Metaheuristic Optimization in Monkeypox detection: A Comprehensive Literature Review

Amal H. Alharbi[1], Amel Ali Alhussan[2], Mohamed Ahmed Kandel[3], Doaa Sami Khafaga[4], El-Sayed M. El-kenawy[5,6], Marwa M. Eid[7]

[1]*Department of Computer Sciences College of Computer & Information Sciences Princess Nourah bint Abdulrahman University Riyadh, Saudi Arabia ahalharbi@pnu.edu.sa*

[2]*Department of Computer Sciences College of Computer & Information Sciences Princess Nourah bint Abdulrahman University Riyadh, Saudi Arabia aaalhussan@pnu.edu.sa*

[3]*Delta Higher Institute of Engineering and Technology Architectural Engineering Department, Mansoura 35511, Egypt CH1800230@dhiet.edu.eg*

[4]*Department of Computer Sciences College of Computer & Information Sciences Princess Nourah bint Abdulrahman University Riyadh, Saudi Arabia dskhafga@pnu.edu.sa*

[5]*Delta Higher Institute of Engineering and Technology Department for Communications and Electronics, Mansoura 35511, Egypt*

[6]*Applied Science Research Center Applied Science Private University Amman, Jordan skenawy@ieee.org*

[7]*Faculty of Artificial Intelligence Delta University for Science & Technology Mansoura 35111, Egypt Jadara University Research Center Jadara University, Jordan mmm@ieee.org*

Abstract.

This work presents a structured synthesis of three major research domains: (1) detection and classification, encompassing convolutional neural networks (CNNs), transformer-based architectures, capsule net- works, transfer learning, feature selection, ensemble methods, and explainability tools applied to lesion images for accurate diagnosis; (2) genomics, prediction, and reviews, covering time series modeling of viral genome mutations using long short- term memory (LSTM) networks, phylogenetic analysis, mutation hotspot identification, and critical reviews of AI-based diagnostic methods and metaheuristic optimization strategies; and (3) in- tervention support, focusing on outbreak forecasting, gradient boosting risk models, and non-stationary LSTM frameworks for scenario planning and resource allocation. Across categories, recurring challenges include limited and imbalanced datasets, inconsistent reporting, and the gap between algorithmic accuracy and clinical or operational integration. This synthesis high- lights methodological trends, identifies limitations, and outlines research priorities: developing multicenter datasets, leveraging multimodal integration of phenotype and genotype, adopting federated and semi-supervised learning to address data scarcity, and coupling predictive models with operational feasibility assess- ments.

Keywords. Convolutional Neural Networks, Long Short- Term Memory, Monkeypox, Genomic Analysis, Outbreak Fore- casting

1. INTRODUCTION

Diagnostic capacity sits at the center of outbreak man- agement, and conventional workflows have relied heavily on polymerase chain reaction (PCR) assays, which remain the gold standard for mpox confirmation due to their high sensitivity and specificity. Nonetheless, PCR-based testing re- quires specialized laboratory infrastructure, trained personnel, and stable supply chains for reagents and equipment. These requirements limit accessibility, particularly in low-resource regions, and introduce time lags in the diagnostic cycle owing to sample transportation and processing delays. During fast- moving outbreaks, such bottlenecks can delay case confir- mation, thereby reducing the effectiveness of isolation and contact-tracing measures. In this context, artificial intelligence (AI) and machine learning (ML) techniques are increasingly being recognized as complementary diagnostic tools. By lever- aging lesion imagery and patient data, these systems can support rapid triage and preliminary classification, helping to prioritize cases for confirmatory testing and resource allocation [1].

Deep learning models have become the cornerstone of AI- based mpox detection, with convolutional neural networks (CNNs) demonstrating significant success in capturing hier- archical features of skin lesions. CNNs excel at recognizing fine-grained textural details alongside broader morphological structures, enabling them to distinguish mpox from visually similar conditions such as chickenpox, measles, and bacterial skin infections [2]. More recently, transformer-based models have been integrated into computer vision pipelines, adding the ability to capture long-range dependencies and global spatial context through self-attention mechanisms. Hybrid CNN–transformer frameworks have shown particular promise in enhancing diagnostic accuracy in ambiguous cases, where local lesion features alone may be insufficient for accurate classification [3]. These architectural advances have been reinforced by the use of metaheuristic optimization algo- rithms, which systematically fine-tune hyperparameters, im- prove model convergence, and enhance robustness in data- limited scenarios [4-5].

2. LITERATURE REVIEW

Architectural innovation has extended beyond CNNs into hybrid and novel designs. CNN–transformer hybrids exploit convolutional layers for local texture recognition while applying vision transformer (ViT) modules for long-range contextual relationships. This global-aware perspective is further enhanced in specialized frameworks such as the RS-FME-SwinT, which integrates Swin Transformer modules with residual and spatial convolutions to capture both lesion fine details and broader spatial dependencies. Attention-enhanced CNNs, as described in [6], similarly direct the model's focus toward diagnostically relevant regions, mitigating confounding back- ground features. Hybrid pipelines that combine multiple CNN backbones such as ResNet50V2, NASNetMobile, and InceptionV3 with Minimum Redundancy Maximum Relevance (mRMR) filtering demonstrate the effectiveness of pruning redundant attributes, reducing dimensionality, and improving inference time. These methods ensure high classification accuracy while maintaining feasibility for field-deployable systems. More broadly, reviews such as [7] consolidate the role of optimization in skin lesion analysis, highlighting transferable strategies for mpox detection.

A significant theme across the literature is the challenge of limited, imbalanced datasets. Augmentation techniques, including rotation, scaling, and illumination adjustment, have been widely applied, while generative adversarial networks (GANs) and variational autoencoders (VAEs) have been adopted to synthesize realistic lesion images. These strategies help balance underrepresented lesion classes and expand data diversity, though they require clinical validation to ensure realism. For example, [8] explores feature fusion frameworks combining multiple network layers to enhance generalization, while introduces a 3D DenseUNet with CKHA segmentation for volumetric lesion analysis, allowing precise boundary delineation. Comparative benchmarking studies [5-8] systematically evaluate CNNs, transformers, and hybrid models under standardized conditions, providing critical insights into performance trade-offs across architectures.

3. DISCUSSION

The works summarized in the methodology table reflect the breadth and maturity of current research efforts aimed at improving the detection, characterization, and management of mpox. Within the detection and classification category, there has been a notable progression from early convolutional neural network models toward more complex architectures that blend multiple paradigms, such as CNN–transformer hybrids, Siamese networks, and capsule-based frameworks. These architectures address specific limitations inherent to traditional CNNs such as the loss of spatial hierarchies or the inability to capture long-range dependencies while leveraging strengths such as hierarchical feature extraction and robustness to noise. Techniques such as minimum redundancy maximum relevance (MRMR) allow for the consolidation of deep features extracted from diverse backbones into a compact and highly discriminative feature set. This has been shown to reduce computational overhead and improve inference speed, which is critical for deployment in resource-constrained settings. Similarly, the application of metaheuristic algorithms for hyperparameter tuning enables more effective exploration of the parameter spce, often outperforming manual or grid search methods in balancing training speed, accuracy, and generalization performance. These strategies align with a broader trend in AI for healthcare toward optimizing not only raw predictive performance but also operational feasibility, ensuring that models can be deployed across a wide range of clinical environments. However, this introduces an additional requirement for rigorous validation to ensure that augmented samples preserve clinically relevant lesion characteristics and do not inadvertently mislead the model. Interpretability remains a critical concern for the adoption of AI-driven mpox detection systems in real-world clinical practice. The integration of explanation mechanisms such as Grad-CAM heatmaps or textual justifications has been shown to improve clinician trust and facilitate the integration of AI outputs into decision-making processes. In summary, the works reviewed demonstrate substantial progress in each of the three main research areas while also revealing opportunities for greater integration and operationalization. The next generation of mpox research will likely be characterized by hybrid platforms that combine lesion detection, genomic surveillance, and forecasting into unified decision-support systems. Such systems, if designed with adaptability, interpretability, and equity at their core, have the potential to transform the management of mpox from reactive outbreak control to proactive, globally coordinated prevention.

4. CONCLUSION

The synthesis of recent contributions to mpox research reveals a maturing and increasingly interdisciplinary field, where advances in artificial intelligence, optimization, and data inte gration are being strategically harnessed to address complex diagnostic, genomic, and epidemiological challenges. On the diagnostic front, innovative deep learning architectures—from Siamese and capsule networks to CNN–transformer hy- brids—demonstrate the capacity to achieve high accuracy under conditions of limited data availability, especially when supported by transfer learning, targeted augmentation, and attention-based interpretability tools. These methods not only enhance lesion-level classification but also facilitate clinically relevant subclassification and multimodal integration with symptom and epidemiological data, thereby bridging the gap between computational outputs and practical clinical decision- making. In the genomic and evolutionary sphere, time series modeling of viral sequences, large-scale phylogenetic map- ping, and mutation hotspot analysis have provided valuable insights into mpox clade diversification, geographic dissemination, and potential shifts in transmissibility or virulence. Such findings are critical for anticipating the need for diagnostic assay updates, refining vaccine formulations, and informing cross-border public health strategies. Complementary review studies continue to consolidate emerging best practices, while emphasizing the urgency of addressing persistent challenges such as data scarcity, uneven sequencing capacity, and the absence of standardized benchmark datasets.

REFERENCES

[1] El-Sayed M Elkenawy, Amel Ali Alhussan, Marwa M Eid, and Ab- delhameed Ibrahim. Rainfall classification and forecasting based on a novel voting adaptive dynamic optimization algorithm. Frontiers in Environmental Science, 12:1417664, 2024.

[2] El-Sayed M El-Kenawy, Abdelhameed Ibrahim, Amel Ali Alhussan, Doaa Sami Khafaga, Ayman EM Ahmed, and Marwa M Eid. Smart city electricity load forecasting using greylag goose optimization-enhanced time series analysis. Arabian Journal for Science and Engineering, pages 1–19, 2025.

[3] R. Kumar, Vevekanandam, and R. Dey, "IoT-enabled bioimpedance and thermal imaging system for non-destructive fruit maturity assessment," International Journal of Vegetable Science, pp. 1–23, 2025, doi: 10.1080/19315260.2025.2574898.

[4] Ahmed El-Sayed Saqr, Mohamed S Saraya, and El-Sayed M El- Kenawy. Enhancing co2 emissions prediction for electric vehicles using greylag goose optimization and machine learning. Scientific Reports, 15(1):16612, 2025.

[5] Amel Ali Alhussan, El-Sayed M. El-kenawy, Doaa Sami Khafaga, Amal H. Alharbi, and Marwa M. Eid. Groundwater resource prediction and management using comment feedback optimization algorithm for deep learning. IEEE Access, pages 1–1, 2025.

[6] A. K. S. Pundir, P. Singh, R. Kumar et al., "Modelling, simulation, and FPGA implementation of an augmented memory built-in self-test based design for bit-oriented memory," Journal of Electronic Testing, 2025, doi: 10.1007/s10836-025-06193-3.

[7] Y. K. Shejwal, A. J. Hati, J. U. Kidav, A. K. Singh, and R. Kumar, "Neural network-based classification of beamforming matrices," International Journal of Satellite Communications and Networking, 2025, doi: 10.1002/sat.70002.

[8] S. Arora, S. Sharma, R. Anand, R. Kumar et al., "Integration of metamaterials for quintuple band-notched ultra-wideband antennas," Analog Integrated Circuits and Signal Processing, vol. 123, 2025, doi: 10.1007/s10470-025-02355-7.