclusion and exclusion criteria.

2.3 Search Strategy

The search was conducted using the following search strategy in Scopus. The search query is presented below:

TITLE-ABS-KEY(("Cervical cancer" OR "Cervix cancer" OR "Cervical neoplasms" OR "Cervix neoplasms" OR "Cervical carcinoma" OR "Cervix carcinoma" OR "Cervical tumor" OR "Cervix tumor") AND ("Pap smear" OR "Papanicolaou test" OR "Pap test") AND ("Machine learning" OR "Artificial intelligence" OR "Deep learning" OR "Neural network" OR "Image analysis" OR "Automated diagnosis")) AND PUBYEAR > 2019 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (SRCTYPE,"j")) The search in MedOfScience used the keyword “Sub-type Cancer classification” and “Prognosis prediction”.

2.4 Study Selection

The screening exercise was conducted by the researcher, who retrieved the titles and abstracts of the studies to assess eligibility based on the pre-defined inclusion and exclusion criteria. Full-text articles were retrieved for all studies that met the eligibility criteria. A systematic review of articles that used machine learning algorithms to diagnose cervical cancer using pap smear images was performed, including articles published from 2020 to 2023. The Scopus website was utilized to search for journals and papers published in relevant areas related to this study. The title, abstract, keywords, article name, and publication year of the identified records were exported to an MS Excel spreadsheet.

The screening of titles and abstracts was conducted, and the full texts of the remaining papers were accessed using the eligibility criteria. All reviewed articles that met the relevance requirements for this research study were included. This review covers longitudinal studies (researching participants over a period) and observational studies that have been conducted on automated diagnosis using pap smear images.

The inclusion criteria include (i) studies focused on cervical cancer, its causes, and symptoms, and (ii) studies on automated diagnosis using pap smear images. Irrelevant articles, records, abstracts, and data were excluded. The screening of eligible records and selection of articles were carried out.

2.5 Data Collection

Data extraction was done by the researcher, and any discrepancies were resolved through the application of the eligibility criteria and personal judgement. The extracted data includes study characteristics, participants, interventions, outcomes, and results.

2.6 Data Extraction

From each paper and article reviewed, the following information was extracted: the authors, year of publication, location, number of participants, and type of algorithm used. A total of 231 articles were identified from the search. After screening these articles according to the inclusion and exclusion criteria, the number was narrowed down to 19 articles for review as shown in Fig. 1 below.

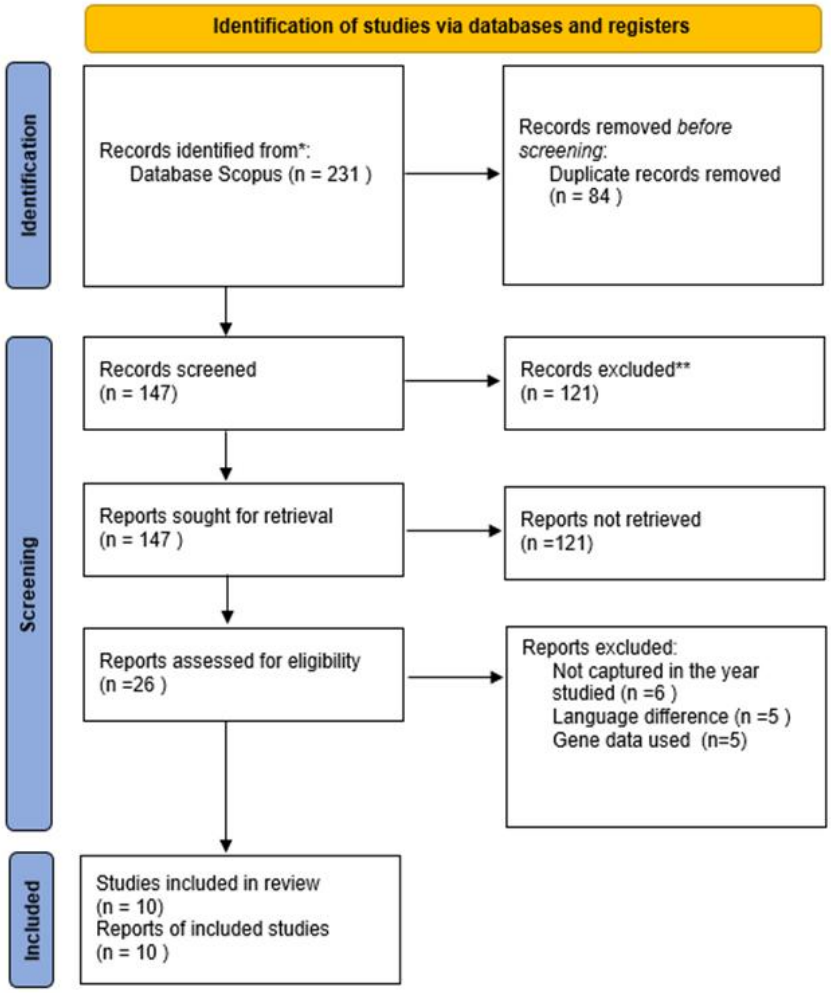

Fig. 1 – PRISMA Flowchart showing the inclusion and exclusion process of the review.

3. Result

The table below shows the characteristics and results of the reviewed papers, the approaches used and the algorithm used to train the model. It also contains the strengths and weaknesses of the reviewed works.

Table 1 – Reviewed Articles

Year	Authors	No of Images	Objective	Algorithm Model	Datasets	Novelties
2022	Mulmule P, Kanphade R[13]	250 images	Classification	Adaptive fuzzy k means clustering		After the evaluation of the performance of both classifiers used for the study, it was observed that the MLP classifier which utilized the hyperbolic tangent activation function outperforms the SVM classifier across all performance criteria used to measure both classifiers. With the MLP classification, it recorded an accuracy of 97%, a sensitivity of 98%, a specificity of 95%, and a positive predictive value of 98%.
2023	Narayan S, Rose R[14]	single cells.	Detection	Decision trees approach	Martin's database	The study introduces an innovative approach to the development of an assistance system/ machine to detect and diagnose cervical cancer promptly[14].
2022	Mahmoud H, Alarfaj A, Hafez A[15]	2600 public Pap smear images	Classification	Fuzzy clustering technique (C-means)	Online Public dataset	
2022	Benhari M, Hossseini R[16]	4005 colposcopy images and 915 histopathology images	Classification	cervix type and cervical cancer classification	Online public datasets	The study provided an integrated cervical screening system that has a better performance than other models previously trained for classification[16].
2022	Alquran H et al.[17]	4049 cells	Classification	Feature fusion	SIPaKMeD datasets	The cervical cancer network was used to extract features from the dataset utilized to extract features from the global average pooling layer, in which the number of extracted features was 1024 graphical features, and the images were tested using various machine learning models using the novel features[17].
2023	Ontor M et al.[7]	Not specified	Diagnosis	YOLOv5 (You Only Look Once Version 5) mode	Open-source repository	The proposed model was able to effectively diagnose cervical cancerous cells based on the experiments carried out and will be very useful in the medical field for early detection procedures[7].
2019	Shanthi P et al.[11]	Not specified	Classification	Convolutional Neural Network (CNN) model	Herlev dataset	A deep convolutional neural network-based model to classify the cervical cell images for detecting malignancy[11].
2019	Allehaibi K et al.		Classification	Mask regional convolutional neural network (Mask R-CNN)	Herlev Pap Smear dataset	

2018	William W et al.[18]		Classification and segmentation	K-nearest-neighbors and support vector machines		From this study, Enhancing performance is achievable by incorporating additional algorithms like support vector machines(SVM), pixel-level classifications, and statistical shape models along with the k-nearest-neighbor algorithm[18].
2019	William W, Ware A, Obungoloch J et al.[19]	Not specified	Diagnosis and Classification	Fuzzy C-means algorithm	Herlev benchmark pap-smear dataset.	The core and primary advantage/ edge that comes with the integration of this tool into the cervical cancer screening workflow is its ability to minimize the time spent by the cytotechnicians reviewing the numerous pap smears by automatically excluding normal cases. This allows them to accurately allocate more time to examining carefully suspicious image slides[19].

Table 1 presents a summary of recent studies that have employed machine learning algorithms to enhance the diagnosis and classification of cervical cancer through the analysis of medical images. Spanning from 2018 to 2023, these studies showcase various methodologies, datasets, and novel approaches to addressing the challenges associated with cervical cancer detection. They primarily focus on two objectives: classification and detection of cervical cancer, indicating a growing interest in leveraging advanced machine learning techniques to improve diagnostic accuracy. Notably, the algorithms utilized range from classical methods such as decision trees and fuzzy clustering to more sophisticated deep learning models like Convolutional Neural Networks (CNN) and YOLOv5. For instance, Mulmule et al. (2022) utilized an adaptive fuzzy k-means clustering algorithm, achieving impressive performance metrics, including an accuracy of 97%, highlighting the potential of machine learning in improving diagnostic reliability. Innovative approaches, such as the decision tree-based assistance system introduced by Narayan and Rose (2023) for prompt detection, reflect a shift toward developing integrated tools for clinical use. Similarly, Ontor et al. (2023) demonstrated the effectiveness of real-time object detection in medical applications using the YOLOv5 model. The diversity of datasets employed in these studies is noteworthy, with some utilizing publicly available datasets while others rely on specific repositories, such as the Herlev dataset. The large number of images, such as the 2600 public Pap smear images analysed by Mahmoud et al., enhances the robustness of the models trained, allowing for more generalized results, although some studies did not specify the number of images used, limiting understanding of the dataset's adequacy for training purposes. The table also highlights several innovative techniques, emphasizing advancements in feature extraction and model training; for example, Alquran et al. (2022) employed a feature fusion approach integrating 1024 graphical features extracted from the cervical cancer network, underscoring the importance of effective feature engineering in improving model performance. Furthermore, the deep learning approach showcased by Shanthi et al. (2019) with their CNN model indicates a trend toward leveraging neural networks for image classification tasks, while the Mask R-CNN approach by Allehaibi et al. further exemplifies the growing interest in segmentation techniques that enhance the accuracy of detecting malignant cells. The integration of these machine learning models into clinical workflows has significant implications for cervical cancer screening, as highlighted by William et al. (2019), who emphasized that the fuzzy C-means algorithm could substantially reduce the time cytotechnicians spend reviewing Pap smears by automating the exclusion of normal cases. This efficiency allows healthcare professionals to focus on more suspicious cases, potentially leading to earlier diagnoses and better patient outcomes.

4. Discussion

The systematic Review carried out reviewed the automation of cervical cancer diagnosis using pap smear images. Nineteen papers were reviewed for this study. The outputs suggest that the automation of cervical cancer diagnosis will improve early diagnosis and reduce the mortality rate. It is important to note that Pap-smear screening is one of the commonest methods used for early diagnosis of cervical cancer[19]. Allehaibi k, et al used a mask regional convolutional neural network for the classification and proper segmentation of the images, this model outperformed others in precision and recall value[9]. William W et al 2018, used a hybrid model which was a combination of the k-nearest neighbour algorithm with support vector machines, and pixel-level classification with statistical shape models and this improved the performance of the model aside from using single algorithms[18]. Yakkundimath R et al, also used a combination of techniques; artificial neural network (ANN), random forest (RF), and support vector machines (SVM), this model gave a maximum accuracy of 93.44% compared to models that use individual-based classifiers[20]. Machine algorithms such as K-means clustering, decision trees, and fuzzy clustering techniques among many were used to adequately train, validate and test machine models using images from previous pap smear tests.

5. Conclusion

The automation of the diagnosis of cervical cancer through the utilization of pap smear images can improve the accuracy of diagnosis and enable early treatments to be administered and will generally reduce the high mortality rate of women with this type of cancer. However, this current study is limited, and further research can be carried out to determine more models that can be used to further increase the accuracy and predict possible suitable treatment routes per patient. Future studies should use larger and more diverse datasets, apply rigorous evaluation metrics, and compare the performance of machine learning models with other combinations. Additionally, future studies should also focus on the clinical applicability and utility of these models for healthcare providers and users.

References

1 R. Kavitha et al., "Ant Colony Optimization-Enabled CNN Deep Learning Technique for Accurate Detection of Cervical Cancer," Biomed Res Int, vol. 2023, 2023, doi: 10.1155/2023/1742891.

2 M. B. Bijoy, S. M. Akondi, S. Abdul Fathaah, A. Raut, P. N. Pournami, and P. B. Jayaraj, "Cervix type detection using a self-supervision boosted object detection technique," Int J Imaging Syst Technol, vol. 32, no. 5, pp. 1615–1630, 2022, doi: 10.1002/ima.22696.

3 C.-W. Wang et al., "Artificial intelligence-assisted fast screening cervical high grade squamous intraepithelial lesion and squamous cell carcinoma diagnosis and treatment planning," Sci Rep, vol. 11, no. 1, 2021, doi: 10.1038/s41598-021-95545-y.

4 S. Priya and N. K. Karthikeyan, "A heuristic and ann-based classification model for early screening of cervical cancer," International Journal of Computational Intelligence Systems, vol. 13, no. 1, pp. 1092–1100, 2020, doi: 10.2991/ijcis.d.200730.003.

5 M. Kalbhor, S. Shinde, H. Joshi, and P. Wajire, "Pap smear-based cervical cancer detection using hybrid deep learning and performance evaluation," Comput Methods Biomech Biomed Eng Imaging Vis, 2023, doi: 10.1080/21681163.2022.2163704.

6 T. P. Deepa and A. N. Rao, "Classification of normal and abnormal overlapped squamous cells in pap smear image," International Journal of System Assurance Engineering and Management, 2023, doi: 10.1007/s13198-022-01805-z.

7 M. Z. H. Ontor et al., "Early-Stage Cervical Cancerous Cell Detection from Cervix Images Using YOLOv5," Computers, Materials and Continua, vol. 74, no. 2, pp. 3727–3741, 2023, doi: 10.32604/cmc.2023.032794.

8 O. Yaman and T. Tuncer, "Exemplar pyramid deep feature extraction based cervical cancer image classification model using pap-smear images," Biomed Signal Process Control, vol. 73, 2022, doi: 10.1016/j.bspc.2021.103428.

9 K. H. S. Allehaibi, L. E. Nugroho, L. Lazuardi, A. S. Prabuwono, and T. Mantoro, "Segmentation and classification of cervical cells using deep learning," IEEE Access, vol. 7, pp. 116925–116941, 2019, doi: 10.1109/ACCESS.2019.2936017.

10 N. Kumaresan and D. Somasundaram, "Review of pap smears cell segmentation and classification techniques for cervical cancer analysis," Studies on Ethno-Medicine, vol. 12, no. 2, pp. 96–105, 2018, doi: 10.31901/24566772.2018/12.02.544.

11 P. B. Shanthi, F. Faruqi, K. S. Hareesha, and R. Kudva, "Deep Convolution Neural Network for malignancy detection and classification in microscopic uterine cervix cell images," Asian Pacific Journal of Cancer Prevention, vol. 20, no. 11, pp. 3447–3456, 2019, doi: 10.31557/APJCP.2019.20.11.3447.

12 W. Chen, L. Gao, X. Li, and W. Shen, "Lightweight convolutional neural network with knowledge distillation for cervical cells classification," Biomed Signal Process Control, vol. 71, 2022, doi: 10.1016/j.bspc.2021.103177.

13 P. V Mulmule and R. D. Kanphade, "Supervised classification approach for cervical cancer detection using Pap smear images," Int J Med Eng Inform, vol. 14, no. 4, pp. 358–368, 2022, doi: 10.1504/IJMEI.2022.123930.

14 S. R. S. V. Narayan and R. J. Rose, "Cervical Cancer Detection Based on Novel Decision Tree Approach," Computer Systems Science and Engineering, vol. 44, no. 2, pp. 1025–1038, 2023, doi: 10.32604/csse.2023.022564.

15 H. A. H. Mahmoud, A. A. Alarfaj, and A. M. Hafez, "A Fast Hybrid Classification Algorithm with Feature Reduction for Medical Images," Appl Bionics Biomech, vol. 2022, 2022, doi: 10.1155/2022/1367366.

16 M. Benhari and R. Hosseini, "An Improved Fuzzy Deep Learning (IFDL) model for managing uncertainty in the classification of pap-smear cell images," Intelligent Systems with Applications, vol. 16, 2022, doi: 10.1016/j.iswa.2022.200133.

17 H. Alquran, M. Alsalatie, W. A. Mustafa, R. A. Abdi, and A. R. Ismail, "Cervical Net: A Novel Cervical Cancer Classification Using Feature Fusion," Bioengineering, vol. 9, no. 10, 2022, doi:S 10.3390/bioengineering9100578.

18 W. William, A. Ware, A. H. Basaza-Ejiri, and J. Obungoloch, "A review of image analysis and machine learning techniques for automated cervical cancer screening from pap-smear images," Comput Methods Programs Biomed, vol. 164, pp. 15–22, 2018, doi: 10.1016/j.cmpb.2018.05.034.

19 W. William, A. Ware, A. H. Basaza-Ejiri, and J. Obungoloch, “A pap-smear analysis tool (PAT) for detection of cervical cancer from pap-smear images,” Biomed Eng Online, vol. 18, no. 1, 2019, doi: 10.1186/s12938-019-0634-5.

20 R. Yakkundimath, V. Jadhav, B. Anami, and N. Malvade, “Co-occurrence histogram based ensemble of classifiers for classification of cervical cancer cells,” Journal of Electronic Science and Technology, vol. 20, no. 3, 2022, doi: 10.1016/J.JNLEST.2022.100170.