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Completed Research

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Abstract

Covid-19 Diagnosis needs new Information Systems technologies as Deep learning methods, especially in medical image screening. We aim to review the applications of deep learning augmented systems in Covid-19 predictions with the help of a large literature collection from four major databases IEEE explore, ACM, Web of Science, and PubMed. We have identified three major research themes from the current literature, Image Classification, Image segmentation, and evaluation methods for DL models. Among the DL techniques, Transfer Learning is identified as the most popular method for different tasks on Chest X-rays and CT scans. Pre-trained models such as ResNet, VGG, DenseNet, and UNet are widely used in the covid-19 diagnosis. While these models are pre-trained on natural images, a Chest X-ray image pre-trained model CheXnet is gaining popularity in Covid-19 image tasks helping in improving accuracies of classifications.

Keywords

Covid-19, transfer learning, deep learning, information systems.

Introduction

Advancements in Information Systems (IS) have drastically improved the way individuals and organizations respond to emerging situations. Information technology is at the heart of innovation. It has created a for implementation of emerging technologies to solve complicated problems and deliver innovation across industries. It is surprising how far we have come from the early days of computers in the 1940s to the current world in terms of technology usage. While IS has played its part in transforming numerous areas such as Finance (Ameen and Ahmad 2011), Supply chain (Gunasekaran and Ngai 2004), business management (Gil Gómez et al. 2010), tourism (Mcadam 1999). Healthcare has lagged other industries in the adoption of technologies. This is due in part to the emphasis on safeguards to protect patient health and safety, data privacy, and a variety of stakeholder interests - until now with the advent of a global pandemic.

Healthcare is arguably the most important area that requires the current attention of digital technologies. Multiple influenza pandemics have been observed in the past hundred years that disrupted social and economic conditions worldwide (Bandayrel et al. 2013; Whitley and Monto 2006). A pandemic is defined as a sudden, rapidly spreading epidemic on a global scale (Guha 2020). Several efforts have been made around the globe to tackle the crisis in different ways (Bandayrel et al. 2013; Fauci 2006; Oxford 2005; Whitley and Monto 2006). Information systems played its part to respond to these crisis conditions. Some examples are tracking the pandemic by monitoring Social media (Lampos and Cristianini 2010), data collection systems, and IT infrastructures (Bandayrel et al. 2013). With the emergence of new IS technologies and Artificial Intelligence advancements, IS can respond and contribute to mitigating the recent COVID-19 pandemic situation in better ways.

COVID-19, also known as SARS-COV-2, is a disease caused by severe acute respiratory syndrome coronavirus2 ("WHO | World Health Organization" 2020), and belongs to a family of SARS and MERS(de Wit et al. 2016). It was first reported in Wuhan, China (Wu et al. 2020) and then spread across the world, leading to World Health Organization (WHO) declaring it as a pandemic. According to WHO, a pandemic is a serious threat of a disease that spreads throughout the world ("WHO | World Health Organization" 2020). Currently, there are over 113 million cumulative cases, 2.5 million confirmed fatalities, and 203 countries, areas, and territories affected around the world, as reported by WHO on February 28^{th}, 2021 ("WHO | World Health Organization" 2020). The Combined Americas and Europe emerged as the most affected continents with 79% of cumulative cases. The widespread nature of this disease requires immediate attention by researchers across the world to reduce its transmission. Studies suggest it is important to immediately isolate the patients showing symptoms to break the chain of transmission and help maintain a healthy population (Ai et al. 2020).

Chest CT images are currently proving to be major resources in detecting the Covid-19 cases, (Ai et al. 2020) suggested that Chest CT images are better in Covid-19 diagnosis due to their high sensitivity when compared to the nucleic acid test, RT- PCR, that is considered as a current popular method. However, RT-PCR suffers from sampling errors and low viral load leading to higher false negatives (Hryniewska et al. 2020). The Radiology Scientific Expert Panel(Kanne et al. 2020) also suggested the importance of the Chest CT images for their high sensitivity in detecting the Covid-19 cases. This provides the opportunity to study the applications of Artificial Intelligence (AI) and Deep Learning (DL) techniques in Chest CT images for Covid-19 identification.

Artificial Intelligence (AI), a term first defined at Dartmouth college in 1956 (Russell and Norvig 2002), is widely used in numerous automated tasks such as speech recognition, and image and video processing (Deng 2014). It became possible due to the extraordinary abilities of neural networks and Deep Learning techniques (Litjens et al. 2017; Shin et al. 2016; Yamashita et al. 2018) such as Transfer Learning(TL), a concept of DL that uses existing knowledge to leverage the neural network's performance and provide better outcomes (Morid et al. 2020).

AI has played a major role in public health and epidemiology in recent years (Rodríguez-González et al. 2019; Thiébaut and Thiessard 2018). After the Covid-19 outbreak, researchers suggested the use of Artificial Intelligence in the early detection of Covid-19 (Santosh 2020). Recently, TL techniques have become popular AI methods in Medical Image Classification tasks, especially after the release of a large number of publicly available chest x-ray images by NIH (Wang et al. 2017, p. 8). Studies such as (Rajpurkar et al. 2017) used chest X-ray images to classify pneumonia and normal chest x-ray images. The authors of (Ausawalaithong et al. 2018) used deep learning for automatic lung cancer predictions in chest x-ray images. The success of DL methods has led to accelerated research in Covid-19 identification in chest CT images (Bullock et al. 2020). Several studies focusing on the identification and classification of Covid-19 from chest images are rapidly being published (Bullock et al. 2020). Currently, there are a few literature review papers available on covid-19. The existing literature reviews focus on topics such as (D. Dong et al. 2020) presented about the role of imaging in the detection and management of Covid-19. Another study (Santosh 2020), presents the need for focusing on active learning and cross-population models on multitudinal data. Yet another study (F. Shi et al. 2020) reviews the AI techniques in imaging data acquisition, segmentation, and diagnosis for COVID-19.

However, with new COVID-19 response articles being published at an enormous rate, we intend to perform text mining to analyze the literature available on COVID-19. This helps to learn about the themes of the current research in the COVID-19 AI community. Additionally, we aim to utilize VOS-viewer to conduct bibliometric analysis to gain further insights into the Covid-19 literature. VOS-viewer software facilitates analyzing large a dataset of publications. It enables us to generate a network diagram of key topics and learn the relationship strength among the topics using "occurrences" and 'total link strength" factors. For our study, we use four web-based libraries to create a rich dataset of publications related to Covid-19.

To this end, in this research study, we aim to answer the following research questions: 1. What machine learning modes are utilized in response to the Covid-19 pandemic? 2. What is the role of medical imaging and how medical imaging tasks are helping automate responses to the crisis? 3. What are the widely employed pre-trained models and to what extent they are being adopted in the current pandemic response? Combining the investigations along with the above directions together, we attempt to attain up-to-date knowledge on the extent to which DL-augmented systems are applied to optimize the collective effort in fighting the ongoing Covid-19 crisis.

Methodology

Data Collection

Firstly, we defined our research questions to guide our meta-analysis on research publications related to DL and Covid-19. Next, we developed the search query to explore research articles related to our study. We included various keywords related to imaging modalities used in the medical field, for instance, “computed tomography”, “X-Ray”, “MRI”, “CT Scans”, “ultrasound”, “therapy”, and “radiology”. “Deep Learning”, “Transfer Learning”, and “Reinforcement Learning” are some of the other keywords included relating to the technologies used in the medical field. We targeted PubMed, IEEE Xplore, Web of Science, and ACM databases for the search of articles. We constrained the search to articles written in English and during the years 2012 to 2020. The year 2012 is important to the DL field as it ascended due to the breakthrough in computer vision (Krizhevsky et al. 2012). A total of 8704 unique articles were gathered. From this rich set, we narrowed our dataset to focus on Covid-19 only research articles using a custom python function. After this step, we have a total of 250 articles in our dataset. This process enabled us to gather relevant articles from the vast literature and thus facilitate answering our research questions.

Data Analysis

We analyzed the gathered articles using various text mining techniques. We followed the text mining process described in (Zeng et al.2021)Firstly, we applied pre-processing methods to the abstract text of gathered articles. In this step, we converted the entire text to lower case, removed commonly used words, stop words, punctuation marks, and any numbers. In the next step, we processed the documents to create tokens from abstract data. The process of splitting phrases/sentences/paragraphs into smaller units such as the word is called tokenization and the small units are called tokens. Tokenization facilitates understanding the meaning of the text by analyzing the tokens. Next, we performed various text mining techniques using NLTK to gain insights from our collection.

We performed exploratory data analysis to understand the main data characteristics of the sub dataset related to Covid-19. In this process, we looked at the most frequent words, word cloud, and n-grams.

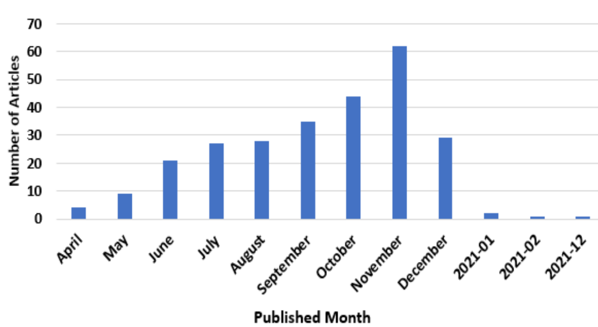


Figure 1.a. Distribution of articles by month

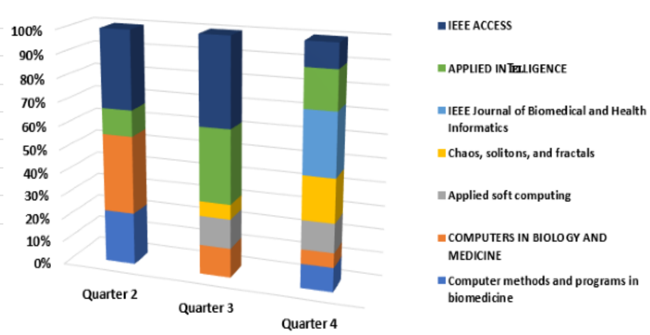


Figure 1.b. Distribution of Top 7 Publication Titles

The distribution of articles per month depicts that most articles in our study were published in November (62). From figure 1 it is evident that there has been a gradual increase in the number of publications related to Covid-19. As expected, during the early months i.e., January, February, and March there were no articles published. Our study also captured a few of the early prints for 2021 February and December.

Among all the articles of our study, a majority of the articles were published in IEEE ACCESS (14) and APPLIED INTELLIGENCE (14) followed by IEEE Journal of Biomedical and Health Informatics (13). The next four journals that published most of the articles were, in order, Chaos, Solitons, and Fractals (10), Applied soft computing (8), Computer in Biology and Medicine (8), and Computer Methods and Programs in Biomedicine (7). In total, the journals listed in Figure 1.b. account for 74 articles or 30% of all the papers related to Covid-19 from our study.

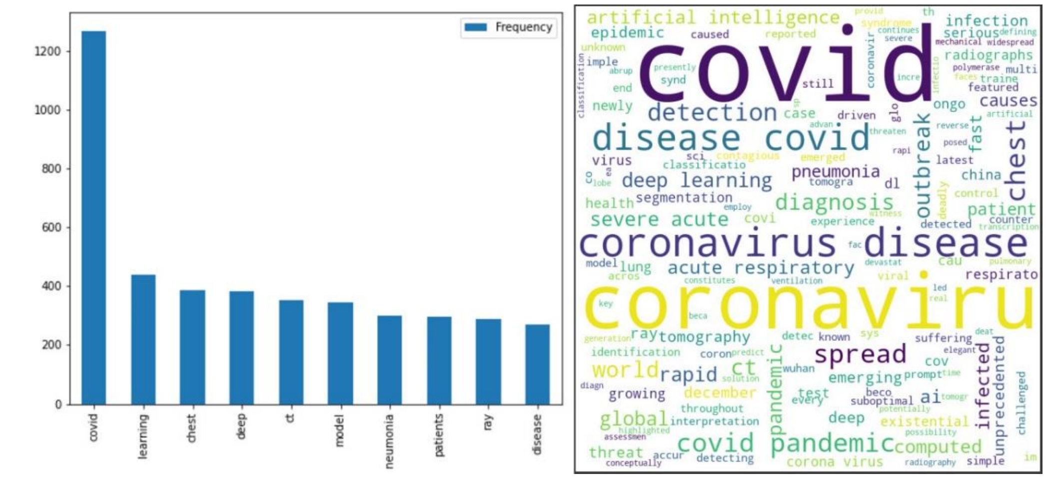
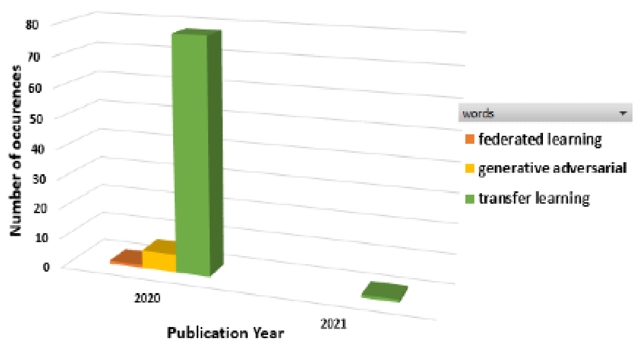


Figure 2. Top 10 most frequent words and Word Cloud

The ten most frequently used words are shown in Figure 2. As expected, “covid” is at the top of the list with a count greater than 1200. The huge gap between the topmost word and the second most frequent word is apparent in the figure. The next most frequent word is “learning” pertinent to Deep Learning/Machine learning with a 400 plus count. As we know Covid-19 mainly impacts the lungs and chest x-rays are used for diagnosis we see the next most frequent word is “chest”. The figure also depicts that the word “deep” has the same count as “chest”. CT scans of the chest are also used in Covid-19 diagnosis, “ct” and “model” also have almost the same word count. Followed by “pneumonia”, “patients” and “ray”, all three have about the same count i.e., a little less than 400. The word “disease” is the tenth most frequent word referred to in the corpus.

Word clouds are quick and straightforward, they provide a glance at the overall data. The size of each term represents its frequency and/or importance. Not surprisingly, in figure 3, the most prominent words in our corpus are “covid” and “coronavirus disease”. The figure captures that Covid-19 is prevalent across the world and is through the words such as “global”, “pandemic”, “world”, and “outbreak”. The figure also depicts that this the current situation and the number of infected is increasing at a higher rate through “ongoing” and “rapid”, “growing” and “fast” respectively. The other prominent words such as “chest”, “ct” and “x-ray” are related to the imaging modality used in the diagnosis of Covid-19. The figure also depicts that “artificial intelligence” and “deep learning” are used in the Covid-19 pandemic. “Segmentation” and “classification” are the two medical image processing tasks performed in the Covid-19 diagnosis.

In the next step, we performed n-gram analysis to learn about the usage of specific learning modes i.e., transfer learning, reinforcement learning, federated learning, and Generative Adversarial Networks in Covid-19 diagnosis. This analysis answers research question 1. What machine learning modes are utilized in response to the Covid-19 pandemic?



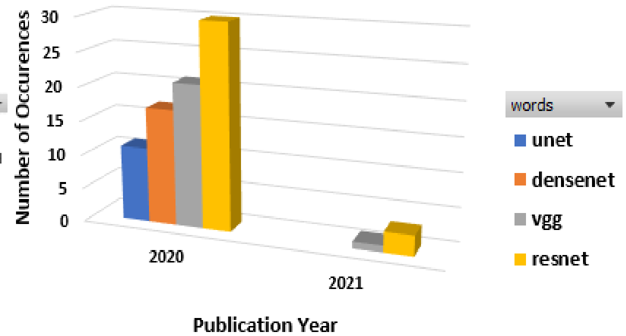


Figure 3.a. Learning modes used in Covid-19 studies

Figure 3.b. DL Models used in Covid-19 studies

Figure 3.a. above represents the learning modes utilized for the pandemic situation. Our dataset contains early access papers hence we also have the year 2021. It is evident from figure 4 that Transfer learning is the dominant learning mode used. Apart from Transfer Learning, we have Generative adversarial Networks and Federated Learning. Transfer Learning is utilized in 78 papers in 2020 and 2021 one paper is referring to TL. While Generative adversarial Networks are referred to in a total of six papers in 2020, Federated Learning is used in only one paper in 2020.

Figure 3.b. depicts the common DL architectures used for Covid-19 diagnosis. Variants of VGG(Simonyan and Zisserman 2015), U-Net(Ronneberger et al. 2015), DenseNet(Huang et al. 2017), and ResNet(He et al. 2015) have been applied in an attempt to automate the classification of Covid-19 images. Among the models mentioned above variants of ResNet appear to be mostly employed, followed by VGG. This answers research question 3. What are the widely employed pre-trained models and to what extent they are being adopted in current pandemic response?

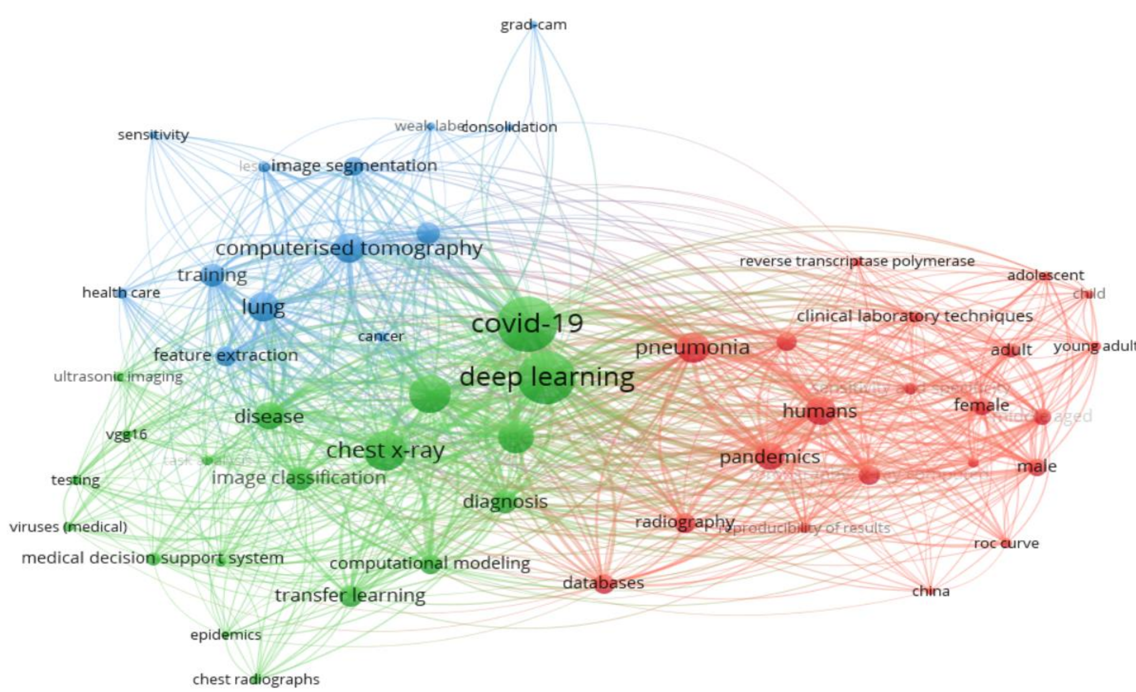


Figure 4. Network diagram using VosViewer

The figure 4 depicts the network analysis related to Covid-19 research studies from our dataset using VosViewer. The size of the colored circle is proportional to the number of occurrences of the corresponding word. Additionally, the circles are connected via links. VosViewer tool measures the relationship strength among the topics using the attribute "total link strength". From the figure, we see three main topics related to Covid-19 research studies from our dataset. The cluster in green color mainly involves studies on image classification, chest x-ray images, and transfer learning. Besides image classification, deep learning and Covid-19 topics are also present in the green cluster. The blue cluster focuses on studies related to image segmentation, CT images, and feature extraction techniques. Whereas the red cluster deals with human aspects and diseases apart from various evaluation methods of models such as sensitivity and specificity. As the Covid-19 cluster is connected to most of the other clusters it has the highest link strength of 1126. It is connected to deep learning, image classification, chest x-ray, transfer learning, CNNs, and various other relatively smaller clusters. This provides the answer to the second research question 2. What is the role of medical imaging and how medical imaging tasks are helping automate response to the crisis? Medical imaging techniques such as CT scans and Xrays can be used by DL techniques to extract crucial information that will help in early screening of Covid-19. Medical imaging tasks classification and segmentation are mainly used in Covid-19 diagnosis. This automation process will relieve the radiologists from strenuous manual work.

Discussion

From our analysis of 250 research publications on the Covid-19 response, it is evident that AI related IS solutions play a crucial role in the mitigation of the ongoing pandemic. As the number of infected persons is increasing across many countries it is paramount to automate Covid-19 diagnosis. Through this meta-analysis study, we find that the total number of publications related to AI and Covid-19 is accelerating consistently throughout the last year and we believe the trend will continue in the near future as the Covid-19 pandemic is ongoing. DL/ML models utilized to diagnose Covid-19 require large datasets to perform well. Covid-19 image datasets such as were released in late Covid-19 Radiography Database ("COVID-19 Radiography Database" 2020), covid-chest x-ray dataset, and COVID-CT-Dataset March 2020. Researchers were able to make use of these free publicly available datasets to conduct their experiments highlighting importance of these image datasets in Covid-19 response. Hence, the research articles started being published in the second quarter of the year 2020. The types of Journals/conferences where the majority of the articles from our study got published have a high impact factor (Ex. IEEE Access impact factor – 3.745) suggesting greater importance and quality of the papers. Also, the articles are published in Journals that focus on both medical and artificial intelligence.

Furthermore, through our analysis, we identified that Transfer Learning and GANs are the most dominant AI techniques used in response to the Covid-19 pandemic. Interestingly, Federated Learning, a privacy-focused learning mechanism is also employed in response to the pandemic. The specific pre-trained models mostly employed are variants of VGG, U-Net, DenseNet, and ResNet. Additionally, we see three broad themes in the collected literature i.e., image segmentation, image classification, and pandemics. The key finding answering our research questions are discussed below in detail.

RQ1: "What machine learning modes are utilized in response to the Covid-19 pandemic?"

Transfer Learning techniques are applied to overcome the critical challenge of the lack of publicly available Covid-19 datasets. As Covid-19 and pneumonia lung disease have similarities, authors have utilized existing datasets such as Chest X-ray14 and CheXpert to pre-train models. The generally-applicable parameters of the pre-trained model are leveraged to train the model with a limited Covid-19 dataset. GANs are also employed to overcome the class imbalance problem. The publicly available datasets have comparatively fewer Covid-19 positive images leading to biased learning of the model. GAN models are used to generate synthetic images. Through this, the number of Covid-19 positive images can be generated to create a balanced dataset. Although only one article from our dataset has utilized FL, the proposed architecture aims to provide data privacy along with improved model generalization. Lack of model generalization and data privacy concerns are among the hurdles that prevent the application of these models in clinical practices. It is evident that incorporating FL with DL techniques could help to overcome these challenges. Hence, further research combining these two learning modes should be conducted.

RQ2: "What is the role of medical imaging and how medical imaging tasks are helping automate response to the crisis?"

Image segmentation is used for quantitative analysis of images and is defined as the process of dividing images into multiple sections with similar properties (Szeliski 2010). Segmentation of medical images is performed to learn the anatomical structure and locate the region of interest (ROI) such as lesions and tumors. On the other hand, image classification is the process of categorizing images into different classes. Classification of images is either a binary class or multi-class classification. In the context of Covid-19, authors utilized the segmentation process on chest CT scans to detect and segment lung abnormalities and lesions and quantify the affected regions. Whereas, classification is mainly used on chest x-ray images. The authors have performed both binary and multi-class classification to detect Covid-19 from other lung diseases such as viral and bacterial pneumonia. The image classification process is applied comparatively at a higher rate than image segmentation which implies that classification suits for Covid-19 diagnosis.

RQ3: What are the widely employed pre-trained models and to what extent they are being adopted in current pandemic response?

Among the various pre-defined CNN architectures, the widely utilized ones for Covid-19 diagnosis are the variants of VGG, U-Net, DenseNet, and ResNet. These model architectures have been employed either individually or are compared against each other. The strong connection of VGG-16 with image classification and U-Net with image segmentation implies the preference of employing VGG-16 for classification tasks and U-Net image segmentation tasks. A few authors (Gianchandani et al. 2020; Misra et al. n.d., p. 19; Shorfuzzaman and Masud 2020; Zhou et al. 2020) have taken a step further and developed ensemble models. These ensemble models are based on multiple independent classifier models using a majority voting ensemble. The majority voting ensemble is a technique that is used to improve model performance by combining the predictions from multiple models. For classification tasks, the predictions of each label are summed and the label with a majority vote is predicted. The individual classifiers are built by fine-tuning (a transfer learning technique) the weights of top layers of standard models such as VGG16, DenseNet, ResNet, AlexNet, and GoogleNet. Another important approach observed is that a couple of authors (Ahishali et al. 2020; Haghanifar et al. 2020; Zhang et al. 2020) utilized a standard model – CheXNet(Rajpurkar et al. 2017) to classify the images. CheXNet is based on Densenet architecture and trained on the Chest X-ray 14 dataset(Wang et al. 2017, p. 8). The weights of CheXNet are initialized from DenseNet which is pre-trained on the ImageNet(Deng et al. 2009) dataset. Furthermore, fine-tuning of top layers and Fully Connected layer of CheXNet model is carried out using Covid-19 dataset, utilizing CheXNet for fine-tuning helps in reducing the domain differences between source and target tasks. Using CheXNet, which is pre-trained on both Imagenet and Chest X-ray data proved to increase accuracy and makes the selection of pre-trained models from the numerous available models easier for COVID-19 diagnosis. Similarly, this trend to use off-the-shelf models based on medical image data (Chest X-rays in the case of CheXnet) can help for greater adoption of deep learning techniques in the medical field. For instance, off-the-shelf models may be available for specific tasks for instance models specific to brain tumor classification or breast cancer classification.

Conclusion

In this study, we conducted a meta-analysis of the literature on DL augmented systems and their application to mitigate the Covid-19 pandemic by investigating the research themes with focus on medical imaging. As Covid-19 continues to create negative impact on human lives, it is crucial to leverage latest technologies to curb the Covid-19 virus. The results from this study illustrate the key role of IS research in implementing DL technologies to help healthcare organizations battle the pandemic situation. Specifically, our findings indicate that the transfer learning is the most popular DL technique utilized for the covid-19 imaging tasks such as image segmentation and image classification, adversarial learning and federated learning are among the emerging learning modes. Numerous pre-trained models such as Res-Net, DenseNet, VGG and U-net are playing a key role in the DL imaging tasks utilizing Chest CT scans and X-ray images. While these models are pre-trained on natural images, medical image pre-trained models like CheXNet are attracting the new researchers as these models are further improving the accuracies by reducing the domain differences between source and target tasks. Success of medical image pre-trained CNNs provides a great opportunity not only for Covid-19 diagnosis but also for health care in general, this could greatly transform the way DL models are implemented in future.

Researchers have utilized advanced techniques such as transfer learning, adversarial learning, and domain-specific pre-trained models to augment DL-based systems to achieve higher efficiency and performance in fighting the Covid-19 crisis. Based on the literature we reviewed, the IS researchers, as part of the interdisciplinary community, have been substantially contributing to applying DL (AI in general) augmented systems in assisting predictions and medical decision-making. Future research opportunities for IS researchers may include adoptions of AI-augmented systems, explainability, data privacy and management, and automated deployment and serving of the systems. Our study includes the following limitations, we focused only on literature related to medical images, multi-modal data such as text and signal processing including literature associated to these can be included to extend this study. Second, the articles gathered are limited to peer-reviewed databases, pre-print databases such as Arxiv and medRxiv that contain the latest developments can be analyzed in future research work. We aim to extend this study by building a hybrid system based on Transfer Learning and Adversarial learning for Chest X-ray images, contributing to the objective of achieving seamless medical image classification in various anatomical areas.

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