A Systematic Review on the Use of AI and ML for Fighting the COVID-19 Pandemic

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Abstract—**Artificial intelligence (AI) and machine learning (ML) have caused a paradigm shift in healthcare that can be used for decision support and forecasting by exploring medical data. Recent studies have shown that AI and ML can be used to fight COVID-19. The objective of this article is to summarize the recent AI- and ML-based studies that have addressed the pandemic. From an initial set of 634 articles, a total of 49 articles were finally selected through an inclusion-exclusion process. In this article, we have explored the objectives of the existing studies (i.e., the role of AI/ML in fighting the COVID-19 pandemic); the context of the studies (i.e., whether it was focused on a specific country-context or with a global perspective; the type and volume of the dataset; and the methodology, algorithms, and techniques adopted in the prediction or diagnosis processes). We have mapped the algorithms and techniques with the data type by highlighting their prediction/classification accuracy. From our analysis, we categorized the objectives of the studies into four groups: disease detection, epidemic forecasting, sustainable development, and disease diagnosis. We observed that most of these studies used deep learning algorithms on image-data, more specifically on chest X-rays and CT scans. We have identified six future research opportunities that we have summarized in this paper.**

Impact Statement: **Artificial intelligence (AI) and machine learning(ML) methods have been widely used to assist in the fight against COVID-19 pandemic. A very few in-depth literature reviews have been conducted to synthesize the knowledge and identify future research agenda including a previously published review on data science for COVID-19 in this article. In this article, we synthesized reviewed recent literature that focuses on the usages and applications of AI and ML to fight against COVID-19. We have identified seven future research directions that would guide researchers to conduct future research. The most significant of these are: develop new treatment options, explore the contextual effect and variation in research outcomes, support the health care workforce, and explore the effect and variation in research outcomes based on different types of data.**

Index Terms—**Artificial intelligence, COVID-19, coronavirus, deep learning, epidemic, literature review, machine learning, pandemic.**

I. Introduction

THE NOVEL and contagious viral pneumonia, COVID-19 (Coronavirus disease-2019), affected more than 42 million people and caused the death of more than 1.2 million people worldwide as of October 2020 [1]. WHO declared it a global pandemic and suggested that early detection, isolation, and prompt treatment could be useful to slow down the COVID-19 outbreak [2]. Therefore, various bodies have committed themselves to conducting research focusing on COVID-19.

With new discoveries being announced at an extraordinary rate, artificial intelligence (AI) has re-emerged into scientific consciousness. AI is a branch of computer science that can be used to build intelligent systems and is often instantiated as a software program [3]. The recent application in diagnosing diseases has broadened the frontier of AI. Medicine and healthcare systems are among the most promising application areas, which can be traced back to as early as the mid-twentieth century [4]. Researchers have proposed and successfully developed several decision support systems related to health and disease diagnosis [5]. The rule-based AI system gained success in the late 1970s [6] and has been useful in detecting disease [7], interpreting ECG images [8], choosing appropriate treatment, and generating hypotheses for physicians [9]. Unlike this first-generation knowledge-based AI system, which relies upon the prior medical knowledge of experts and the formulation-based rules, modern AI leverages machine learning algorithms to find patterns and associations in data [10]–[12]. The recent renaissance in AI can be attributed to the successful application of deep learning to a great extent by training an artificial neural network with large labelled datasets. A modern deep learning network usually contains hundreds of hidden layers [13]. The recent resurgence of AI has fueled the question of whether AI-doctors will soon replace human physicians shortly. While this remains to be seen, researchers believe that AI-driven intelligent systems can significantly help human physicians in making better and quicker decisions, and even sometimes remove the necessity of human decisions (e.g. radiology) [14]. The increasing data in

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healthcare resulting from the increased use of digital technology and the advancement of big data analytics can be attributed to the recent success of AI in healthcare [14]. The ubiquitous usage of mobile devices has made it easier to collect and achieve these data through mobile applications [15]. Although, AI research in healthcare is emerging, most of the research is focused on three diseases: cancer, neurology and cardiology. Guided by evidence, a strong AI can reveal the insights into medical data, which can eventually be used for decision support and forecasting [16]–[18].

As AI has proven useful in healthcare, researchers suggest that it may also be helpful in fighting against COVID-19. From forecasting of the pandemic to designing anti-viral-replication molecules, AI has caused a paradigm shift in health care. Recent researches on COVID-19 using AI suggest that it can be helpful in detecting COVID-19 infection and infected populations, predicting the next outbreak, finding the attack pattern and even finding a cure [19], [20], [21]. Some recent researches have shown the implications of AI [22] like biological data mining and machine learning(ML) algorithms [23] in detection, diagnosis, classification of COVID-19, and vaccine development [24]. Authors in [23] assessed these techniques on the eight selected studies focusing to the reliability and acceptability of. In [22], the authors evaluated and bench marked the AI techniques used in the image data and presented a set of future guidelines for the evaluation metrics. In contrast, our research explores the works on a broader spectrum including but not limited to the application of AI in detection, diagnosis, epidemic forecasting, and performance evaluation. We also provide guidelines for the future researchers in terms of possible application of AI and machine learning in fighting any other pandemic like COVID-19. Taken together, our review explores the existing AI-based research that has been conducted to fight the COVID-19 pandemic.

The organization of the remaining sections is as follows. The methodology to conduct this review study is discussed in section 2. The review data analysis and findings are discussed in section 3. Section 4 presents the main findings and the potential scope of future research to fight COVID-19, and the concluding remarks, limitations, and suggestions for future research are presented in section 5.

II. Methodology

In this research, a systematic literature review procedure [25] was adopted.

A. Search Strategy

For selecting the primary articles, the major databases such as IEEE Xplore, Springer Link, ACM digital library, Science Direct, and Google Scholar were searched for related articles. The articles were searched using several keywords related to 'COVID-19' (e.g. 'CoV2' or 'Coronavirus' or 'COVID-19') and keywords related to the machine learning, artificial intelligence and deep learning, for example, ('Machine learning' and 'CoV2' or 'Coronavirus' or 'COVID-19'), ('Artificial intelligence' and 'CoV2' or 'coronavirus' or 'COVID-19'), ('Deep learning' and 'CoV2' OR 'coronavirus' or 'COVID-19'), ('Machine learning' AND 'influenza' and 'CoV2' or 'Coronavirus' or 'COVID-19'), ('Artificial Intelligence' AND 'influenza' and 'CoV2' or 'coronavirus' or 'COVID-19'), ('Artificial intelligence' AND 'lockdown' and 'pandemic' and 'CoV2' or 'coronavirus' or 'COVID-19'), ('Machine learning' and 'lockdown' and 'pandemic' and 'CoV2' or 'coronavirus' or 'COVID-19'), and ('Prediction' AND 'outbreak prediction' and 'ML' and 'AI' and 'CoV2' or 'coronavirus' or 'COVID-19').

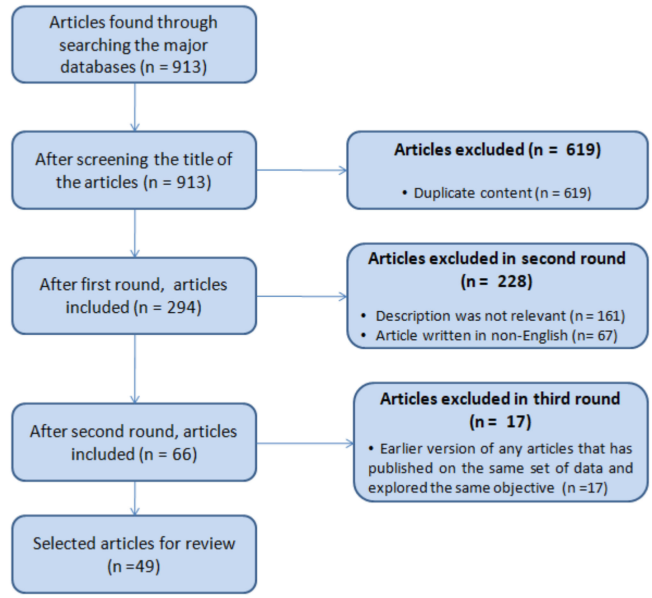

Fig. 1. Article inclusion and exclusion process flowchart.

B. Inclusion and Exclusion Criteria

The criteria for selecting an article were as follows: (a) The article is written in English, and (b) the article adopts, develops, or proposes AI and ML techniques, algorithms, systems, methods, or applications to fight the COVID-19 pandemic. In addition, we used the following exclusion criteria: (a) duplicate articles that are found through several scholarly databases; (b) articles that are not focused on our research objectives; (c) articles that are not written in English; and (d) earlier versions of any article that has been published on the same set of data exploring the same objective.

C. Study Selection

The search results comprised 913 articles from the stated databases. The Prisma flowchart in Fig. 1 shows the article selection process in different phases following the exclusion-inclusion criteria. From 913 articles, the study selection process was initiated by removing duplicated articles, and a total of 619 were excluded during the first round of screening. Next, articles written in English were screened based on their abstract, and in some cases the introduction, to assess their compatibility with the inclusion criteria. At the end of the second round of the selection process, a total of 66 articles were included. At round three, 17 articles were excluded since more recent versions of these articles had been published on the same set of data and explored the same objective. After applying the stated inclusion-exclusion process in three stages, a total of 49 articles were included in the review. The final set of articles includes original research, review articles, and short articles including perspective, commentary, and letters to the editor.

D. Data Extraction

Data extraction was conducted to explore different AI and ML techniques, algorithms, and systems and their implications for fighting the COVID-19 pandemic. Thus, the selected articles were read meticulously to collect and extract research data and construct the review article. The entire research process was supervised and monitored by two senior researchers with expertise in AI, ML, and health informatics to ensure the reliability and quality of this review article. For each selected article, this study extracted data primarily related to the article type, publication time, research objectives, study context, study outcomes/findings, methodology/algorithm/techniques used, dataset used, and study subject. Finally, the extracted data were synthesized and analyzed to summarize the existing research and identify the potential scopes for future research.

III. Data Analysis and Findings

A. Type of Publications

Out of 49 articles, 33 (67%) were published as original research. Of the remaining 16, 10 were review articles, two were editorial, and four were published as research perspectives (short conceptual articles). Thirty-five (73%) articles were published in academic journals, while 14 (27%) articles were archived as pre-print. Among the pre-prints, 10 (71%) were original research. All the selected articles were published or archived in online databases between January and August 2020.

B. Research Purposes and Objectives

We synthesized the existing research in terms of purposes and aims to explore the contribution of AI in addressing the COVID-19 pandemic. A summary of the synthesized data is presented in Table I to show the research scopes and purposes of the original research. Most of the articles (n = 19, 39%) were published focusing on detecting COVID-19 infected patients using different AI-based algorithms that include, for example, the convolutional neural network (CNN) model, support vector machine (SVM), generative adversarial network (GAN), and transfer learning. Chest X-ray images, CT images, mobile sensor data, and COVID-19 symptoms were used to predict/detect the COVID-19 patients. Studies focusing on predicting or detecting diseases primarily aimed to identify, screen, and detect COVID-19 patients and also to predict, differentiate, or classify the patients into categories of infection, no infection, and other viral or bacterial infections. For example, Wang *et al.* [26]] proposed a CNN-based prediction system named COVID-Net that identifies COVID-19 infected and non-infected patients using chest X-ray images. The proposed model was pre-trained on the ImageNet (open source) dataset and then trained on the COVIDx (author-created) dataset that included 13 800 chest X-ray images of 13, 725 people. The dataset includes 183 images from 121 COVID-19 positive patients, 8066 images from healthy patients, and 5538 images from non-COVID-19 patients.

A total of nine (18%) articles focused on diagnosing COVID-19 patients through AI (Table I). Articles that focused on identifying COVID-19 patients are classified into the 'diseases diagnosis'. In these articles, AI was used to diagnose the identified COVID-19 patients to classify patient categories (severe, mild) and tracking their progress [28], distinguish COVID-19 from pneumonia [42], efficiently diagnose COVID-19 using X-ray images [43], predict survival and death for severe COVID-19 patients [44], identify patients who would develop more severe illness [46], estimate uncertainty to improve the diagnostic performance [47], predict the risk of COVID-19 patients [48], and to repurpose commercially available drugs to disrupt viral proteins of SARS-Cov-2 [54].

Three (6%) articles aimed to forecast the COVID-19 epidemic to estimate the progress or growth of the epidemic in terms of its size, lengths, peaks, and ending time as well as predict the development trend of the epidemic in a specific country or geographical region [19], [50], [55]. We found only one study [52] that analyzed confirmed cases of COVID-19 through a binary classification using regression analysis. It explores the correlation among confirmed cases of COVID-19 in four countries (China, Italy, South Korea and Japan) and environmental factors (low, high and average temperature, humidity and wind flow). Another article [32] compared the prediction performance of the proposed algorithm with the existing VGG-16, GoogleNet, and ResNet50 methods using two different subsets of data, while in [53], an AI-based model was developed based on the existing studies regarding AI in ICU and respiratory diseases to improve COVID ICU patient management.

The remaining (around 33%) articles include review articles, editorials, perceptions, commentary, and short communication. A summary of the synthesized data is presented in Table II. A total of ten review studies were included. Each study has a different perspective and aim related to fight with the COVID-19 pandemic. For example, Naude [56] highlighted the contributions and constraints of AI, while Bullock *et al.* [57] identified a roadmap of AI applications to combat the virus. Another review analyzed the AI-based techniques used in the CT and X-ray based medical imaging [25]. One of the two editorials highlighted how AI-based solutions could assist to design anti-viral replication molecules, but with the supervision of humans [55]. In another editorial, a workflow was presented to highlight the processes and applications of AI to fight the pandemic [58]. Different perspectives are highlighted in perspective articles. First, the perspective articles demonstrated the needs of AI and the methods of data sharing (via smart city networks) for better monitoring and management of urban health [59]. Second, studies have discussed the importance of active learning-based AI tools for coronavirus outbreaks [60]. Third, studies have suggested how AI and Blockchain can be used to help the community during the COVID-19 pandemic with equipment and

TABLE I
KEY PURPOSES OF THE REVIEWED STUDIES

Purposes	Brief Description	Reference	Frequency
Diseases detection	Identify the infected individual more quickly	[21]	19
	Screen coronavirus diseases using deep learning	[27]	
	Identify the coronavirus patients	[28]	
	Develop a CNN-based algorithm to detect COVID-19 from CT images	[20]	
	Detect COVID-19 with the help of AI and smartphone sensors	[29]	
	Use an anomaly model based on a deep learning network to make the screening process faster for COVID-19 detection from X-ray images	[26]	
	Detect COVID-19 from X-ray images using transfer learning with CNN	[30]	
	Detect COVID-19 from X-ray images using a deep CNN model	[31]	
	Propose an algorithm to detect COVID-19 from CT images using a deep CNN model and SVM classifier	[32]	
	Develop a deep learning model CoroNet using the Xception CNN to detect COVID-19 from X-ray images	[33]	
	Build a framework that uses smartphone sensors to detect COVID-19	[29]	
	Classify patients into non-COVID 19 infection, COVID-19 infection, and no infection from X-ray images using a deep CNN model	[26]	
	Compare the performance of seven DL models to find the best model for COVID-19 detection	[34]	
	Develop and evaluate the performance of an AI model to detect COVID-19 and also evaluate the performance of radiologists to detect the disease by using and without AI support	[35]	
	Detect the COVID-19 by identifying the characteristics from chest X-ray using a deep learning model(CAD4COVID-XRay)	[36]	
	Detect COVID-19 from X-ray images using generative adversarial network (GAN) and deep learning transfer	[37]	
	Develop and evaluate and AI-based system for detecting COVID-19 from a globally diverse and multi-institution dataset	[38]	
	Develop several AI models to identify COVID-19 positive patients using blood counts without knowledge of symptoms or history of the individuals	[39]	
	Detect COVID-19 with faster R-CNN using X-ray images for real-time assessment	[40]	
Diseases diagnosis	Diagnose the identified patients to classify (in to patients' categories) and tracking the progress COVID-19 patients	[41]	9
	Distinguish COVID-19 from pneumonia using deep learning	[42]	
	Efficiently diagnose COVID-19 using X-ray images through deep CNN models	[43]	
	Develop a tool to predict survival and death for severe COVID-19 patients	[44]	
	Diagnosis COVID-19 positive case faster using both non-image and image clinical data	[45]	
	Develop a system to identify patients who would develop more severe illness among the patients with mild cases of COVID-19	[46]	
	Develop a system to improve the diagnostic performance from posterior-anterior (PA) X-ray images of lungs with COVID-19 cases	[47]	
	Analyse and predicting the risk of COVID-19 patients based on ML models using patient's baseline clinical parameters	[48]	
	Develop a deep learning-based model to repurpose commercially available drugs to disrupt viral proteins of SARS-Cov-2	[49]	
Epidemic forecasting	Forecast of the COVID-19 to estimate size, lengths and ending time of COVID-19 across China	[19]	3
	Predict the trend of the infection for the next 80 days using deep learning as well as the progress of the epidemic (epidemic sizes and peaks)	[50]	
	Predict the growth of the COVID-19 pandemic using mathematical modeling, ML and cloud computing	[51]	
Sustainable development	Analyze the correlation among environmental factors and confirmed cases of COVID-19	[52]	1
Performance comparison	Compare the prediction performance of the proposed algorithms with the existing methods	[32]	4
	Compare seven different DL models to find out the best model for disease detection	[34]	
	Compare the performance of radiologists in distinguishing COVID-19 from other pneumonia with and without AI assistance	[35]	
	Compare the performance of a DL model with six other radiologists	[36]	
Patient management	Improve management of COVID-19 ICU patients	[53]	1

TABLE II
SCOPES OF OTHER TYPES OF RESEARCH

Purposes	Brief Description	Reference	Frequency
Review Literature	Review the related work to highlight the contributions and constraints of AI in fighting the COVID-19 pandemic	[56]	10
	Review related work to identify a roadmap of AI applications to fight against the pandemic	[57]	
	Review the AI based techniques used in the CT and X-ray based medical imaging data acquisition, segmentation, and diagnosis to fight against the COVID-19 pandemic	[25]	
	Review the articles focusing on AI in radiology and pandemic control to highlight the current status and common problems of AI-based systems to diagnosing the COVID-19	[63]	
	Synthesize the importance and performance of 12 different data mining and ML techniques to detect and diagnose the CoV family diseases, including MERS-CoV and SARS	[64]	
	Examine the COVID-19 epidemic to depict how the modern AI and ML technologies have recently been employed to address the challenges during the outbreak	[65]	
	Explore the importance of AI, ML, and deep-learning based techniques in speeding up the vaccination development	[24]	
	Explore the significance of AI in drug repurposing for coronavirus diseases and propose an AI based model adopting different deep learning algorithms (RNN,CNN,DBN) for drug repurposing	[54]	
	Review the AI techniques for detecting COVID-19, classifying COVID-19 medical images patients, and propose a method for evaluating and bench-marking AI techniques suitable for detection and classification of COVID-19 medical images	[66]	
	Explore three technology based initiatives for fighting with COVID-19, including AI based search tools, COVID-19-focused datasets, and the contact tracing mobile applications	[67]	
Editorial	Highlight how AI-based solutions may assist in fighting against the COVID-19 pandemic	[55]	2
	Review existing works, current efforts, and potential work ideas to fight against COVID-19 using AI, ML algorithms, deep learning, and neural networks.	[58]	
Perspective	Highlight the needs of AI and methods of data sharing via smart city networks for better monitoring and management of urban health during the COVID-19 outbreak	[59]	4
	Discussed the importance of active learning based AI tools for coronavirus outbreak.	[60]	
	Introduce AI and Blockchain and suggest how they can be used to effectively help the community with equipment and donations	[61]	
	Highlight the utility of evidence-based prediction tools/models in a number of clinical settings to fight the COVID-19 pandemic	[62]	

donations [61]. Finally, some research has highlighted the utility of evidence-based prediction tools or models to fight against COVID-19 in a number of clinical settings [62].

C. Context of Study

Some articles focused their research on specific countries, while others conducted research from a global perspective. A total of 12 articles (24%) focused on a specific country, as shown in Table III.

One of these articles considered confirmed cases from 34 provinces of China to propose a forecasting system [19], while another study focused on 42 provinces in Japan, China, South Korea and Italy for environmental parameters, weather trends, and confirmed cases to measure correlations and also build a classification model [52]. CT scans of lungs from patients in both the USA and China, [28] [35] as well as CT scan of lungs only from China [20] [45] were used for training and testing automated AI-based tools for diagnosis and tracking, while in [68], chest CT scan data of patients from the USA, China, Japan and Italy were collected to detect COVID-19. Epidemiological data from three provinces of China (Hubei, Guangdong and Zhejiang) and SARS 2003 epidemic data from all over China were used to predict the epidemic across the country [50]. CT images and full blood counts of patients were collected from Italy [32] and San Paolo, Brazil [69] respectively, for detecting COVID-19. Again, non-image data were collected from only Wuhan, China [44], and Wenzhou city of Zhejiang province [46] for the detection and diagnosis of COVID-19. As we see, most articles concentrated on data from China, as it is the original epicenter of the pandemic.

Contextual articles focused mainly on epidemic forecasting and sustainable development. Most of the disease detection and diagnosis-related articles, and all the recommendation-type articles, used global perspectives as well as public datasets and were not context specific (see Fig. 2). The findings indicated that the disease detection and diagnosis techniques were mostly not context-dependent, while the research focusing on epidemic forecasting and sustainable development purposes used

TABLE III
A BRIEF DETAILS ON DATA USED IN THE CONTEXTUAL LITERATURE

Literature	Objective	Data Source	Data Volume	Data Type
[19]	Epidemic forecasting	WHO and local Chinese news media collected Data	15,384 and 36,602 cases Clinically confirmed and lab confirmed cases respectively	Time series data (Non -Image)
[52]	Sustainable development	Data from 42 province of China, Japan, Italy and South Korea	-	Environmental, geographical and demographical data from 28 January 2020 to 26 February 2020(Non -Image)
[28]	Diseases diagnosis	Chainz(development dataset), data from hospital in Wenzhou, China, Chainz, El-Camino Hospital (CA), LIDC (testing dataset), El-Camino Hospital (CA) (lung segmentation development)	157 patients	CT scan images of lungs(Image)
[70]	Disease detection	China	453 images from 99 patients	CT images of chest (Image)
[50]	Epidemic forecasting	Covid-19 outbreak data reported by the National Health Commission of China(Wuhan, Hubei province, Guangdong province, Zhejiang province) , Migration data was retrieved from a web based program, 2003 SARS epidemic data was retrieved from an archived news-site (SOHU)	-	Non -Image
[32]	Disease detection	Societa Italiana di Radiologia Medica e Interventistica (Itali)	150 CT images	Time series data(Non -Image)
[44]	Diseases diagnosis	Wuhan (China) clinical Data	3129 cases of COVID-19 patients	Time series(Non -Image)
[46]	Disease detection	Clinical data from Wenzhou, Zhejiang, China.	53 hospitalized patients'	Medical data (Non -Image)
[45]	Disease diagnosis	Chest CT studies and clinical data from China	905 patients	Chest CT images And clinical data (Non-image)
[35]	Disease detection	Chest Xray from Hunan province, China	512 patients	Chest X-ray (Image)
[68]	Disease detection	Chest CT images of patients from China, Italy, Japan, USA	2724 scans from 2617 patients	Chest CT images
[69]	Disease detection	Full blood count of patients from The Hospital Israelita Albert Einstein, Sao Paulo, Brazil	Total 527 admitted and only tested patients	Full blood count

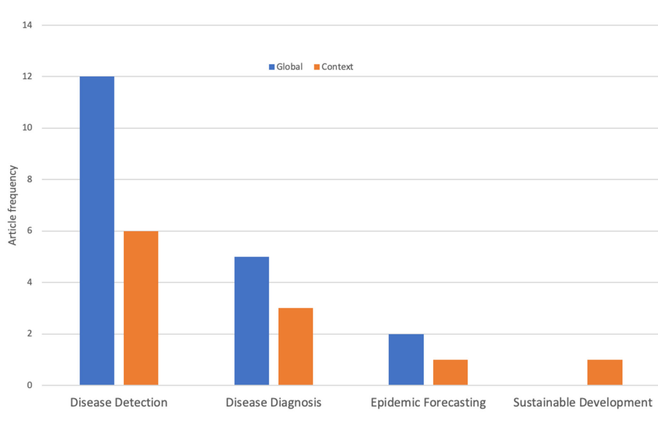

Fig. 2. A brief overview of the study.

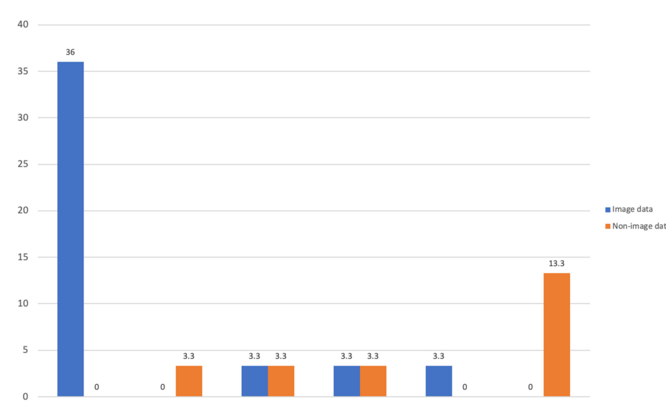

Fig. 3. The percentage of literature using different data type for different algorithm.

contextual data. There were four cross-country studies—one of them [52]] focused on finding correlations between multiple countries' COVID-19 cases. Other studies [28], [35], [46] focused on cases from multiple countries to enhance the performance of their disease detection tool. Table III shows the details of the data used in these contextual studies.

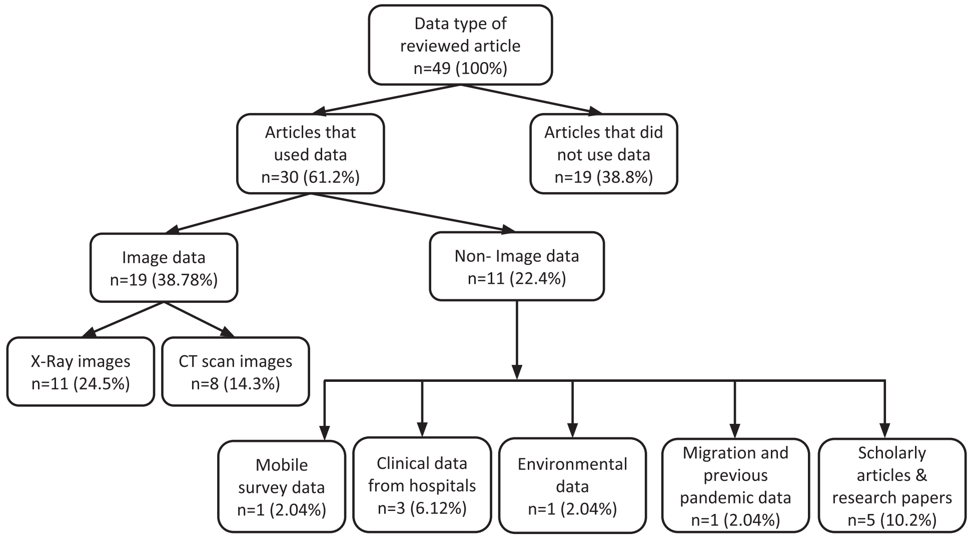

Fig. 4. Analyzing the Data used in the reviewed articles.

D. *Exploration of the Used Data Type*

Thirty studies (61%) used different types of data, including text and images, to corroborate their findings, as shown in Fig. 4. Among the 33 original studies, all the aforementioned 30 that used data showed dependency on proper data assessment of the developed AI- and ML-based systems, whereas the other three studies only proposed systems without any implementation.

Nineteen (39%) of the articles used image data in the form of X-ray images and CT images of the chest. These images were mostly used in disease detection and diagnosis. Eight studies (16%) used public datasets of X-ray images, of which six used the COVID-19 dataset from the GitHub repository created by Dr. Joseph Cohen, while others collected X-ray images for other lung disease patients, (e.g. pneumonia) from GitHub, Kaggle, and Open-i repositories, and hospitals [40], [71]. Four of the other studies that used X-ray images collected data from various hospitals from China and the USA, while one study collected data from Societa Italiana di Radiologia Medica e Interventistica [29], a hospital in Italy. All eight studies that used CT scan images collected their data from different hospitals.

The other eleven articles (22%) used non-image data, predominantly in the form of text and numbers, with the purpose of disease detection, epidemic forecasting, sustainable development, introducing advanced concepts, and disease diagnosis and progression. Thousands of data points were collected through a mobile survey for a study [21] that included information related to location, age, gender, race, travel, and close contact with any affected person. Furthermore, the study collected health data related to COVID-19 symptoms over a period of 14 days. Clinical data including information on baseline characteristics, medical history, and COVID-19 diagnosis from hospitals in Wuhan and other provinces in China were collected for disease prediction and progression purposes (Table III). Pirouz *et al.* [52] used environmental and urban data accumulated from 42 different provinces in China, Japan, South Korea, and Italy to analyze the correlation among environmental factors (low, high, and average temperature, humidity, wind flow) and confirmed cases of COVID-19, while Yang *et al.* [50] used migration and the 2003 SARS epidemic data for epidemic forecasting of COVID-19. Finally, five studies [24], [49], [58], [64], [66] used various research papers and scholarly articles for the purpose of proposing potential ideas to combat COVID-19 using AI, among which a study [49] developed a deep learning-based model to determine if currently available antiviral drugs were effective against the coronavirus. We observed that 10 (20%) studies used data that were collected from different provinces in China, making China the major source of initial COVID-19-related data.

E. *Exploring the AI Techniques*

Most of the research papers ($n = 36$, 73%) aimed to use AI for classification (COVID-19 detection, differentiation from other respiratory diseases), forecasting, and prediction (see Table I). The time and cost associated with the gold standard of testing COVID-19 (PCR takes two to three days to get the results), drove researchers to find an easier, cheaper, and faster way to detect COVID-19 using computational techniques. Therefore, most of the research (57%) aimed to detect and diagnose it. Table IV briefly presents the objective, scope, and results of using different AI algorithms.

COVID-19 has put researchers and health professionals in a difficult situation due to lack of timely information and historical data. Intelligent systems cannot work unless they are trained with enough reliable data. Applications of AI and other related techniques, such as ML and deep learning, are conducted based on previous experiences, i.e. data and models. Given that there is very little information related to COVID-19, researchers mostly rely on X-ray images and CT scans, although very few chest X-ray (CXR) images of COVID-19 are available. CXRs are prescribed as one of the first diagnostic tests by physicians. Most earlier research used CXR images to detect COVID-19 (25%), and others used chest CT images (see Fig. 4). The recent development of deep neural networks has opened up a new

TABLE IV
A SUMMARY OF THE ALGORITHM USED IN THE LITERATURE FOR DIFFERENT OBJECTIVES

Objectives	Algorithms	Evaluation Results	Literature
Disease detection	AI- based algorithm	Only model was proposed, no implementation	[76]
	CNN	Accuracy (82.9%), specificity (80.5%), sensitivity (84%)	[20]
	CNN	Accuracy (97.8%)	[30]
	CNN	F1-score (0.89)	[43]
	CNN	Sensitivity (100%), specificity (100%), accuracy (100%), F1-score (100%)	[71]
	CNN	Accuracy (98%), recall (96%), specificity (100%)	[31]
	CNN, SVM	Accuracy (98.27%), sensitivity (98.93%), specificity (97.60%) F-1 score (98.28%), precision (97.63%), Matthews correlation coefficient (96.54%)	[32]
	CNN,SVM	Accuracy(95.38%), FPR(95.52%), F1- score(91.41%) , kappa (90.76%)	[77]
	GAN Network	Accuracy (99.9%)	[37]
	Decision trees, random forests, and support vector machines	Accuracy(80%)	[46]
	CNN and grad cam	Accuracy (90.8 %), AUC(0.949)	[38]
	Random forest, Lasso-elastic-net regularized generalized linear (GLMnet), ANN	AUC(0.94)	[39]
	CNN	Accuracy(97.36%) of classification accuracy, sensitivity (97.65%),precision (99.28%)	[40]
Epidemic forecasting	Modified auto-encoder for modeling time Series	The estimated average errors of 6, 7, 8, 9 and 10-step forecasting were 1.64%, 2.27%, 2.14%, 2.08%, and 0.73% respectively	[19]
	Epidemiological model and ML-based AI model	The two models' predictions and actual data were plotted in a graph and there was a fit between the actual and predicted data	[50]
	Machine Learning technique of Levenberg-Marquardt	The coefficient of determination, $R^2 > 0.5$, which is higher for the proposed model for most of the countries	[51]
Sustainable development	Regression analysis and Group method of Data Handling	Accuracy (85.7%)	[52]
Diseases diagnosis	CNN and grad cam	AUC (0.989), sensitivity (98.2%)	[41]
	CNN	AUC (0.96)	[42]
	XGBoost machine learning algorithm	Death prediction accuracy (100%), survival prediction accuracy (90%)	[44]
	CNN	Accuracy (0.8982) of Bayesian CNN for prediction, predictive entropy (0.99) as a measure of uncertainty	[47]
	Neural Network, random forest, decision tree (CRT)	Sensitivity(88.0%,), specificity(92.7%), PPV(68.8%), NPV(97.7%), accuracy(92.0%), AUC (0.90)	[48]
	CNN	Atazanavir shows inhibitory potency with Kd of 94.94 nM against the SARS-CoV-2 3C-like proteinase, Remdesivir (113.13 nM), Efavirenz (199.17 nM), Ritonavir (204.05 nM) and Dolutegravir (336.91 nM)	[49]

frontier in image classification. This review found that most of the research papers (21%) used different architectures of deep neural networks (see Fig. 5) to classify images, both CXR and CT scans (see Table V). Under the umbrella term machine learning, deep learning is the approach of training an artificial neural network "deeply" using many more layers than conventional neural networks [72]. Similarly, a recent increase in computation power has revealed the potential of neural networks [73]. As such, when it comes to image data, the convolutional neural network (CNN) dominated all other algorithms and techniques (see Table IV). A CNN takes images as input, assigns bias and filters to that image, and is able to classify an image. In other words, CNNs are simply deep neural networks that use *convolution*(a special linear operation) in any of the layers

TABLE V
SUMMARY OF PAPERS THAT USED DEEP LEARNING IN THE FIELD OF COVID-19

Literature	Architecture	Task	Results	Study Outcome
[28]	U-net, Resnet-50-2D	Classification ,quantification and tracking: COVID-19 patients	0.996 (AUC) 98.2% (sensitivity) 92.2% (specificity)	AI based software
[70]	ResNet-18	Feature extraction from image data	73.1% (Accuracy) 67% (specificity)and 74% (sensitivity)	A CNN based algorithm leveraging decision tree and SVM
[42]	ResNet-50	Classification : COVID-19 and pneumonia	0.96(AUC)	A CNN based model: COVnet
[77]	Resnet50	Classification : COVID-19	95.38%(Accuracy), 95.52%(FPR), 91.41%(F1-score) , 90.76%(kappa)	A CNN based model
[30]	VGG19 , Mobile Net ,Inception ,Xception Inception ResNet v2	Classification: COVID-19, Model Evaluation	97.82% (Accuracy)	A proposal: best deep learning network
[43]	VGG19, DenseNet121, ResNetV2, InceptionV3, InceptionResNetV2, Xception, and MobileNetV2	Classification:COVID-19, model evaluation	F1-scores : normal :0.91 COVID-19 : 0.89	A proposal: best deep learning network
[71]	InceptionV3	Classification:COVID-19	100% (Specificity) 100% (accuracy) 100% (PPV) 100%, (NPV) 100% (F-1 score)	A proposed model, implementation and evaluation
[31]	ResNet50, InceptionV3 and Inception-ResNetV2	Classification: COVID-19	98% (Accuracy) 96% (recall) and 100%(specificity)	A proposal: best deep learning network
[38]	AH-Net	Classification: COVID-19	Accuracy (90.8%), AUC(0.949)	A proposal: best deeplearning network
[40]	VGG-16 , R-CNN	Classification: COVID-19	Accuracy(97.36%),sensitivity (97.65%),precision (99.28%)	A CNN based model

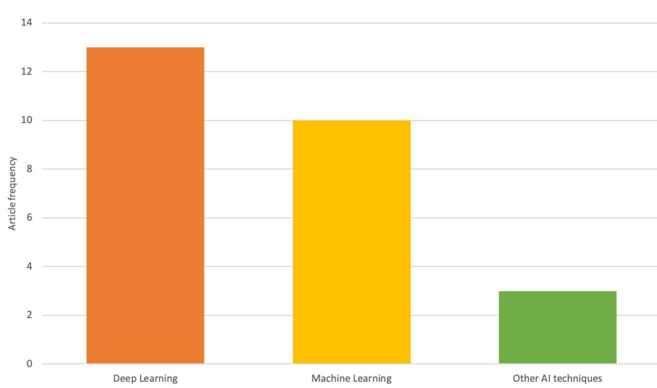

Fig. 5. The frequency of literature used different AI techniques.

instead of matrix multiplication [74]. Using CNN as a base, several studies come up with their own architecture [26]. The experiment done by He *et al.* [75] showed that during image classification, a deeper approach (56 layers) had more training error than a shallower (20 layers) one. Adding a residual block in the network solved the problem of training a very deep neural network. It is known as the residual network (Res-Net). This study found out that among several CNNs, the Res-Net architecture was the most used one (see Fig. 3). Using the Res-Net architecture as a backbone, the models are different from one another on several parameters (i.e. hidden parameters, epochs, and optimizer). Some studies have also used a combination of different deep neural architectures. For example, Ezz *et al.* [43] compared six other different models with Red-NetV2 to propose the best one. Some studies, for example Wang *et al.* [70], used a combination of Res-Net with other machine learning algorithms. The authors used Res-Net for feature extraction from CXR as well as leveraging SVM and decision trees to develop a new algorithm. Other than classification, Biraja *et al.* [47] used different architectures (i.e. Bayesian CNN and Monte Carlo drop weights) along with Res-Net to assess the uncertainty associated with applying deep neural networks to detect COVID-19. The pervasive use of deep learning networks and architectures are briefly presented in Table V.

Other than deep learning approaches, traditional machine learning algorithms have also been applied when it comes to non-image data (see Fig. 3). Using a combination of regression analysis and group method of data handling (GMDH), Pirouz *et al.* [52] tried to find a correlation and forecast based on demographic factors. Moreover, Yang *et al.* [50] combined epidemiological models with an ML model to show the effectiveness of the disease containment in China and predict the epidemic. In addition to this, Loey *et al.* [37] used neural networks (GAN network) for detecting COVID-19, whereas Jiang *et al.* [46] used a decision tree, and SVM-based algorithm to detect COVID-19 from X-ray images.

The studies depended on the train-test split method for validation of their models, as none of these models had been used to test on real patients. As a validation metric, the studies mostly used accuracy, specificity, sensitivity, f-1 score, and area under the receiver operating characteristic (ROC) curve (AUC). Among other evaluation metrics, false positive rate (FPR), true positive rate (TPR), and positive and negative predictive values (PPV and NPV, respectively) were also used. The findings of the review suggest that deep learning algorithms achieve a comparatively higher score in most of the evaluation metrics (see Table IV, and V).

COVID-19 and other pneumonia-like seasonal flus share similar symptoms in the initial stages, which makes it difficult to differentiate. This review found six articles (12%) that used ML and AI to distinguish COVID-19 from other diseases that showed similar initial symptoms. The research achieved a high accuracy score [27] by using CNN in distinguishing COVID-19 from influenza, where they tested their model using the train-split method. As an example, Harmon *et al.* [68] trained their model using real patient data. Their deep learning and AI-based model achieved 90.8% accuracy, with 84% sensitivity and 93% specificity. Five out of the six articles used CT and X-ray images to train their models (see Table V). For example, Banerjee *et al.* [69] strived to distinguish COVID-19 from normal cold and influenza using a full blood count. Their model achieved an AUC of 0.86. These studies suggest that, despite having similarities, AI and ML have the potential to detect COVID-19 from other diseases that show similar symptoms.

IV. Future Research Opportunities

In this section, we have briefly presented the challenges and further research opportunities for AI/ML, not only to fight the COVID-19 pandemic but also for future pandemics.

A. Pursue Research Considering Different Study Context

We observed that only one-third of the research (37%) used contextual data, while the rest (63%) conducted research using data from more than one country. As China was the primary hotspot for the pandemic, a comparatively greater number of contextual studies have been conducted in China owing to the availability of more data and increased time to observe its nature. As the pandemic progressed, data from other countries also became available. Hence, there is considerably more scope for future contextual research that aims to explore and predict the similarity of the pattern of the pandemic among Chinese studies and other regional studies.

B. Explore the Potential Purposes of Research

Existing research has been conducted to detect and diagnose COVID-19, epidemic forecasting, sustainable development, and patient management. We observe that a relatively small number (11%) of studies have been conducted on epidemic forecasting, sustainable development, and patient management. Further research can be done focusing on these areas. We observed that studies on epidemic forecasting and sustainable development used contextual data. We believe that epidemic forecasting-based research should always be contextual.

C. Use of a Large Set of Data in Research

There are opportunities to collect different types of data (e.g. images, texts, videos, etc.) and make it available for researchers to conduct different experiments. Such efforts will be highly valuable for fighting the pandemic. Most of disease detection and half of the disease diagnosis-based research were conducted using global data. However, we suggest that more research in this direction could use diverse global data for better performance. A few studies (20%) on disease detection and the other half of the research on disease diagnosis also performed context-based analysis on specific regions. Hence, future studies may consider other affected regions for disease pattern exploration as well. It can be implied from the studies considered in this review that a smaller amount of data was used for conducting machine learning and deep learning research. Future research could investigate whether bigger datasets could result in better structured, authenticated, and generalized outcomes. Additional studies could be carried out to validate some original research studies ([29], [53]) that did not use data and only proposed models. The claims found in the studies can be explored more with sufficient data in the future.

D. Explore the Effect and Variation in Research Outcomes Based on Different Types of Data

The majority of the existing research that has developed an AI/ML-based tool with the purpose of disease detection and progression has employed training and testing methods. The methods, in general, require related data sets to train and validate the systems to correctly predict the outcome of a given problem, which in this case is detecting the disease accurately. Several (39%) deep learning-based research studies [68], [28] used chest X-ray and CT scan images to determine the presence of opacity in lungs that indicates COVID-19. However, there are other lung diseases, such as pneumonia, COPD, asthma, seasonal flu, influenza, etc. Due to this, similar effects on X-ray and CT images of lungs can be observed. Future studies can include other symptoms of patients in the format of text to train the system, along with the images of lungs to differentiate COVID-19 from other diseases. Blockchain can be an efficient and secured system for this large and multi-modal data management [78].

E. Explore the Contextual Effect and Variation in Research Outcomes

Only one cross-country research [52] has been conducted with the purpose of sustainable development, where correlation among confirmed cases and environmental and demographic factors of four different countries were calculated and compared.

The study conducted by Imtiaz *et al.* [79] in the context of a developing country (Bangladesh), explored the factors for the adoption precautionary measurements and authors in [80] exploit the challenges faced by a specific subset of the population: the Rohingya refugees. Other cross-country research studies, and contextual studies focusing on a specific demographic can be pursued in the future to determine if the virus spread depends on environmental factors.

F. Managing the ICU Surge During the COVID-19 Crisis

It has been reported that some hospitals decided to treat only young people, leaving elderly citizens who had less survival possibility as the hospitals ran out of resources [81]. Further research can be pursued to predict which patients have a higher likelihood of being critical cases based on their medical history and symptoms(e.g. [82]). This would help the hospitals determine which patients can be cured at home and who will need ICU support. Research studies focusing on ICU admission would be helpful in the early release of some patients, thereby making space for the patients who need it most. At the same time, studies can also prevent premature departure from ICUs.

G. Support the Health Care Workforce

The lack of health professionals has been observed in highly affected areas [83], [84].They had to work beyond their limits, making them vulnerable to human error. AI-assisted systems could be helpful here. A rule-based AI can monitor all the data in the ICU and suggest that professionals take necessary steps. An efficient AI can help allocate and control the flow of oxygen level: a crucial treatment provided for COVID-19 patients.

H. Develop New Treatment Options

Researchers all over the world have currently been working on developing new treatment options, including drugs and vaccines for COVID-19. Different organizations have already been using AI to find a vaccine. From data analysis to decoy generation, AI can be helpful, and there are plenty of opportunities for improvement with these algorithms (e.g. Rosetta [85] and Quark [86]).Furthermore, AI can be used for simulation and analysis of different candidate vaccines.

V. Conclusion

In this study, we aimed to determine the significance of machine learning, deep learning, and other techniques under the umbrella term of *artificial intelligence* to fight the global pandemic, COVID-19. We segregated the research into five different categories based on their objectives. In our study, we also determined that using AI and ML can be helpful in differentiating between seasonal flu and COVID-19 infections with acceptable accuracy (AUC of 0.86 [69]). Moreover, our study found that AI and ML have mostly been used for detection and diagnosis. Most of these studies used deep learning algorithms to image data, more specifically on chest X-rays and CT scans [26].The contextual studies that were found in our work were mostly done in China [19]. Based on these findings, we have proposed six potential future research directions.

Taken together, our systematic review of AI and ML techniques has provided an exhaustive overview in fighting the COVID-19 pandemic. State-of-the-art methods ranging from disease detection to pandemic forecasting were presented. These were analyzed and compared in various dimensions considering the data used, input features, the AI and ML techniques, as well as their diverse objectives in the area. Throughout the study, we have provided a variety of insightful information, including application nature, the usage of AI and ML, and the corresponding evaluation conducted for each study.

Our study has a number of limitations, but at the same time, it provides some avenues for future research in the identified directions. First, we used some specific keywords for searching the relevant materials. Although our search keywords provided effective results to achieve the goal of our study, there might be a risk of missing some important materials that did not emerge from our search queries. Second, we think timely and up-to-date materials related to coronavirus and AI techniques are the key elements that we have identified, studied, and summarized in this paper. Third, we are only interested in the application of AI and ML to fight COVID-19 in the context described in section II. Although we found many studies that fused AI and ML techniques to other biological methods [87], [88], we did not consider these types of research to evaluate in the review because they are not properly in line with our research objective, and we consider this a limitation of our work. However, this can be addressed and evaluated in the future when we extend our search query and our research objective.

Therefore, future work is needed to collect and analyze more relevant resources. Supportive information, such as new datasets with high-dimensional features, more classes, and cooperation with the medical community, could add value to handling this health threat using AI and ML, and could guide governments and communities in the early control of the impact of the virus. In addition to extracting information, future research can be conducted to analyze data privacy and security in the relevant areas. Moreover, incorporating advanced technologies, such as the Internet of Things, with a focus on evaluating and improving the relevant AI and ML algorithms with increased efficiency, is highly recommended to remotely assist COVID-19 patients.

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