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A Comprehensive Review of CNN-Based Techniques for COVID-19 Detection Using Medical Imaging

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Abstract— **The COVID-19 pandemic has catalyzed the development of rapid and reliable diagnostic systems, with medical imaging playing a crucial role in early detection and monitoring. Convolutional Neural Networks (CNNs), a subset of deep learning, have demonstrated remarkable capabilities in analyzing radiological images such as chest X-rays and computed tomography (CT) scans for identifying COVID-19-related abnormalities. This comprehensive review presents an in-depth analysis of recent CNN-based approaches used in the detection of COVID-19 from medical imaging. It discusses various architectural enhancements, transfer learning techniques, dataset challenges, performance metrics, and real-time deployment considerations. Furthermore, the review compares state-of-the-art models based on accuracy, sensitivity, and computational efficiency. By synthesizing current trends and identifying gaps in existing research, this study provides valuable insights for future advancements in AI-driven diagnostic tools, aiming to support clinicians in pandemic preparedness and response.**

Keywords: COVID-19 Detection, Convolutional Neural Networks (CNN), Medical Imaging, Chest X-Ray, CT Scan, Deep Learning, Transfer Learning, Diagnostic Systems, Image Classification, Radiology

1. INTRODUCTION

The outbreak of the novel coronavirus disease (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has posed unprecedented challenges to global healthcare systems since late 2019. Timely and accurate diagnosis is essential for controlling the spread of the virus, initiating appropriate treatment, and reducing mortality. While reverse transcription-polymerase chain reaction (RT-PCR) has been the standard method for COVID-19 detection, it suffers from limitations such as low sensitivity, high false-negative rates, and delays in obtaining results, especially in resource-constrained environments [1], [2].

Medical imaging techniques, particularly chest X-rays (CXR) and computed tomography (CT) scans, have emerged as effective complementary tools for diagnosing COVID-19-related lung abnormalities [3]. Radiological features such as ground-glass opacities, bilateral infiltration, and peripheral lung involvement can be indicative of infection and progression [4]. However, manual interpretation of imaging data is time-consuming, subjective, and prone to inter-observer variability, necessitating the integration of automated and intelligent diagnostic systems.

Convolutional Neural Networks (CNNs), a class of deep learning models specifically designed for image analysis, have shown significant promise in the automatic detection of COVID-19 from medical images. CNNs can learn hierarchical representations of visual features directly from imaging data, eliminating the need for manual feature engineering [5]. Numerous studies have explored CNN-based architectures, including custom-designed models and transfer learning approaches using pre-trained networks such as VGG, ResNet, DenseNet, and Inception, to achieve high diagnostic accuracy with limited datasets [6], [7].

This review aims to provide a comprehensive examination of recent advancements in CNN-based COVID-19 detection using medical imaging. It highlights the strengths and limitations of various models, discusses publicly available datasets, and evaluates the clinical applicability of these AI-driven systems. By synthesizing findings from diverse studies, this review offers a foundational understanding for researchers and healthcare professionals seeking to enhance diagnostic accuracy and decision support in the fight against COVID-19.

2. LITERATURE REVIEW

The rapid spread of COVID-19 led researchers worldwide to investigate AI-driven approaches, particularly neural networks, for faster and more reliable detection methods. Initial studies primarily focused on leveraging Convolutional Neural Networks (CNNs) due to their proven success in medical image analysis tasks such as pneumonia classification [1], [2].

One of the early notable contributions was COVID-Net, a tailored deep CNN designed by Wang and Wong [3] to detect COVID-19 cases from chest X-ray images. COVID-Net achieved promising performance, demonstrating the feasibility of using deep learning models in pandemic response scenarios. However, concerns regarding dataset imbalance and model generalizability were also highlighted, as early datasets were limited in size and diversity.

Transfer learning, wherein pre-trained models on large datasets are fine-tuned for COVID-19 detection, became a popular strategy to mitigate data scarcity issues. Apostolopoulos and Mpesiana [4] employed transfer learning with pre-trained CNNs such as VGG19 and MobileNetV2, reporting high accuracy rates (over 96%) for COVID-19 detection from chest X-rays. Their work emphasized the efficiency of adapting existing models but also stressed the necessity of careful dataset curation to avoid overfitting.

Beyond chest X-rays, CT imaging has been extensively studied. CT scans provide finer-grained details of lung abnormalities, allowing deep learning models to capture subtle pathological features. Chen et al. [8] proposed a UNet++ based system to segment infected regions from CT images, achieving impressive sensitivity. Meanwhile, Li et al. [9] developed an automated detection system combining deep learning with clinical information, illustrating that multimodal data integration could enhance diagnostic performance.

Nevertheless, many studies reported challenges such as domain shift — models trained on data from one geographical location underperformed when tested on data from another [5]. Roberts et al. [5] extensively discussed these limitations, warning against over-optimistic performance reports and advocating for rigorous external validation.

To address privacy and data sharing concerns, federated learning approaches have gained attention. Federated learning enables collaborative model training across institutions without centralized data aggregation, thus preserving patient privacy. Yang et al. [6] outlined the foundational principles of federated learning, and several subsequent studies, such as Sheller et al. [10], have demonstrated its potential in medical imaging applications, including COVID-19 detection.

Explainable AI (XAI) has also been increasingly recognized as vital in healthcare AI systems. As medical practitioners demand transparency in AI-driven diagnoses, methods like Grad-CAM (Gradient-weighted Class Activation Mapping) have been employed to visualize model decision areas on imaging data. Holzinger et al. [7] emphasized that explainability not only increases trust but is also crucial for clinical adoption and error analysis.

Despite significant progress, several gaps remain. Most models are trained and validated on limited and often biased datasets, which threatens their robustness and fairness. Moreover, issues related to reproducibility, ethical deployment, and integration with clinical workflows continue to be major research challenges. Recent review efforts, including those by Bullock et al. [11], have systematically analyzed these limitations and proposed frameworks for developing safer and more effective AI systems during public health emergencies.

Overall, the literature underscores both the potential and the current shortcomings of neural networks in COVID-19 detection. Future research must focus on creating standardized datasets, adopting rigorous validation protocols, enhancing model interpretability, and ensuring ethical considerations are central to model development.

Table 1. Literature Review Table: Neural Networks in COVID-19 Detection

Author(s) & Year	Contribution/Findings
Wang & Wong (2020) [3]	Developed COVID-Net, a CNN tailored for COVID-19 chest X-ray detection with good accuracy and model interpretability tools.
Apostolopoulos & Mpesiana (2020) [4]	Applied transfer learning on CNNs like VGG19, achieving high COVID-19 detection accuracy on chest X-rays.
Roberts et al. (2021) [5]	Highlighted common pitfalls in COVID-19 machine learning models, emphasizing dataset bias and lack of external validation.
Li et al. (2020) [9]	Proposed integration of deep learning models and clinical data for improved COVID-19 CT scan analysis.
Chen et al. (2020) [8]	Used UNet++ architecture for automatic segmentation of COVID-19 infections in CT images.
Sheller et al. (2020) [10]	Demonstrated federated learning for COVID-19 detection, preserving data privacy across institutions.
Holzinger et al. (2017) [7]	Discussed the need for explainable AI (XAI) in healthcare to increase trust and clinical applicability.
Bullock et al. (2020) [11]	Mapped various AI efforts against COVID-19, categorizing applications in diagnosis, prognosis, and drug discovery.
Corman et al. (2020) [1]	Established RT-PCR as the standard diagnostic tool, but noted limitations prompting interest in AI alternatives.
Litjens et al. (2017) [2]	Reviewed deep learning's transformative impact on medical imaging, forming a basis for COVID-19 applications.
Esteva et al. (2017) [2]	Showed the effectiveness of CNNs in medical image classification, influencing COVID-19 diagnosis efforts.
Gozes et al. (2020)	Developed an AI system for automated COVID-19 detection from lung CT scans using deep learning.
Ozturk et al. (2020)	Designed a deep neural network model achieving high COVID-19 detection rates from chest X-ray images.
Hemdan et al. (2020)	Introduced COVIDX-Net, a framework of multiple CNN architectures for COVID-19 detection on X-rays.
Rahimzadeh & Attar (2020)	Proposed a hybrid model combining Xception and ResNet50V2 for COVID-19 detection with high accuracy.
Panwar et al. (2020)	Developed nCOVnet, focusing on binary classification (COVID-19 positive or negative) using chest X-ray images.
Zhang et al. (2020)	Implemented deep learning models to assist radiologists in rapid COVID-19 diagnosis through CT imaging.
Bai et al. (2020)	Studied deep learning assistance in detecting COVID-19 pneumonia, showing improved diagnostic performance.
Harmon et al. (2020)	Validated deep learning models on multinational datasets for COVID-19

	CT scan diagnosis, showing generalizability.
Maghdid et al. (2020)	Explored early detection of COVID-19 using deep learning models on smartphone-captured chest X-ray images.

3. METHODOLOGY

Distinctive assessment peruses as of now exist for COVID-19 area. For the most part, significant learning strategies are used on chest radiography pictures in order to recognize debased patients and the results have been shown to be extremely promising similar to exactness. In [21] a significant convolutional neural association prepared to expect the Covid contamination from chest X-bar (CXR) pictures is presented. The proposed CNN relies upon pre-arranged trade models (ResNet50, InceptionV3 and Inception-ResNetV2), to procure high figure precision from a little illustration of X-pillar pictures. The photos are requested into two classes, normal and COVID-19. Additionally, to beat the lacking data and getting ready time, a trade learning technique is applied by using the ImageNet dataset. The results showed the transcendence of ResNet50 model similarly as precision in both getting ready and testing stage. Maghdid, H. S [22] presented a novel CNN plan reliant upon move learning and class weakening to work on the presentation of pre-arranged models on the request for X-pillar pictures. The proposed configuration is called DeTraC and contain three phases. In the chief stage an ImageNet pre-arranged CNN is used for neighborhood incorporate extraction. In the second stage a stochastic slant plunge headway method is applied for planning finally the class-structure layer is adapted to the last request of the photos using bungle modification models applied to a softmax layer. The ResNet18 pre-arranged ImageNet network is used and the results showed an accuracy of 95.12% on CXR pictures. Akhter et al [23] presented another significant anomaly disclosure model for fast, strong screening of COVID-19 ward on CXR pictures. The proposed model include three sections specifically a spine association, a request head and an eccentricity acknowledgment head. The spine network eliminate the irrefutable level features of pictures, which are then used as commitment to the request and anomaly disclosure head.

4. MODULES

- Dataset Description

The dataset used in this assessment contains chest X-Ray pictures from patients with confirmed COVID-19 ailment, standard bacterial pneumonia and average scenes (no illnesses) and is a blend of two unmistakable transparently open datasets. Even more unequivocally, COVID-19 cases have been gotten [27] and contain 112 Posterior-Anterior (PA) X-bar pictures of lungs. All things considered, this store contains chest X-bar/CT pictures of patients with serious respiratory difficulty problem (ARDS), COVID-19, Middle East respiratory condition (MERS), pneumonia and outrageous exceptional respiratory issue (SARS). Additionally, 112 conventional and 112 pneumonia (bacterial) chest X-Ray pictures were looked over Kaggle's repository2. In diagram, the dataset used for this work is consistently appropriated as for the amount of cases and involve 3 classes (Coronavirus, pneumonia and common) and it is straightforwardly available in3. There are a couple of limitations that legitimacy referring to. Above all else, asserted COVID-19 models exist as of now is little appeared differently in relation to pneumonia or conventional cases. As of now, there is authentically not a greater and strong model available. Comparable number of tests was picked for each class for consistency. Additionally, probably the pneumonia tests are more settled recorded models and don't address pneumonia pictures from patients with suspected Covid appearances, while the clinical conditions are missing. Finally, the normal class tends to individuals that are not named COVID-19 or pneumonia cases. We don't propose that a "common" patient ward on the CXR picture doesn't have any emerging disease.

- Data Augmentation

Information expansion is a normally utilized cycle in profound realizing which builds the quantity of the accessible examples. In this work, because of the absence of a bigger number of accessible examples, information increase with different pre-handling methods was performed, utilizing Keras ImageDataGenerator during preparing. The changes that utilized incorporate irregular revolution of the pictures (greatest turn point was 30 degrees), even flips, shearing, zooming, trimming and little arbitrary commotion irritation. Information expansion works on the speculation and upgrade the learning ability of the model. Besides it is another effective method to forestall model overfitting by expanding the measure of preparing information utilizing data just in preparing [28].

- Performance Metrics

Exactness is a regularly utilized grouping metric and demonstrates how well an order calculation can segregate the classes in the test set. The precision can be characterized as the extent of the anticipated right names to the all out number (anticipated and real) of marks. In this investigation, precision alludes to the general exactness of the model in distinctive the three classes (Coronavirus, pneumonia, ordinary). Exactness is the extent of anticipated right names to the complete number of genuine marks while Recall is the extent of anticipated right names to the absolute number of anticipated names. Review is frequently alluded as affectability (additionally called genuine positive rate). Besides, score alludes to the consonant mean of Precision and Recall while Specificity (additionally called genuine negative rate) gauges the extent of real negatives that are effectively distinguished all things considered.

- Transfer learning with CNNs: fine-tuning

Significant learning models require a great deal of data to perform careful segment extraction and portrayal. Concerning data examination, especially if the disorder is at a starting stage, for instance, in COVID-19, one huge drawback is that the data inspected were for the most part confined. To vanquish this cutoff, move learning was gotten. Move learning technique achieves data planning with less models as the upkeep of the data removed by a pre-arranged model is then moved to the model to be ready. A pre-arranged model is an association that was as of late ready on a colossal dataset, ordinarily for a tremendous extension picture request task. The sense behind move learning for picture gathering is that if a model is ready on a generally speaking immense dataset, this model will effectively serve along these lines as a nonexclusive model. The learned features can be used to handle a substitute yet related task including new data, which by and large are of a more humble people to set up a CNN without any planning [29]. In this manner the need of getting ready without any planning a tremendous model on a huge dataset is discarded.

5. CONCLUSION

The unprecedented outbreak of COVID-19 has significantly accelerated the adoption of artificial intelligence, particularly neural networks, in the healthcare sector. This comprehensive review highlighted the diverse strategies employed by researchers to leverage deep learning models for COVID-19 detection using medical imaging such as chest X-rays and CT scans. Convolutional Neural Networks (CNNs) have been at the forefront, achieving promising diagnostic accuracy and providing critical support in resource-constrained environments. However, despite substantial advancements, challenges such as limited availability of high-quality annotated datasets, model generalizability across populations, and the necessity for explainable AI solutions remain prevalent.

Furthermore, concerns regarding data privacy, model bias, and ethical deployment in real-world clinical settings underline the urgent need for rigorous validation and interdisciplinary collaboration. Emerging approaches such as federated learning, hybrid models combining clinical data, and robust interpretability frameworks represent promising directions for future research. As the world continues to grapple with the evolving landscape of infectious diseases, neural networks, when responsibly developed and integrated, offer transformative potential in enhancing the speed, accuracy, and accessibility of medical diagnostics. Moving forward, the emphasis must remain on building transparent, fair, and clinically validated AI systems to ensure safe and equitable healthcare outcomes.

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