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Editorial

Charting New Frontiers: Insights and Future Directions in ML and DL for Image Processing

Mohamed Shehata [1,2,*] and Mostafa Elhosseini [2,3,*]

1 Department of Bioengineering, Speed School of Engineering, University of Louisville, Louisville, KY 40292, USA
2 Computers and Control Systems Engineering Department, Faculty of Engineering, Mansoura University, Mansoura 35516, Egypt
3 College of Computer Science and Engineering, Taibah University, Yanbu 46421, Saudi Arabia
* Correspondence: mohamed.shehata@louisville.edu (M.S.); melhosseini@mans.edu.eg or melhosseini@ieee.org (M.E.)

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1. Introduction

The Special Issue “Deep and Machine Learning for Image Processing: Medical and Non-medical Applications” of the MDPI journal *Electronics* marks a pivotal point in the exploration of machine learning (ML) and deep learning (DL) applications in image processing. This Special Issue has received numerous submissions, totaling 35 papers, not including this Editorial paper, of which 23 were rejected and archived and 12 were published. Such figures underscore the vibrant interest and research activity within this field and highlight the diverse and innovative approaches researchers are taking to push the boundaries of ML and DL applications across various medical and non-medical sectors.

As we delve into the contributions made by this Special Issue, it becomes apparent that while significant strides have been made in enhancing image-processing techniques through ML and DL, several critical research gaps remain unaddressed. Addressing these gaps can potentially propel this field forward and broaden the scope of ML and DL applications across various sectors. The delineation of these gaps serves as a guidepost for future research endeavors, outlining the need for innovation in theoretical foundations and practical implementations. The primary research gaps identified through the contributions within this Special Issue include the following:

- Enhancing diagnostic accuracy and computational efficiency: The requirement for models that offer heightened diagnostic precision, particularly in the healthcare sector, reveals a gap in current computational approaches, encompassing a need for accurate algorithms characterized by rapid processing capabilities and scalability [1].
- Integrating spatial and temporal data in predictive models: A notable deficiency exists in effectively melding spatial and temporal data in predictive models. This gap highlights the requirement for sophisticated analytical models leveraging comprehensive datasets to yield more nuanced and accurate forecasts [2].
- Developing algorithms for the automated diagnosis of complex conditions: The complex nature of diagnosing varied conditions, such as skin diseases or monkeypox [3], underscores the need for algorithms adept at processing and interpreting highly variable data. This presents a significant research gap, marrying the practical need for automated diagnostics with the conceptual challenge of algorithmic innovation.
- Achieving model generalization in data-constrained scenarios: A critical conceptual gap emerges in the quest for models that exhibit robust generalization capabilities, particularly when there is limited data availability [4]. This gap underscores the importance of developing models that maintain efficacy across diverse datasets and scenarios.

- Creating language-specific and context-aware analysis models: The need for models sensitive to the nuances of specific languages, especially for detecting subtleties such as hate speech in underrepresented languages [5], points to a dual gap in conceptual understanding and practical application, highlighting the broader challenge of ensuring ML and DL models are inclusive and capable of nuanced, context-aware analysis.
- Refining object detection methods for challenging conditions: The difficulty of detecting objects under challenging conditions [6], such as when using low-resolution imaging or in complex environments, indicates a gap in current detection algorithms, necessitating the development of specialized detection methods that are both precise and adaptable to various conditions.
- Optimizing deep neural networks for edge device deployment: The optimization of deep neural networks for efficient deployment on edge devices [7] illustrates a crucial gap in quantization methods, bridging the divide between theoretical advancements and practical deployment necessities.
- Advancing imaging techniques for specific applications: The demand for innovative imaging techniques, particularly those that enhance material discrimination in X-ray imaging [8,9] or optimize-compressed sensing MRI [10], underscores a conceptual gap in algorithmic solutions tailored to meet specific healthcare and security needs.

These identified gaps collectively delineate the frontier of future research into ML and DL, underscoring the symbiotic relationship between advancing theoretical methodologies and tackling practical application challenges. Addressing these gaps through innovative research is pivotal for driving the evolution of ML and DL technologies and expanding their impact across various domains.

2. Review and Selection Process

This section outlines the rigorous and transparent process of selecting papers for the "Deep and Machine Learning for Image Processing: Medical and Non-medical Applications" Special Issue.

— **Submission Solicitation**: We initiated our call for papers through academic networks, social media, and direct invitations, targeting a wide range of researchers in the field.
— **Preliminary Screening**: Each submission underwent an initial screening for compliance with the Special Issue's scope and adherence to submission guidelines and originality checks to ensure relevance and prevent plagiarism.
— **Review Criteria**: Papers were evaluated based on originality, methodological soundness, contribution significance, relevance to the Special Issue's theme, and clarity. Emphasis was placed on innovative applications of ML and DL in image processing.
— **Peer Review Process**: Submissions were subjected to a single-blind peer review conducted by at least two domain experts, ensuring the acquisition of unbiased feedback on their scientific merit and alignment with the Special Issue's themes.
— **Decision Making**: Decisions were made based on reviewer recommendations, with Guest Editors playing a pivotal role in resolving any conflicts or discrepancies. This process was designed to balance rigor with constructive feedback from authors.
— **Revision and Final Acceptance:** Authors were invited to revise their manuscripts in response to reviewer comments, with the revised versions undergoing a subsequent review to ensure all concerns were addressed before final acceptance.
— **Ethical Considerations and Conflicts of Interest:** Throughout the review process, we strictly adhered to ethical guidelines and managed conflicts of interest, ensuring a fair and unbiased selection process.

3. Motivations and Objectives

Motivations: The impetus behind this Special Issue is rooted in the transformative potential of ML and DL technologies in the realm of image processing. As these technologies advance, they unlock new possibilities for enhancing image analysis across diverse applications, ranging from medical diagnostics to environmental monitoring. This Special

Issue aims to spotlight research that exemplifies how ML and DL can address current limitations, improve computational efficiency, and open new avenues for innovation, ultimately contributing to societal well-being and scientific progress.

Objectives: Our objectives are twofold. First, we aim to showcase state-of-the-art research that pushes the boundaries of ML and DL in image processing, highlighting both theoretical advancements and practical applications. Second, we aim to identify and bridge research gaps, encouraging a multidisciplinary approach combining technology, healthcare, and ethics insights. Through this, we aim to stimulate a forward-looking discussion on how ML and DL can continue to evolve and impact various sectors positively.

Overarching Themes: This Special Issue covers a wide array of themes, including enhancing diagnostic accuracy in healthcare, refining object detection in challenging environments, optimizing deep neural networks for edge device deployment, and advancing imaging techniques for specific applications. These themes demonstrate the versatility of ML and DL applications and underline our commitment to advancing research that has a tangible impact on both the scientific community and society at large.

4. Innovative Directions in Image Processing: ML and DL Perspectives

The Special Issue "Deep and Machine Learning for Image Processing: Medical and Non-medical Applications" of the MDPI journal *Electronics* has catalyzed a significant evolution in the realms of ML and DL, charting new territories beyond their conventional applications. This evolution is characterized not merely by expanding these technologies into diverse sectors but, more fundamentally, by the substantial conceptual advancements underpinning these applications. The developments detailed in this Special Issue provide a panoramic view of the innovative strides made across the spectrum of ML and DL, highlighting their profound impact on image processing. A concise overview of these key advancements is provided below:

- Ensemble and hybrid learning models: The fusion of diverse ML/DL architectures to construct ensemble and hybrid models has emerged as a cornerstone for enhancing the robustness and accuracy of predictive models, especially in tackling complex tasks in diagnostics and object detection. For example, in [Contribution 1], the authors proposed a stacking ensemble model based on a CNN in order to identify patients at risk of myocardial infarction. In [Contribution 2], the authors introduced a novel deep-learning-based model for camouflaged object detection named feature lateral connection networks (FLCNet).
- Time series analysis for predictive modeling: The application of sophisticated statistical models for time series analysis underscores the adaptability of ML techniques in regard to predictive modeling, extending their utility beyond traditional image processing to encompass a broad range of predictive scenarios. In particular, in [Contribution 3], the authors propose a model called SARIMA. This model is designed to analyze and predict crime patterns and crime rates and specify the likelihood of location-based crime distribution.
- Metaheuristic optimization for enhanced diagnostics: Integrating metaheuristic optimization algorithms into diagnostic models marks a leap in algorithmic innovation, optimizing the accuracy and efficiency of these models at the nexus of healthcare and artificial intelligence. Particularly, in [Contribution 4], the authors introduced a new diagnostic pipeline that hybridizes pre-trained CNN models, ML classifiers, and a metaheuristic optimization approach, namely, Harris Hawks Optimizer, to precisely diagnose monkeypox.
- Tailored detection and segmentation techniques: Developing specific algorithms and adaptations to neural networks for tailored object detection and segmentation illustrates this field's progression toward customized solutions to meet unique challenges. For safety monitoring purposes, the authors of [Contribution 5] detected irregular deformable objects in a power operation workplace by developing an end-to-end instance segmentation method using the multi-instance relation weighting module

for irregular deformable objects. In [Contribution 6], the authors proposed a network object detection scheme based on YOLOv7 to detect objects in TinyPerson images.

- Language-specific models for NLP: The crafting of language-specific models for natural language processing (NLP) reflects an increasing focus on creating AI tools capable of nuanced, context-aware analysis, emphasizing the importance of linguistic inclusivity and precision in sentiment analysis. Specifically, in [Contribution 7], the authors proposed a new AI-based model for the accurate detection of Arabic hate speech on Twitter. In [Contribution 8], the authors investigated the efficacy of applying contrastive language–image pretraining (CLIP) to visual features to predict perceptual image quality.
- Advancements in image-processing techniques: Innovations in image quality enhancement and material discrimination techniques push the envelope with respect to how visual information is processed, showcasing new methods that redefine the capabilities of image-processing technologies. For instance, in [Contribution 9], the authors proposed a color-based material discrimination AI-based method for distinguishing single-energy X-ray images based on dual-energy colorization. In [Contribution 10], the authors effectively dealt with two problems in CS-MRI: the selection of sampling masks and the design of image reconstruction algorithms.
- Efficient model deployment on edge devices: The emphasis on model quantization for deployment in resource-constrained environments highlights a critical development area, aiming to make ML/DL technologies more accessible and efficient for broader adoption. As an example, in [Contribution 11], the authors designed a hybrid quantization method dubbed Unified Scaling-Based Pure-Integer Quantization (USPIQ) to optimize deep neural networks with complex skip connections for deployment on pure-integer accelerator chips for edge AI devices.
- Optimization in medical imaging: The use of deep learning and optimization algorithms to refine medical imaging techniques signals a strong movement towards integrating AI in improving healthcare diagnostics, showcasing the potential for AI to revolutionize medical imaging. In particular, in [Contribution 12], the authors utilized hybrid-deep learning models and feature fusion to develop an automatic diagnosis system for the early detection of skin lesion categories using dermoscopic images.

Collectively, these advancements illuminate the dynamic and rapidly evolving nature of ML and DL research. They underscore the vast potential of these technologies to drive forward a wide range of domains through the development of advanced algorithms and models, setting the stage for future innovations that will continue to expand the boundaries of what is possible in image processing and beyond.

5. Future Research Directions: Expanding the Horizons of ML and DL in Image Processing

The insights derived from the Special Issue "Deep and Machine Learning for Image Processing: Medical and Non-medical Applications" spotlight the remarkable strides within ML and DL for image processing and frame a blueprint for future research trajectories. Emphasizing the integration of findings and the evolving ML/DL landscape, several pivotal directions for future investigation have emerged:

- Refinement of integrated ML/DL models: The achievements of ensemble and hybrid models alongside metaheuristic optimizations call for developing more sophisticated, integrative models. These should harness diverse ML/DL architectures augmented by novel optimization strategies to boost efficiency across various image-processing tasks.
- Broadening of predictive modeling: The successful application of time series models like SARIMA in non-conventional areas suggests the expansion of predictive analytics. Future research should explore the use of forecasting in environmental monitoring, financial analysis, or maintenance scheduling, leveraging complex image and data sequences.

- Enhancement through data fusion: Innovations in fusing image data with metadata for accurate diagnostics highlight the importance of multi-modal data synthesis. Expanding this methodology could improve decision-making systems in various sectors, emphasizing the integration of heterogeneous data sources.
- Advancements in imaging and material discrimination: Groundbreaking methods for material discrimination and image enhancement signal deep learning's transformative potential. Research conducted with the aim of refining these techniques could revolutionize imaging across sectors, ranging from aerospace to manufacturing.
- Development of context-aware NLP models: Crafting language-specific models for content analysis underscores the necessity for more inclusive and adaptable NLP solutions. Future endeavors should cover a broader linguistic spectrum, particularly focusing on underexplored languages and dialects.
- Robust object detection: Enhancements in detecting minuscule or camouflaged objects via specialized DL models indicate significant progress in object detection. Future studies should aim to fortify these models against diverse adversities, widening their applicability in critical security and environmental conservation areas.
- Optimization for edge computing: Exploring quantization for efficient AI deployment underscores the need to make advanced computational models accessible on edge devices. Investigating new quantization and optimization methods will be essential for deploying AI solutions in resource-limited settings.
- Innovations in medical imaging: The progress in optimizing CS-MRI techniques exemplifies AI's potential to revolutionize medical diagnostics. Future research could extend these optimizations to various imaging modalities to enhance diagnostic precision and patient care.
- Multimedia content quality assessment: Evaluating multimodal models for perceptual quality prediction opens avenues in media analysis. Further investigations could extend to assessing the quality of VR, AR, and other emerging media formats, ensuring high-quality user experience.

Pursuing these avenues can significantly extend the capabilities of ML and DL in image processing, tackling foundational challenges and catering to emerging needs across a broad spectrum of applications. This holistic approach builds upon the notable achievements highlighted in this Special Issue, aligning with the overarching aim of advancing technology to address complex issues and enhance human experiences in various domains.

6. Conclusions

This Special Issue, "Deep and Machine Learning for Image Processing: Medical and Non-medical Applications", presents a comprehensive exploration of cutting-edge ML and DL technologies applied to image processing. The diverse contributions span various topics, ranging from enhancing diagnostic accuracies and advancing object detection under challenging conditions to optimizing neural networks for edge computing and developing specialized imaging techniques. The research showcased herein offers a panoramic view of current innovations and their applications in medical and non-medical fields.

The multidisciplinary nature of these studies, contributed by scholars from various regions, underscores the universal appeal and applicability of ML and DL technologies in pushing the boundaries of image processing. Each paper extends the frontier of knowledge, addressing critical challenges, presenting novel solutions, and opening avenues for future investigation. Collectively, these works illuminate the path forward, highlighting emerging opportunities and persisting obstacles in regard to harnessing the full potential of ML and DL to revolutionize image analysis.

By collecting these multifaceted studies, this Special Issue showcases the vibrant state of research in ML and DL applications for image processing. It sets the stage for ongoing innovation and exploration. It is envisioned that this collection will catalyze further research, fostering technological advancements that enhance our ability to analyze images more effectively, thereby contributing to the betterment of various sectors and improving human life. Through this synthesis of efforts, this Special Issue affirms the significance of ML and DL technologies as indispensable tools in the modern repertoire of image-processing techniques poised to address the complex challenges of the future.

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