

# Machine Learning and Internet of Medical Things for Handling COVID-19: Meta-Analysis

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## Abstract

Early diagnosis, prioritization, screening, clustering and tracking of COVID-19 patients, and production of drugs and vaccines are some of the applications that have made it necessary to use a new style of technology to involve, to manage and deal with this epidemic. Strategies backed by artificial intelligence (AI) and the Internet of Things (IoT) have been undeniable to understand how the virus works and try to prevent it from spreading. Accordingly, the main aim of this survey article is to highlight the methods of ML, IoT and the integration of IoT and ML-based techniques in the applications related to COVID-19 from the diagnosis of the disease to the prediction of its outbreak. According to the main findings, IoT provided a prompt and efficient approach of following the disease spread. Most of the studies developed by ML-based techniques for handling COVID-19 based dataset provided performance criteria. The most popular performance criteria, is related to accuracy factor. It can be employed for comparing the ML-based methods with different datasets. According to the results, CNN with SVM classifier, Genetic CNN and pre-trained CNN followed by ResNet, provided

highest accuracy values. On the other hand, the lowest accuracy was related to single CNN followed by XGboost and KNN methods.

## 1 Introduction

The COVID-19 outbreak has created many challenges in human life around the world [1, 2]. The most devastating impact which is increasing casualties and deaths (around the world) have made it clear the need for social and business restrictions [3]. With the expansion of the COVID-19 pandemic, the world community has faced many other problems in various aspects of life such as, economic and social life, psychological wellness, political interactions, cultural activities, educational limitations, religious restrictions, and even sport events [4, 5]. Such examples highlight the need for effective and intelligent systems to deal with such crises in pandemic situation [5]. Early diagnosis, prioritization, screening, clustering and tracking of patients, and production of drugs and vaccines are some of the applications that have made it necessary to use a new style of technology to involve, to manage and to deal with this epidemic [6]. Machine Learning (ML) and Artificial intelligence (AI) algorithms displayed promising ability in prediction and classification [7-18] including disease prediction [19-30], virus genome analysis [20, 31, 32], and medical imaging and Internet of Things [33-36]. Strategies backed by artificial intelligence (AI) and the Internet of Things (IoT) have been undeniable to understand how the virus works and try to prevent it from spreading [5, 37]. These techniques have evolved with the development of computing resources with cloud computing and recent advances in machine learning (ML). All of these advances enable researchers to successfully process large amounts of data and extract information from it. ML-based methods used in processing and modeling data on COVID-19 disease can increase efficiency and speed up results by improving computations.

Gou et al. developed a survey for evaluating the ML-based techniques for diagnosis of COVID-19 using medical data collection, image preprocessing, feature extraction, and image classification. The study evaluates Transfer, ensemble, unsupervised and semi-supervised learnings, and convolutional neural networks, graph neural networks, and explainable deep neural networks. Evaluations focused on the advantages and limitations of the diagnosis techniques [38]. Abumalloh et al. presented a state-of-the-art of ML-based techniques for handling medical image processing in the context of the COVID-19 crisis [39]. Khan et al. developed a survey of the applications of AI for preventing the COVID-19 pandemic [40].

As can be deduced, many survey studies have been developed in this regard. But, the existence of a study that can systematically review and discuss two interrelated areas of the ML and the IoT in the form of an article has been lost from the research literature. Accordingly, the main purpose of this review article is to examine the methods of ML, IoT and the integration of IoT and ML-based techniques in the applications related to COVID-19 from the diagnosis of the disease to the prediction of its outbreak.

The study has three main sections. The first section is to present the importance of IoT and IoT-ML based techniques in COVID-19 applications. The second section is to present the importance of ML-based techniques in COVID-19 applications. The last part is to present the main findings, challenges and future perspectives.

## 2 Methodology

### 2.1 Dataset preparation

Systematic review may successfully provide technical and effective literature for a specific topic [41]. A systematic review requires proper collection of papers around the subject. Preparing dataset is one of the main steps of determining the quality of review work [41]. Finding the most related studies requires proper keywords and proper searching libraries. In the present study, the most relevant studies have been collected from WOS, and Scopus libraries. Table 1 presents the main keywords and searching queries.

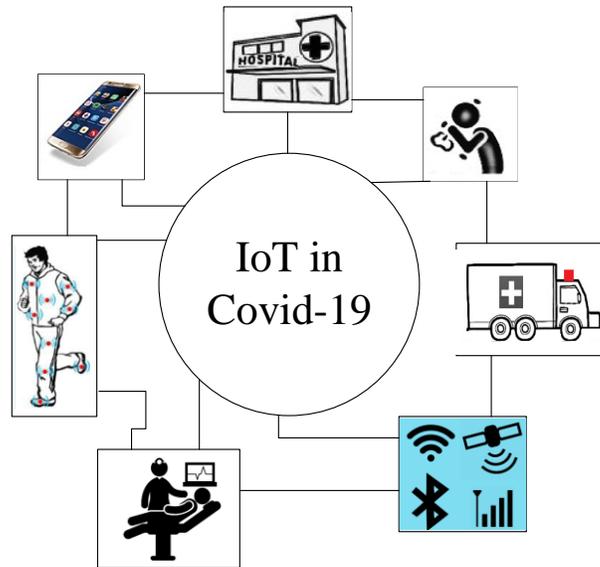
**Table 1.** Searching queries

Search within	Operators	keywords
Article title, Abstract, Keywords	AND	COVID-19, Pandemic, diagnosis, detection
Abstract, Keywords	OR/AND	COVID-19, Pandemic, Prediction, Monitoring
Abstract, Keywords	OR/AND	COVID-19, Pandemic, Classification, Identification
Abstract, Keywords	OR/AND	COVID-19, Pandemic, IoT, Machine learning

## 2.2 IoT for COVID-19

IoT is an interconnected set of computing tools from simple to complex that can be used in conjunction with mechanical or digital machines in the presence of humans, animals, or objects. IoT technology can easily transfer data from the source to the destination through the network without the presence of the operator. This technology can actually be considered as a special tool in human-human interaction or human-computer interaction [42, 43]. An IoT platform includes the minimum equipment required, such as smart devices equipped with the web [44]. These systems consist of processors, sensors, and communication hardware to collect, send, control, manage, and generally convert data into accessible data [44, 45]. These systems connect to an IoT port used to send data to the cloud so that data can be analyzed and shared [46]. These devices can operate by connecting to other related systems based on the information they receive [47]. These tools perform many of their tasks without human intervention.

Today, the use of IoT technology in the field of health and treatment is growing, rapidly [48]. The main applications of IoT in the process of treatment and intelligent health can include identification, digitization of medical information, patient transfer to the hospital, use of vital signs sensors, use of smart phones in communication, and in general, digitization of medical processes [49, 50]. Use of IoT has become more popular and important due to COVID-19 pandemic [51]. Due to the fact that this virus is highly contagious and has a high risk to human health and has caused many problems for the medical staff, using non-contact methods to diagnose as soon as possible, control patients, monitor the condition of patients with acute illness, as well as maintaining social distance, can be an important factor in breaking off part of the virus infection cycle [52, 53]. In the field of non-contact methods, the IoT is a leader and can solve many problems in this field [54]. Figure 1 presents the main applications of the IoT in COVID-19 era.



**Figure 1.** Applications of IoT in COVID-19

Table 2 presents the highlighted studies for the application of IoT-based techniques to tackle COVID-19. This table represents the studies based on the main four columns. Objective that briefly describes the main objective of each study. Methodology/proposed algorithm that presents the main algorithm and procedure employed by each study. Keyword indicates the main points and concentration of the study and finally, application section presents the field of the application of each method.

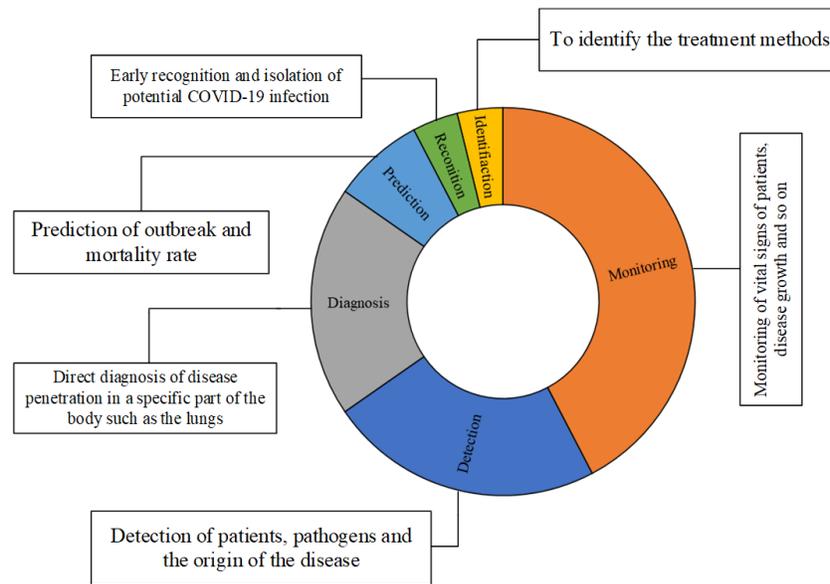
**Table 2.** The main studies for the application of IoT based techniques for handling COVID-19

Order	Objective	Methodology/ Proposed Algorithms	Keywords	Application	Reference
1	To aim an innovative IoT-based online solution for tracking COVID-19 outbreaks	IoT-based platform to contact and to trace the infection	IOT: symptom-based device-to-device (D2D) communication	Prediction and monitoring	[55]
2	To compare DL techniques to detect COVID-19	DL-based COVID-19 diagnosis technique in order to model instances for each type and to diagnosis the vulnerabilities	IOT: DL algorithm, AE	Diagnostic	[56]
3	To develop an IoT-based DL platform for early detection of COVID-19	Chest X-Ray pictures for training and testing of Regional-based Convolutional Neural Networks (RCNN) through IoT-based framework	IoT, COVID-19, Deep learning, Region Proposal Network (RPN)	Diagnostic	[57]
4	To develop a monitoring and detection system according to real-time data from in the presence of the machine learning algorithms	SVM, ANN, Naïve Bayes, K-NN, DT, Decision Stump, 1-R, and 0-R.	machine learning algorithms, COVID-19	Identification and monitoring	[58]

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5	To investigate the IoT for diagnosis of COVID-19 patients using interconnected network	12 IoT based monitoring systems are identified and discussed.	Internet of things (IoT)	Monitoring	[59]
6	To investigate participants' health conditions and remembering the maintain physical distancing	A lightweight and low-cost IoT node using a smartphone, and fog-based ML for data handling	Internet of Things (IoT), smartphone application, Machine Learning (ML), Fuzzy system	Monitoring	[60]
7	To aim a smart edge monitoring system using smart gadgets	To diagnose coronavirus infection using gadgets, deep edge computing and IoT to detect the virus suspected H2H chain	COVID-19, Edge Computing, IoT	Monitoring	[61]
8	To employ a noncontact IR sensor to evaluate for the body temperature	Checking the health condition	IoT, detection system	Detection	[62]
9	To develop a Medical Diagnosis Humanoid to provide a complete diagnostic system for COVID-19	Autonomous navigation, detection, and monitoring system	IoT, AI, ML, Medical Diagnosis Humanoid	Monitoring and Diagnosis	[63]
10	To develop a low-cost robotic system to diagnosis and help virus affected people	To track hand gestures using radio frequency	Wireless Robot, Gesture Recognition, IoT	Diagnosis and monitoring system	[64]
11	To contribute IoT and associated sensor technologies to trace, track and mitigate COVID-19 virus by developing hardware sensor	to integrate IoT techniques and provide insight on the expected outcomes	AI, IoT, big data, data sharing, cloud computing	Diagnosis and monitoring system	[65]
12	To extract the social relationships between mobile devices by allocating the limited protective resources	To employ dynamic WUG model using social IoT	Social Internet of Things; susceptible-exposed-infected-removed; reinforcement learning	Detection	[66]
13	To develop Internet of Things to prevent the spreading of COVID-19	investigating an infected person using IoT	Internet of Things; health care; cloud computing	Detecting and Monitoring	[67]
14	To develop a platform for biometric face detection along with COVID-19 outbreaks	IoT-based Multi-task Cascaded Convolutional Network	detection, cascaded CNN, cloud computing, IoT, edge computing,	Detection and recognition	[68]
15	To introduce a high resolution AQ monitoring system	A preliminary validation of the Air Heritage pervasive Air Quality monitoring concept	Smart Air Quality monitors, IoT, Artificial Intelligence, COVID19,	Monitoring	[69]
16	To develop an IoMT architecture with respect to combat COVID-19.	IoMT platform, emerging IoMT applications, to apply within the medical environment	COVID-19, IoMT application, security	Detection	[34]
17	To test information technology for handling the COVID-19 pandemic	AI, block-chain, Big Data and robots, for optimally handling pandemics	COVID-19, information technology, AI, big data, indonesia	Detection and monitoring pandemic	[70]

Figure 2 presents the contribution of different applications which are performed by IoT techniques to track COVID-19 related fields.

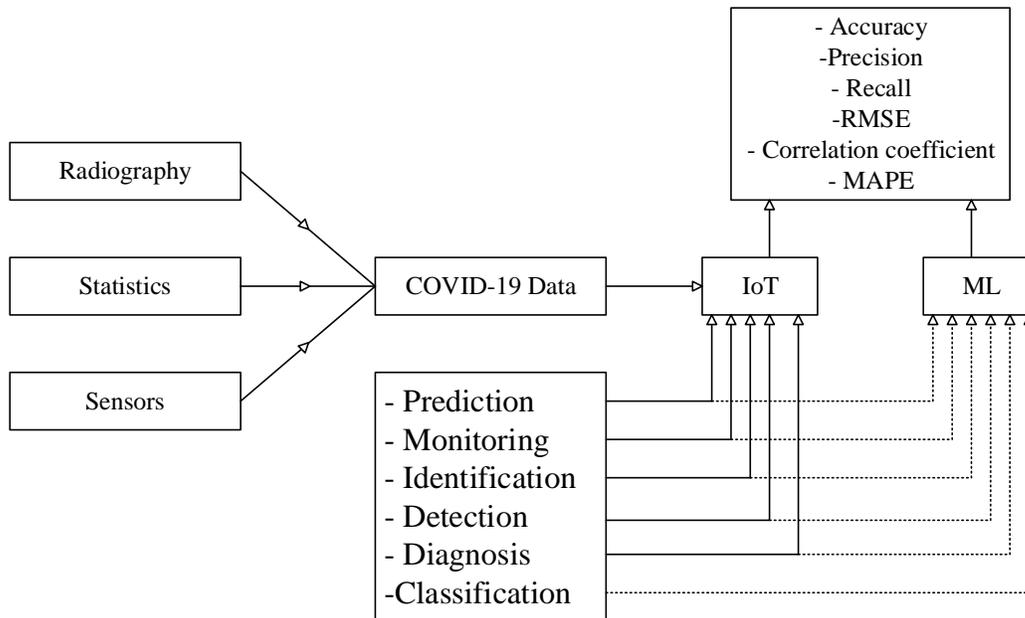


**Figure 2.** The share of each application type for IoT-based systems

Figure 2 is generated based on Table 2 to present the main applications and their portions by studies for handling IoT in COVID-19 pandemic. Monitoring, detection, and diagnosis are the main application of IoT based techniques in tackling COVID-19 pandemic. Monitoring can be performed in different ways. Accordingly, Roy et al. employed IoT as a real-time solution for monitoring of COVID-19 outbreaks [55]. Also Otoom et al employed IoT to provide monitoring and detection data using real-time system to feed to the machine learning algorithms for further applications or handling [58]. Singh et al and Vedaiei et al used IoT as a tool for monitoring COVID-19 patients and their health condition in cooperating an interconnected network [59, 60]. Ashraf et al proposed a smart edge surveillance system to monitor wearable smart gadgets which are operated according to IoT based technology [61]. Karmore et al developed a Medical Diagnosis Humanoid to provide a complete diagnostic system for COVID-19 using IoT based technology [63]. De Vito et al presented the outputs of a high resolution AQ monitoring system which was based on an IoT based technique [69].

Baskaran et al used a non-contact infrared sensor to examine for the body temperature for the detection of the COVID-19 patients [62]. Wang et al exploited the social relationships in the platform of Social IoT to solve controlling issues of COVID-19 epidemic by sharing the limited protective resources [66]. Kumar et al investigated an IoT based platform to prevent the spreading of COVID-19 [67]. Kolhar et al developed a platform of a decentralized IoT based biometric based on face detection platform for handling COVID-19 outbreaks [68]. Aman et al developed an architecture of IoT based framework for medical applications with respect to combat COVID-19 [34]. Manalu *et al* investigated the information technology to response COVID-19 pandemic trend in accordance with the IoT technology [70].

Figure 3 presents the main contribution of these papers. According to the reviewed studies, COVID-19 dataset can be imported from three main sources including Radiography, statistics of health centers, and Sensors for prediction, monitoring, identification, detection, diagnosis and classification purposes. The output of the techniques needs to be evaluated for confirming the approach performance and accuracy values. The frequently used parameters for performance analyzing include Accuracy, Precision, Recall, RMSE, Correlation coefficient and mean absolute percentage error. This can be considered as a brief explanation as the main contribution of the present study. This study successfully presents the advantages and disadvantages of each technique for a specific task in handling COVID-19 dataset and propose the future perspectives. Also, this study can detect the main challenges and limitations.



**Figure 3.** Main contributions of the current study

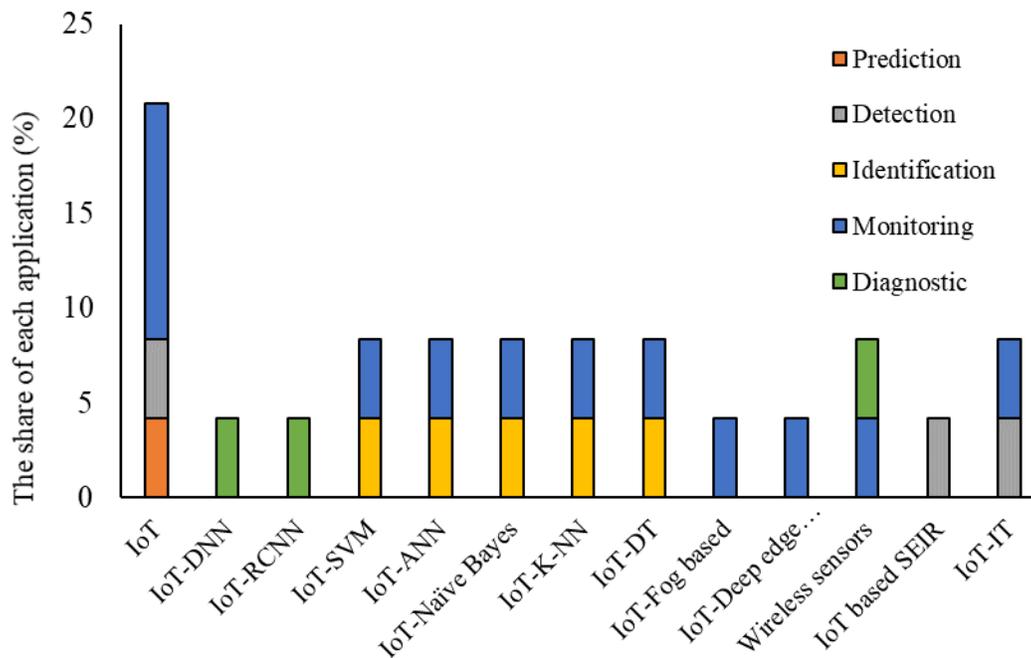
There is a need to categorize the main applications of IoT and the relevance technique in accordance with the COVID-19. Table 3 presents the main contributions of the study for the application of IoT and integrated IoT-ML based techniques.

**Table 3.** The main contribution of the study for the application of IoT based techniques

Methodology	Prediction	Monitoring	Detection	Identification	Diagnostic
IoT	☑	☑	☑		
IoT-DNN					☑
IoT-RCNN					☑
IoT-SVM		☑		☑	
IoT-ANN		☑		☑	
IoT-Naïve Bayes		☑		☑	

IoT-K-NN	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
IoT-DT	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
IoT-Fog based	<input checked="" type="checkbox"/>	
IoT-Deep edge computing	<input checked="" type="checkbox"/>	
Wireless sensors	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
IoT based SEIR		<input checked="" type="checkbox"/>
IoT-IT	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

As shown in Table 3, IoT based technology requires using ML-based techniques for completing the task. Figure 4 presents the share of each methodology in the applications by percentage.



**Figure 4.** The share of each application (%)

As shown in Figure 4, IoT has been used more than other applications to monitor and detect COVID-19 cases. While, it has been less popular in the identification.

### 2.3 ML techniques for pandemic prediction of COVID-19

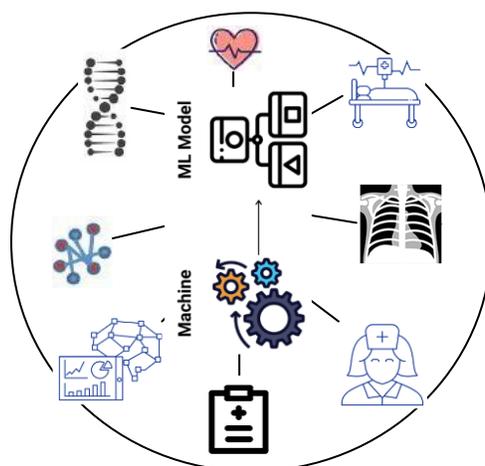
Utilizing ML platform led to reducing the adverse effects of the disease and accelerating the healing process [51]. Combination of AI and ML have led to advances in treatment, medication, screening, prognosis, contact tracking and the drug/vaccine development process and reduced human intervention

in medical performance [71]. ML is also used as a tool for management of virtual queues to prevent crowds in physical waiting rooms or long queues. It is used to predict waiting times and implement calls in a privacy manner in conjunction with the cell-phone platform [72].

ML method is widely used in data analysis by producing an analytical model intelligently. This method is a subset of artificial intelligence that analyzes data and produces a model for estimating, categorizing, optimizing, predicting, identifying problems, as well as decision making [73, 74].

New computing technologies have made the problems assessed by ML-based techniques today a little different from the way they are analyzed based on past technologies [75]. These techniques began to evolve from pattern recognition to a comprehensive theory of the ability of computers to perform specific tasks without the need for special planning [76, 77].

In the field of medicine and treatment, ML is known as one of the most practical tools for analyzing medical data, identifying, predicting, and even treating in different situations. With the advancement of medical science in today's world and the production of large volumes of medical data, there is an urgent need to analyze this data [78]. Figure 5 presents the main applications of ML-based techniques for medical science to tackle COVID-19 pandemic. Identifying the prevalence, effective parameters in the eradication of the virus, identifying patients in the early stages, patients' pattern behaviors, and predicting outbreak and mortality rates can be considered practical and effective areas of ML-based techniques [1, 79].



**Figure 5.** the main applications of ML-based techniques for medical science

Table 4 presents the highlighted studies for the application of ML-based techniques for handling COVID-19. Similar to Table 3, Table 4 discuss them in four columns. Objective column that briefly describes the main objective of each study. Methodology/proposed algorithm presents the main algorithm and procedure employed by each study. Keyword indicates the main points and concentration of the study and finally, application section presents the field of the application of each method.

**Table 4.** ML-based techniques for COVID-19

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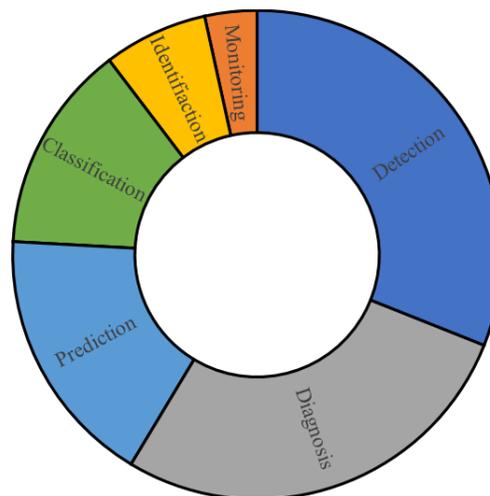
Order	aim	method	Key words	application	Ref
1	To develop a mask face detection model	deep transferring learning (ResNet50) as classifier and SVM to be compared with ensemble method	deep transferring learning, SVM, and ensemble	Detection	[80]
2	To employ ML based platform as a healthcare application to proper decision making for COVID-19 detection	Integration of random forest, Gaussian naive bias and Generative adversarial network	Artificial intelligence, Cloud/fog computing, IoT	Detection	[81]
3	To propose an AI based technique integrated by CT scan and chest x-ray images to identify, and predict the positive infected patients	pre-trained CNN	COVID-19, DT, X-ray images, AI	Identification and diagnosis	[82]
4	To employ a novel CNN architecture for classifying COVID-19 from chest X-rays.	CNN architecture	DL, CNN, mine data patterns	Classify and identification	[83]
5	To develop an AI based methods for fast diagnosis of COVID-19 cases	ResNet-101 in comparison with Radiology data	AI, CNN, ResNet-101	Diagnosis	[84]
6	To detect COVID-19 promptly using CNN	CNN technique	DL, CNN, Squeeze Net	Detection	[85]
7	To develop and test a new computer-aided diagnosis (CAD) to investigate COVID-19	CNN	CNN, DL, CAD	Diagnosis	[36]
8	To propose an intelligence computer-aided model to support daily clinical applications	convolution neural network (CNN) with SVM classifier architecture on chest X-ray	Medical decision support system; Deep learning	Detection	[86]
9	To develop an AI based model for proper screening and monitoring COVID-19	AD3D-MIL	screening, CAD, DL, ML	Monitoring	[87]
10	To present a CNN based technique for early COVID-19 diagnosis from chest X-ray	CNN	AI, CNN, DL	Diagnosis	[35]
11	To investigate a medical decision support system by CNN	CNN	Decision support; CNN; DL; ML	Diagnosis	[88]

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12	To propose an intelligent methodology to diagnosis the COVID-19 cases	The multi-criteria decision-making (MCDM) using TOPSIS in the presence of SVM based classifier	COVID19 diagnostic, machine learning, benchmarking; TOPSIS,	Diagnosis	[89]
13	To study the utility of AI in a prompt and accurate diagnosis of COVID-19 in the presence of chest X-ray images	pre-trained CNN	AI; COVID-19; machine learning, Convolutional Neural Networks	Diagnosis	[90]
14	ML-based classification approach for handling COVID-19	Extreme gradient boosting (XGBoost) model	dinucleotide frequencies, feature representations, genomic signatures, human pathogens, ML, extreme gradient boosting	Classification	[91]
15	ML-based classification algorithm for handling infectious diseases, such as COVID-19	KNN, SVM, DT and LR	machine learning, classification, COVID-19,	Classification	[92]
16	To detect the COVID-19 cases using RNN technique	LSTM architecture of RNN method for detection based on Cough sound, Breathing sound and voices	AI, DL, RNN	Detection	[93]
17	To present a fuzzy rule basing system to predict COVID-19 daily cases	Fuzzy rule based	COVID-19, AI, fuzzy rule based inference	Prediction	[94]
18	To present a multi-scale discriminative segmentation network to detect COVID-19	MSD-Net	COVID-19, CT, DL	diagnosis	[95]
19	To develop a hybrid AI technique for the prediction of COVID-19	Integrated natural language processing module and the LSTM	COVID-19, prediction, epidemic model, hybrid AI,	Prediction, detection	[96]
20	To present a solution for identifying pneumonia using CXR images	GCNN	GCNN, Computed Tomography, Chest X-Ray, AI	Classification	[97]
21	to examine the emotions expressed by people using social media to track and diagnosis sentiment behind COVID-19	LR, Multinomial Naïve Bayes, DT, RF, SVM and XGBoost classifiers	twitter; emotions; sentiment analysis; pandemic; domain-specific; COVID-19; ML; dataset	Detection	[98]
22	To propose ML-based approach for the forecasting of COVID-19 cases	MLP and ANFIS	ML, COVID-19 cases, prediction, detection	Detection	[1]

23	To develop hybrid ML-based technique for the globally prediction of COVID19 cases	Multilayered perceptron integrated by grey wolf optimizer	Machine learning, COVID19 cases, prediction, detection	Detection	[79]
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According to Table 4, ML-based techniques are employed for detection, identification, monitoring, diagnosis, prediction and classification purposes in the presence of the COVID-19 dataset. Figure 6 presents the summary of each application, separately. Singh and Kaur employed ML based platform using hybrid random forest, Gaussian Naïve Bayes and Generative adversarial network as a healthcare application to detect COVID-19 cases [81]. Vinod et al developed a pre-trained CNN method as an ML based technique integrated by CT scan and chest x-ray images to identify, detect, and predict the positive infected patients [82]. Ardakani et al developed an ML based technique (ResNet) for fast diagnosis of COVID-19 cases compared to radiology data [84]. Polsinelli et al developed a study to detect COVID-19 promptly using CNN as a frequently used DL-based architecture [85]. Nour et al proposed an intelligence computer-aided model based on CNN with SVM classifier architecture on chest X-ray to support daily clinical applications [86]. Chowdhury et al investigated the utility of AI in the rapid and accurate detection of COVID-19 in the presence of chest X-ray images [90]. Sethi et al employed Logistic Regression (LR), Multinomial Naïve Bayes, Decision Tree (DT), Random Forest (RF), SVM and XGBoost classifiers analyze the emotions expressed by people using social media to monitor and detect sentiment behind COVID-19 [98]. Ardabili et al developed ML-based techniques for the prediction of COVID-19 outbreaks [1]. In another study, Ardabili et al also employed hybrid ML-based technique (Multilayered perceptron integrated by grey wolf optimizer) for the globally prediction of COVID-19 cases [79]. In addition, Loey et al employed DL based ResNet method in the presence of SVM-based classifier was employed to detect a mask face [80].



**Figure 6.** The share of each application type for ML-based systems

According to Figure 6, detection, diagnosis, and prediction can be considered as the main categories of the application of ML-based methods in COVID-19. In general, one of the main sections of analyzing IoT-based and ML-Based techniques applied for a specific field is their evaluation in terms of accuracy, error, or in other word performance of the model. Table 5 presents the evaluation criteria employed for each model.

**Table 5.** The main evaluation criteria for analyzing the performance of models

	Accuracy	Recall	Precision	AUC	Sensitivity	specificity	Determination coefficient	RMSE	MAPE	MAE	F1-score
deep transferring learning (ResNet50)	<input checked="" type="checkbox"/>										
RF-NB-GAN		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>								
CNN	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>					<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
ResNet-101	<input checked="" type="checkbox"/>				<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>					
AD3D-MIL	<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>							
TOPSIS							<input checked="" type="checkbox"/>				
XGBoost	<input checked="" type="checkbox"/>										
kNN	<input checked="" type="checkbox"/>										
SVM	<input checked="" type="checkbox"/>										
DT	<input checked="" type="checkbox"/>										
LR	<input checked="" type="checkbox"/>										
LSTM	<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>							<input checked="" type="checkbox"/>
Fuzzy							<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	

MSDN			☑	☑			
Naïve Bayes	☑	☑	☑				
RF	☑						
MLP							
ANFIS					☑	☑	
MLP-GWO					☑		☑
IoT (Medical based)	☑		☑				
Fog-based	☑						
Deep edge computing	☑						
Wireless sensors	☑						
IoT based SEIR	☑						
IT	☑						

According to Table 5, accuracy, followed by recall and precision parameters have owned the highest portion of the evaluation criteria employment for analyzing COVID-19 based dataset using IoT and ML-based techniques. In the following, Table 6 is generated from Table 4 for indicating the share of each ML-based techniques for each application and their main contributions. According to Table 6, ResNet as an architecture of deep learning methods followed by CNN, XGBoost, SVM, DT and LR have been used more often to tackle work with COVID-19 related data.

**Table 6.** The main contribution of ML-based techniques in COVID-19 applications

	Prediction	Monitoring	Diagnosis	Identification	Detection	Classification
ResNet50	☑	☑	☑	☑	☑	☑
RF-Naïve bayes-GDN					☑	
CNN			☑	☑	☑	
ResNet-101			☑			
AD3D-MIL		☑				



**Figure 7.** The share of each application (%)

## 2.4 Evaluation criteria

Models developed using ML and IoT-ML requires an evaluation step for recognizing their performance and accuracy values. According to the studies reviewed, the most effective and frequently used evaluation criteria are including Accuracy, Recall, Precision, Root mean square error (RMSE), Correlation coefficient and Mean absolute percentage error (MAPE). These criterias compare the models' output and actual values and provides a comparison score [1, 79]. In the present study, we employed the criteria values reported by each study for evaluating and comparing the models. Table 7 presents the main criteria for evaluation.

**Table 7.** The main evaluation metrics

$\text{Accuracy} = \frac{\text{True}_p + \text{True}_n}{\text{True}_p + \text{True}_n + \text{False}_p + \text{False}_n}$	where $\text{True}_p$ denotes the true positives, $\text{True}_n$ the true negatives, $\text{False}_p$ the false positive, and $\text{False}_n$ the false negatives.	(1)
$\text{Recall} = \frac{\text{True}_p}{\text{True}_p + \text{False}_n}$	where $\text{True}_p$ denotes the true positives and $\text{False}_n$ the false negatives.	(2)
$\text{Precision} = \frac{\text{True}_p}{\text{True}_p + \text{False}_p}$	where $\text{True}_p$ denotes the true positives and $\text{False}_p$ the false positives.	(3)
$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \hat{x}_i)^2}$	where $N$ denotes the total number of samples, $x_i$ the actual samples, and $\hat{x}_i$ the predicted samples.	(4)
$\text{Correlation Coefficient} = \frac{\text{Cov}(x, \hat{x})}{\sigma_x \sigma_{\hat{x}}}$	where $x$ refers to actual samples, $\hat{x}$ to predicted samples, $\text{Cov}(x, \hat{x})$ to the covariance between $x$ and $\hat{x}$ , and $\sigma$ to the standard deviation (calculated for both $x$ and $\hat{x}$ )	(5)
$\text{MAPE} = \frac{100}{N} \sum_{i=1}^N \left  \frac{x_i - \hat{x}_i}{x_i} \right $	where $N$ denotes the total number of samples, $x_i$ the actual samples, and $\hat{x}_i$ the predicted samples.	(6)

## 3 Main findings and evaluations

This section presents the main findings of IoT based techniques (Table 8) and ML-based techniques (Table 9). Each table includes two main columns called findings and pros. and cons.

**Table 8.** The main findings of the study for the application of IoT-based techniques

Order	Findings	Pros. and Cons.	Ref.
1	The proposed solution can identify and track the infected individual and successfully tracks all people who are in the area of disease spread	This framework integrates symptom information as a rapid and efficient approach, thus tracking the prevalence of the disease	[55]
2	DL applications are vulnerable to coronavirus attacks	The method is very vulnerable and requires further studies	[56]
3	The model provides an accuracy of 98% for detection	Combining DL and the IoT makes it easier for radiologists to control the spread of the virus	[57]
4	According to results, all the techniques, except the Decision Stump, OneR, and ZeroR provided accuracies values more than 90%	The proposed platform reduced the communicable diseases using early detection of cases and provided tracking the recovered cases, and a better understanding of the infections	[58]
5	IoT reduces clinical cost and optimizes treatment outcome of the patients	The platform improves patient satisfaction and decreases readmission rate in the hospital	[59]
6	The system can assist tracking the daily activities and decrease the risk of exposure to the COVID-19	The app announces the user to keep a physical distance of 2m. Also, a Fuzzy-based technique evaluates the environmental risk and user health to estimate the risk of real time spreading. This platform can successfully reduce the coronavirus spread	[60]
7	The platform detects and tracks the infected person	The platform tracks COVID-19 and improves infected person and keeps the dataset for further analysis	[61]
8	The provided package enhances the testing process for increasing the efficiency of the system	This approach will increase the maximum collaboration from the employees	[62]
9	This platform is a cost-effective, safety-critical mobile robotic technology and successfully copes with diagnosis task Also the multiple diagnostic devices increases the detection accuracies	The system effectively provides a complete diagnosis and figuring out COVID-19 patients also contains multiple diagnostic devices, without any need for human interferences	[63]
10	The robot technology protect virus affected persons. The system is also recognizing the patient's Gesture and tracking the instructions	The robot collects data from patient performs tasks without image processing system	[64]
11	IoT-based technology prevent the global pandemic	improves the control and tracking of a fast-spreading virus such as coronavirus	[65]
12	The proposed methodology is sustainable for disease tracking by an early identification of cases	This technique can successfully handles both governments and other decision-making authorities	[66]
13	This system improves the decision-making procedure	The system is connected through cloud computing and effectively supports the real-time data	[67]
14	Edge computing improved the findings on the decentralized load of face recognition	The platform enhances the robustness of detection and diagnosis	[68]
15	The proposed system could successfully cope with the task	IoT equipped ML can successfully save, and visualize monitoring the volunteers	[69]
16	This study suggests that integrated and hybrid techniques will follow up the near future, using simulation, and forecasting purposes	A higher degree of safety and privacy for humanity	[34]
17	The platform employed for the study have an effective role in the success of pandemic handling	The platform increases accessibility to the proper dataset	[70]

According to Table 8, most of these studies lack numerical analysis for the method performance. One of the main reasons can be the nature of IoT technique which goes through a practical process and shows its performance in practical applications and does not need to provide numerical statistics. In all these applications, IoT could successfully cope with the task. Such that, IoT provided a fast and

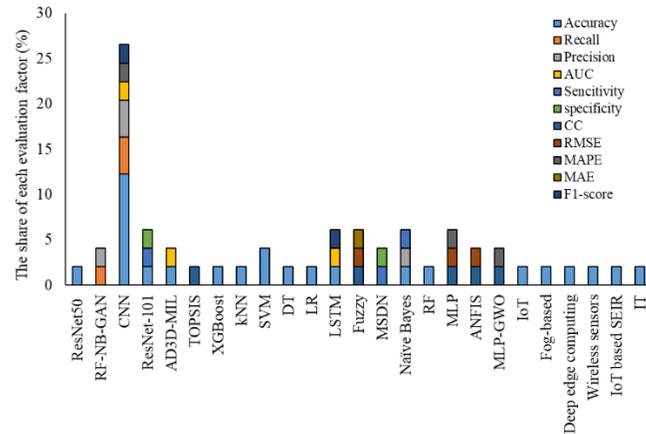
efficient approach of tracking the disease spread [55]. On the other hand, it can be employed as a real-time framework to minimize the impact of communicable diseases through early detection of cases [56]. In the study by Singh et al, IoT technology successfully increased patient satisfaction and reduces readmission rate in the hospital [59]. However, for detection purposes, there is a need for integrating IoT platform with ML-based techniques. In the study by Rahman et al, DL applications with IoT platform provided promising findings to detect AE attacks. However, there is a need for further research, attention, and implementation of appropriate defense mechanisms, safeguards, and controls [56]. Kolhar et al employed Multi-task Cascaded Convolutional Network architecture (MCCNN) and findings claimed that the efficiently integrated by Raspberry Pi increased the robustness of detection and recognition [68].

**Table 9.** The main findings of the study for the application of ML-based techniques

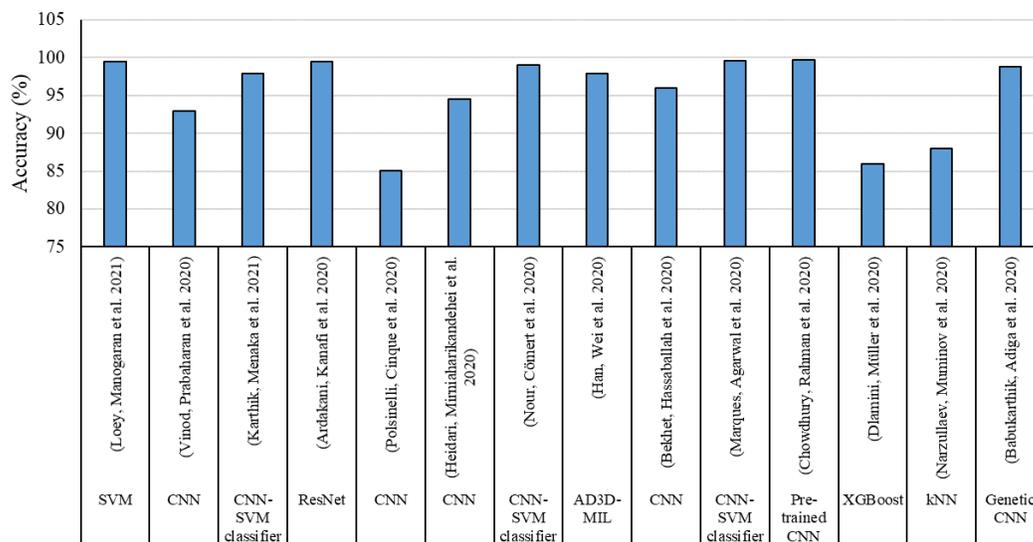
Order	Results	Pros. and cons.	Ref
1	The SVM classifier in the presence of RMFD, SMFD and LFW dataset achieved 99.64, 99.49 and 100% testing accuracy values.	The proposed model provided lowest processing time and highest accuracy	[80]
2	Recall=0.93, Precision=0.871 with lower processing time	The system is cost-effective by reducing processing time and sustainable by increasing the accuracy values considerably. The proposed framework can also be used to prioritize patients who require an ambulance.	[81]
3	Accuracy=93% and recall score=88% using chest x-ray images	The proposed method can successfully help radiologist's prompt detection of coronavirus cases	[82]
4	Accuracy (97.94 %) and AUC (98.39 %)	a channel-shuffled dual-branched CNN architecture can effectively learn salient features and increases the accuracy and precision values of the modeling	[83]
5	Sensitivity=100%, specificity=99.02% and accuracy=99.51% and for radiology data, sensitivity 89.21%, specificity=83.33% and accuracy=86.27%	This model is low cost and is used as a complementary method during CT imaging	[84]
6	Accuracy=85.03%, sensitivity=87.55%, specificity=81.95%, precision=85.01% and F1-core=86.20%	Higher classification rate by analyzing thousands of images	[85]
7	Accuracy=94.5%, confidence interval=95%, sensitivity=98.4% and specificity=98.0%	develops a DL-based CAD scheme of chest X-ray images and improves detecting COVID-19 infected	[36]
8	Accuracy=98.97%, sensitivity=89.39%, specificity=99.75%, and an F-score=96.72%	reduces the misdiagnosis rates, and improves evaluation rates and detects positive COVID-19 infections	[86]
9	Accuracy=97.9%, AUC=99.0%, and Cohen kappa score=95.7%.	Reliable screening of COVID-19 from chest CT	[87]
10	96% of accuracy	The proposed model performance is clinically validated with expert radiologists	[35]
11	Accuracy of 99.62% and 96.70%. Average recall value of 99.63% and 96.69% respectively for binary and multiclass	Automated medical diagnostics for enhancing decision making rates	[88]
12	Correlation coefficient=0.9899	providing significant variance for each criterion	[89]
13	Accuracy=99.7%, precision=99.7%, and sensitivity=99.7%	Improving the speed and accuracy of COVID-19 detection	[90]

14	86% accuracy for the task of classifying	The proposed model could successfully improve the classification accuracy	[91]
15	Accuracy of 88, 91, 87 and 89% for kNN, SVM, DT and LR, respectively	The proposed method can be applied anywhere, without prior training or calibration	[92]
16	F1-score of 97.9, 98.8 and 92.5%, AUC of 97.4, 98.8 and 84.4% and accuracy of 97, 98.2 and 88.2% respectively for Cough sound, Breathing sound and voices, respectively.	To improve the COVID-19 detection through a cost-effective approach	[93]
17	R2 = 0.96, RMSE = 254, MAE = 186	The proposed method could successfully estimate the number of daily cases	[94]
18	Sensitivity and specificity of 0.8645, and 0.9889.	This model provides automated and accurate segmentation of CT images	[95]
19	MAPEs=0.52%, 0.38%, 0.05%, and 0.86% respectively for the next six days in Wuhan, Beijing, Shanghai, and countrywide	To minimize the errors of the prediction and to enhance the detection efficiency	[96]
20	Accuracy=98.84%, Precision=93%, Sensitivity=100%, and Specificity=97.0%	The proposed model improved classification rate in comparison with ReseNet18, ReseNet50, Squeeze net, DenseNet-121, and Visual Geometry Group	[97]
21	Accuracy for both SVM and Decision Tree could provide the maximum value by average value of 93%	Higher accuracy for perceiving the perception of people infected by COVID-19	[98]
22	RMSE and CC values for five countries including, China, Italy, USA, Iran and Germany	The proposed models enhanced the forecasting rate of COVID-19 cases	[1]
23	MAPE=13.15% and CC=0.99	The proposed models increased the forecasting rate of COVID-19 cases	[79]

According to findings of Table 9, the most share of studies developed by ML-based techniques for handling COVID-19 based dataset provided performance criteria. The most share of the performance criteria, according to Figure 8 is related to accuracy factor. Accuracy factor is a general and normalized factor. Therefore, it can be employed for comparing the ML-based methods with different datasets. Figure 9 presents the accuracy values for each model for comparing their performance in handling COVID-19 dataset.



**Figure 8.** The share of each evaluation factor (%) for analyzing results



**Figure 9.** Accuracy values

Figure 9 indicates CNN with SVM classifier, Genetic CNN and pre-trained CNN followed by ResNet, provided highest accuracy values. On the other hand, the lowest accuracy was related to single CNN followed by XGboost and KNN techniques.

### 3.1 Challenges and limitations

Nowadays, when the world is struggling with COVID-19 disease, every innovation and technology is used to fight this disease. Like many other areas, healthcare requires the support of new technologies

such as IoT, and ML. Exploring of disease-related dataset, data preparation, prevention, and control of infectious diseases, has become one of the main purposes of AI. IoT and ML have a vital personality in better understanding, dealing with the COVID-19 crisis, and discovering the COVID-19 vaccine. ML-based technology allows computers to predict the pattern and speed of disease transmission with the intelligence they have and by mimicking large amounts of data. This result-oriented technology is employed for proper screening, analysis, forecasting and tracking of current and potential future patients. AI uses information from people with coronary heart disease, improved and dead people as tracking data.

To combat the spread of the corona virus, IoT-based methods of communicating with patients provide transparency and a better understanding of how the virus is spread, and strengthen the treatment and research process. ML is one of the new technologies in tracking the spread of the virus and finding effective parameters in it. The ML method can successfully identify high-risk patients and predict the necessary measures to deal with possible infections to reduce the point of effect of the disease. ML-based methods can estimate the risk of patient mortality through previous analysis. This technique improves the planning, treatment, and reduction of patients and is a complementary medical tool that works with data and evidence. On the other hand, this technology improves decision making and reduces the cost of treatment and diagnosis. At the same time, in the field of medical imaging, ML tools helps to recognize the patterns in the images and strengthen the ability of radiologists to diagnose the possibility of disease and early diagnosis of the disease.

One of the main limitations of IoT, and ML-based techniques for applications in COVID-19 is the lack of a complete dataset. This can be due to the unique development of models by limited data for a specific application within the same data field. The purpose of using IoT, AI, or ML-based techniques is to solve a specific problem in the real world with a real application that requires the use of special hardware and equipment. There are limitations in the cost and availability of developing and equipping communication hardware in therapeutic, diagnostic, estimation, and forecasting applications for IoT technology or ML-based techniques. Also, there are limited best practices available for IoT developers. The lack of IoT edge authentication and licensing standards has led to restrictions on the application and enactment of laws, regulations, and policies in the use of this technology, and this has led to the absence of IoT-based incident response activities as the best methods. All of these limitations mean that there is still no focus on identifying ways to gain situational awareness of the security of IoT assets in a medical complex.

#### **4 Conclusion**

The present study categorizes the applications of IoT, IoT-ML, and ML-based techniques to tackle COVID-19-related problems. The main applications are categorized into monitoring, detection, identification, classification and diagnosis. Studying, comparing and investigating of these applications requires a proper judgment about the performance and effectivity of outputs. According to a deep consideration about the evaluation criteria, it has been investigated that the accuracy, followed by recall and precision parameters have owned the highest portion of the evaluation criteria employment for analyzing COVID-19 based dataset using IoT and ML-based techniques.

Most of the studies lack of numerical analysis for the method performance. One of the main reasons that can be the nature of IoT technique which goes through a practical process and shows its performance in practical applications. In all the applications, IoT could successfully cope with the

tasks. Such that, IoT provided a fast and efficient approach of tracking the disease spread. Most of the studies developed by ML-based techniques for handling COVID-19 based dataset provided performance criteria. The most popular performance criteria is related to accuracy factor. It can be employed for comparing the ML-based methods with different datasets. According to the results, CNN with SVM classifier, Genetic CNN and pre-trained CNN followed by ResNet, provided highest accuracy values.

Policy-making in the field of COVID-19 disease to examine the weaknesses and strengths and vulnerabilities of society in terms of the penetration of pathogenic viruses can be considered as additional measures and future studies. On the other hand, the study of collective behaviors can also be considered as perspectives to complete studies in order to prevent similar social harms and reduce costs incurred and not to surprise human life.

## 5 Conflict of Interest

*The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*

## 6 Author Contributions

SSB and SA designed the study; SA, AY, BP, and AKK, AM wrote the paper. SS, AB, HAR, and AD edited the manuscript. SA, AY, BP carried out all the analyses. SSB, SA, AY, BP generated all figures and all tables. HAR and AB were not involved in any analyses. All authors have read and approved the final version of the paper.

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