Multimedia Systems (2022) 28:1189–1222
https://doi.org/10.1007/s00530-021-00818-1

SPECIAL ISSUE PAPER

Fusion of AI techniques to tackle COVID-19 pandemic: models, incidence rates, and future trends

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Received: 5 November 2020 / Accepted: 29 May 2021 / Published online: 13 July 2021

Abstract
The COVID-19 pandemic is rapidly spreading across the globe and infected millions of people that take hundreds of thousands of lives. Over the years, the role of Artificial intelligence (AI) has been on the rise as its algorithms are getting more and more accurate and it is thought that its role in strengthening the existing healthcare system will be the most profound. Moreover, the pandemic brought an opportunity to showcase AI and healthcare integration potentials as the current infrastructure worldwide is overwhelmed and crumbling. Due to AI's flexibility and adaptability, it can be used as a tool to tackle COVID-19. Motivated by these facts, in this paper, we surveyed how the AI techniques can handle the COVID-19 pandemic situation and present the merits and demerits of these techniques. This paper presents a comprehensive end-to-end review of all the AI-techniques that can be used to tackle all areas of the pandemic. Further, we systematically discuss the issues of the COVID-19, and based on the literature review, we suggest their potential countermeasures using AI techniques. In the end, we analyze various open research issues and challenges associated with integrating the AI techniques in the COVID-19.

Keywords AI · COVID-19 · Healthcare · Machine learning · Deep learning

1 Introduction

The ongoing worldwide pandemic caused by the coronavirus (also called COVID-19) disease was first observed in December 2019 and has affected over 117 million people and over 2.6 million people have succumbed to it [34]. It is a communicable disease, which spreads from human-to-human as well as animal-to-human transmission via air contact. The World Health Organization (WHO) has declared the virus as a global pandemic and people all over the world have been advised to remain indoors and avoid contact with other people. This has resulted in the closure of businesses across the globe. Governments across the globe have imposed strict measures such as quarantining their citizens, imposing strict lockdowns, and restrictions in international and domestic travels to minimize the spread of coronavirus and ensure their citizens' safety. However, despite all these measures put in place, they are often defied, leading to the virus not being contained and leading to its rampant spread. Many organizations worldwide, including private, semi-government, and government, are working hand-in-hand to develop a vaccine for this virus. Still, until an effective vaccine is developed, the only solution is to adhere to the government norms practice the principles of self-hygiene. COVID-19 poses impacts on three fronts like healthcare, world economy, and supply chain. Traditional methods of combating the pandemic include contact tracing of citizens to trace the origin of infection and their medical diagnosis and treatment by the medical professionals and a team of

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medical researchers globally working on discovering vaccines for the same.

The magnitude and impact of the COVID-19 virus are profound, which cannot be controlled with the previously used methods to restrain other viruses. For instance, the exponential spread of the virus has infected many people around the world that makes it impossible to trace the origin manually, which is due to the limited number of medical staff in any country [99]. Developing vaccines using traditional methods needs years of research and development to materialize. Since no vaccine has ever been found for any virus of the coronavirus family. The researchers also do not have any previous experience in developing vaccines for such a deadly virus.

The advent of AI revolutionizes each domain of social and personal lives. AI is programmed to act like a human brain and replicate its thought processes, which automate various tasks. AI is data-driven that makes decisions based on data it was trained on. AI is required to deal with the current pandemic, as it has the edge over the traditional procedures as discussed above. Although AI certainly cannot replace doctors, it surely helps them make efficient and accurate diagnostic decisions. The healthcare sector can be transformed by integrating it with AI tools and techniques [51]. During pandemic situations, the healthcare systems are overwhelmed by the huge number of patient requests and AI can aid them with the diagnosis and treatment processes as quickly as possible with minimum expenditure. AI algorithms can easily be integrated with the existing infrastructure such as cameras and sensors to automate the contact tracing process. During the vaccine development process, AI helps to run simulations for the potential drug to predict its effectiveness.

Motivated from the facts mentioned above, in this paper, we have explored the potential applications and use-cases of AI in controlling and mitigating the effects of the COVID-19 pandemic. We have identified six diverse fields in which AI can potentially contribute. We have presented a comparative analysis of the existing AI techniques that researchers across the globe have proposed. Then, we have identified the challenges faced during the integration of AI and COVID-19. Finally, we suggested the potential future research directions in the same field.

1.1 Comparisons with the existing surveys

Researchers worldwide have conducted significant work in the domain of tackling COVID-19 through digital technologies since its inception. The nature and the exponential spread of the virus have compelled researchers to look for novel and innovative technologies to combat its effects. Since early 2020, works are being carried out in utilizing AI techniques and various surveys have been published by the researchers. Many research articles show the applications of different technologies in combating the COVID-19 effect. For example, Ting et al. [153] and Chamola et al. [25] provided a comprehensive review on the uses of different technologies such as the Internet of Things (IoT), Unmanned Aerial Vehicle (UAV), blockchain, 5G, and AI in tackling the effect of the pandemic, whereas, Javaid et al. [72] reviewed the Industry 4.0 technologies such as cloud computing, edge computing, holograms, and Virtual Reality (VR), and their potentials in COVID-19 effect. Then, Nyugen et al. [106] presented a hybrid architecture, which utilizes both AI and blockchain technologies. Vaishya et al. [156] and Naude et al. [101] gave their insights about the potentials of AI techniques in dealing with the COVID-19 pandemic. Shi et al. [138] presented all AI techniques that can be used for the diagnosis of the disease from medical imaging such as CT scans and X-ray. The potential shortcomings of utilizing AI in such epidemics were discussed by Naude et al. [102]. The relative comparison of existing surveys on AI applications for the COVID-19 has been discussed in Table 1.

1.2 Motivations and contributions

This section discusses the motivations and contributions of the proposed survey.

1.2.1 Motivations

AI is currently one of the most researched topics with promising applications and results in every domain. The implementation of AI algorithms has become easy due to the data boom in recent years and affordable computing power. AI has many subfields such as machine learning (ML), deep learning (DL), natural language processing (NLP), and computer vision (CV), which can be used for pattern recognition, explanation, and prediction based on the data with comparable human-level accuracy. These applications help to manage the pandemic's socio-economic impacts and can be used hand-in-hand with the current infrastructure to manage the infections. In the COVID-19 outbreak, medical researchers worldwide are trying their best to create the vaccine, while AI researchers are exploring how to use AI and other analytical tools in this fight. So, we believe that AI can potentially contribute to mitigate the effect of the COVID-19 pandemic and identified the current restrictions on these contributions.

As per the literature, there exist six areas where AI can directly or indirectly contribute to countering the effects of COVID-19: (1) early warnings and alerts, (2) tracking and prediction, (3) data dashboards, (4) diagnosis and prognosis, (5) treatments and cures, and (6) social control. Therefore, it is important that the authorities take special care in handling these details and their justifications and communications to

Table 1 A Relative comparison of the existing state-of-the-art surveys on the fusion of AI techniques in COVID-19 pandemic with the proposed survey

Related surveys	Year	Objective	Key contributions	Limitations
[106]	2020	AI and blockchain based solutions to combat COVID-19	The authors presented a novel architecture utilizing both blockchain and AI technology	Current shortcomings of both AI and blockchain were pointed out
[153]	2020	Identify how digital tools can be helpful in the COVID-19 pandemic	The authors presented a wide range of digital technologies such as IoT, big data, AI, and blockchain and their potential applications in public health measures	The acceptance of such digital technology by the general public
[25]	2020	Identify how new technologies can aid in managing the impact of COVID-19	The authors presented a comprehensive review about the potential use case of IoT, UAV, blockchain, AI, and 5G	The limitations of each technology were not discussed
[123]	2020	Explore the role of AI and blockchain to flatten the COVID-19 curve	The authors presented a mobile application incorporating AI and blockchain components, which can be used against the COVID-19 pandemic	The application is still in the development phase
[138]	2020	Explore the applications of AI in the diagnosis of COVID-19 using imaging data	The authors reviewed various AI techniques that can be used on X-ray and CT scans for making clinical decisions	The reliability of decisions and the lack of a comprehensive data-set for training
[72]	2020	Identify the potential applications of Industry 4.0 technologies in the COVID-19 pandemic	Potential applications of technologies such as AI, IoT, big data, VR, holograms, cloud computing, etc. in the pandemic, the scenario was presented	The adaptations of most of the technologies are not wide-spread and most of them are in the research phase
[156]	2020	Identify the potential application of AI in the COVID-19 pandemic	The authors presented potential applications of AI in the various stages such as early detection, contact tracing, prediction, and prevention	The accuracy of the methods were not given
[101]	2020	Identify the potential application of AI in the COVID-19 pandemic	The authors presented potential applications of AI in various stages of COVID-19 transmission	Many potentials of AI were not given in this early review
[102]	2020	To determine the potential short-comings of using AI in the COVID-19 pandemic	The authors presented various limitations and constraints of AI while utilizing it in various stages of COVID-19	Challenges of integration of AI and healthcare domain were not discussed
The proposed survey	2020	Review of all the AI techniques and their applications to tackle the COVID-19 pandemic	A comprehensive review regarding the possible use-cases of AI integration with the healthcare domain	Real-life implementation of some techniques were not discussed

the general public. Table 2 shows several research questions, which motivated us to explore the potentials of AI in tackling the effect of the COVID-19 pandemic.

From the literature, we identified no survey that discusses AI techniques for all the mentioned six areas. Amazed by the prowess of AI Techniques in healthcare, we took up this survey article. AI techniques have been proven as a cost-effective and highly effective alternative and need the hour for this present once-in-a-lifetime pandemic. With the advent of newer deep learning models, these AI techniques have evolved to give significant results in their efficacy and reliability and can significantly change the healthcare industry. This motivates us to write a comprehensive survey on AI techniques to combat COVID-19 situations.

1.2.2 Contributions

Following are the main contributions of the paper.

- We discussed the severity of the COVID-19 pandemic and its potential threats to social life and presented the comparative analysis of existing state-of-the-art surveys published by researchers across the globe with the proposed survey.
- We present the fusion of AI techniques to combat the COVID-19 situations in prospect to specific applications.
- We highlight various open issues in integrating AI with the COVID-19 and also discuss future research directions.
- We present a case study on AI techniques used for treatment and cure.

1.3 Methods and materials

We required a broad overview of all AI applications about the COVID-19 situation for our comprehensive survey on future AI practices in the pandemic situation. So, we referred only to standard peer-reviewed and high repute journals only. Some of these include Springer, Wiley, ACM Library, IEEEXplore, and Elsevier. We also referred to online technical blogs and white papers written by the organizations working in this direction. In our search criteria, we have used keywords and search strings such as "AI techniques for COVID-19", "Applications of AI in healthcare", "Digital technologies for COVID-19", and "AI assisted measures of COVID-19", and others. In several review papers, the search string was not either present in the title or abstract and for such cases, we had to do a manual search. AI has applications in various domains, so the search string "AI for COVID-19" often gave papers, which are not related to our survey. In order to include all the current trends and research directions, we have also included early access articles.

1.4 Structure of this survey

The structure of the paper is as follows. Section 2 presents a detailed review of COVID-19 pandemic and AI techniques, including ML and DL techniques. This section further highlights the characteristics of AI and its potential uses in the COVID-19 pandemic. In Sect. 3, we present the fusion of AI

Table 2 Research questions and discussions

Research questions	Motivation
What are the current challenges in the healthcare domain in pandemic times?	The exponential rise in the number of cases has lead to overburdening of the existing healthcare infrastructure and the challenges hospital resource allocation
What is the key requirement of the healthcare domain?	The key requirement of the healthcare domain is safety, efficiency, and timely service
What is the importance of AI in the healthcare domain?	AI can reduce diagnostics time, reduce errors, predict health outcomes, and can automatically update healthcare information present in various devices
What are the potential applications of AI for COVID-19	AI can help to reduce the burden on the healthcare industry by aiding in diagnostics, helping the government in ensuring that social distancing norms are being obeyed, and can also help in the faster discovery of the vaccine
What are the advantages of integrating AI with the healthcare system?	AI decisions are data-driven, so better diagnosis efficiency and automatization of some tasks can reduce the administrative costs and unnecessary visits to the hospitals
What is the current research direction in the AI-healthcare domain?	Over the previous years, AI is being used in many domains, and especially in the healthcare domain, it is getting attention from both researchers and medical professionals

techniques in various areas to control COVID-19 situations. Section 4 highlights the challenges and future research directions in the integration of AI in the COVID-19 pandemic. Finally, Sect. 5 concludes the paper. Table 3 shows all acronyms used in the paper and Fig. 1 depicts the structure of the paper.

2 AI and COVID-19: background, definition, and motivation

This section discusses the background knowledge of various concepts used in the proposed survey such as COVID-19, and the possible integration of AI and COVID-19.

2.1 Artificial intelligence

In this subsection, we discuss the major AI techniques utilized for the reduction of COVID-19 pandemic effect. Following are the description of such techniques.

- Convolutional neural networks (CNN): It is the most frequently used DL classification technique for the datasets consisting of images and videos [61]. It has various layers which perform different tasks such as dimensionality reduction and conversion of the data to vector form [152, 171].
- Recurrent neural network (RNN): It is an upgraded and modified version of the feedforward NN. It is recurrent because each layer depends on the output of the previous layer as opposed to the case in feedforward networks [148].
- K-nearest neighbour (KNN): This algorithm is amongst the most common neighborhood classifier [55], which assumes that the similar items belong to the same class are close to each other. The algorithm can be utilized for various purposes, such as prediction and classification. However, choosing an optimum value of k is still a research question [144].
- Decision trees (DT) : The statistical model of DT represents the dataset in the form of tree-like structure [75, 92]. The model considers all the possibilities and we can track the path to the decision. Using DT on larger datasets does cause the problem of overfitting.
- Linear regression: The main purpose of this model is to minimize the prediction error on testing data. This model represents the relationship between dependent and independent variables [155]. The equation which contains only one independent variable is known as a simple linear regression model otherwise, multiple linear regression where more than one independent variable is involved [155]. This model works only for linear values.
- Logistic regression (LR): It is used when the dependent variable is in continuous form. The value can range exclusively from 0 to 1. LR can be either binary, ordinal, or multinomial. The linear regression fails when the output is in binary forms, such as to predict whether the email is spam as it is unbounded, so we utilize LR for such applications. The technique fails when the data are not in a categorical form, showing its high dependency on it [119].

2.2 COVID-19

In this subsection, we present an overview of the COVID-19 pandemic and its effects. Novel coronavirus was first discovered in Wuhan, the province of China, at the end of 2019. It is a respiratory illness, which affects the lungs the most [62]. The symptoms of COVID-19 are similar to that of pneumonia that spreads from person-to-person. WHO has announced this virus as a pandemic due to its alarming spread [131]. Scientists worldwide are trying to map this virus with the bat's genes where it was originally spread first (as the exact source is not known), but after all their efforts, no one yet has succeeded in creating the vaccine. To deal with this pandemic has been a challenging situation for the medical force worldwide. It not only affects humans, but also disrupted the wildlife life cycle [141]. The whole world is plagued with the COVID-19 pandemic, with over 15 million confirmed cases, over 700 K deaths and over 185 plus countries affected as of now. Figure 2 shows the effect of COVID-19 worldwide. Figure 2a shows the country-wise rise in COVID-19 cases and Fig. 2b depicts the country-wise death tolls in COVID-19 pandemic. The spread of the COVID-19 pandemic has been categorized into four stages as [23]:

1. Stage 1: No cases
2. Stage 2: Sporadic cases
3. Stage 3: Cluster of community spread
4. Stage 4: widespread community spread

Figure 3 shows the four different stages of COVID-19 pandemic spread. The most worrying thing about these stages is that the person does not know whether he/she is COVID-19 infected or not, and this makes it more difficult for the government to handle this situation in subduing the spread. Due to its mode of transmission (i.e., person-to-person and communicable over the air), some industries' work is shut down or closed permanently. Some industries such as air travel, oil-based, and tourism-based companies have never experienced such a downfall in many major companies' revenues, which declared themselves as a bankruptcy. It is forecasted by many global institutions such as OECD,

Table 3 Acronyms

2 D	2-Dimensional
5 G	Fifth generation
ACM	Association for computing machinery
AI	Artificial intelligence
ANN	Artificial neural network
ARIMA	Autoregressive integrated moving average
AUC	Area under the ROC curve
CCTV	Closed-circuit television
CNN	Convolutional neural network
COCO	Common objects in context
COVID	Coronavirus disease
CT	Computed tomography
DCT	Disease cancelling technology
DL	Deep learning
DNA	Deep network analyzer
DNN	Deep neural networks
DQL	Data query language
DQN	Deep Q-network
DT	Decision trees
DVB	Digital video broadcasting
EHRs	Electronic health record
EMR	Electronic medical report
FDA	Food and Drug Administration
FIP	Feline infectious peritonitis
FPI	Federation Internationale Pharmaceutique
GA	Genetic algorithm
GPU	Graphical processing units
GRU	Gated recurrent unit
GT-CNN	Ground truth convolutional neural network
ICU	Intensive care unit
IEEE	Institute of electrical and electronics engineers
IoT	Internet of things
IP	Internet protocol
KNN	k-Nearest neighbours
LASSO	Least absolute shrinkage and selection operator
LED	Light emission diode
LR	Logistic regression
LSTM	Long short term memory
L-SVM	Linear support vector machine
MDP	Markov decision process
MEC	Mobile edge computing
ML	Machine learning
MRA	Multi-radio access
MT-DTI	Molecule transformer-drug target interaction
NLP	Neuro linguistic programming
NLP	Natural language processing
NN	Neural network
NPI	Non-pharmaceutical intervention
OECD	Organization for economic cooperation and development
RCNN	Region-based convolutional neural networks
RES	Residual networks
ResNet	Residual neural network

Table 3 (continued)

RF	Random forest
RF	Radio frequency
RNA	Residual networks
RNN	Recurrent neural network
RSM	Respiratory simulation model
SCF	Spectral correlation function
SSD	Solid state drive
SVM	Support vector machine
TDD	Time division duplex
UAV	Unmanned aerial vehicle
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual reality
WHO	World Health Organization
YOLO	You only look once

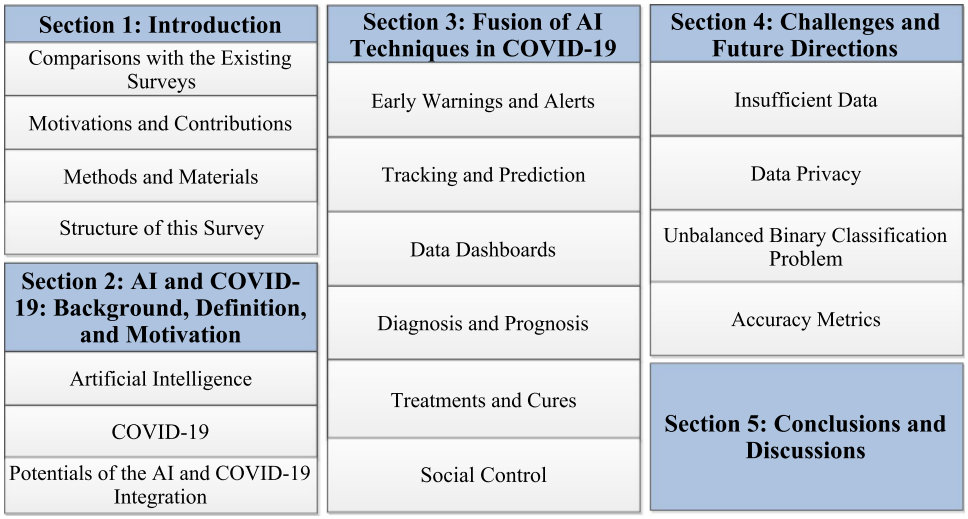


Fig. 1 Organization of paper

that this pandemic will crash the economy and the world will see its lowest economic growth rate since 2009 [43].

No vaccine has ever been developed for this coronavirus family and the course of treatment usually consists of two paths-suppression and mitigation. Suppression is to curb the virus's growth by eradicating human-to-human transmission, while the purpose of mitigation is to reduce the health impact brought on upon by the virus rather than slow down its growth [42]. Treatment usually consists of Non-pharmaceutical intervention (NPI). Since the virus has reached almost every corner of the world, many governments have enacted laws to enforce NPI on the citizens to reduce its growth. The measures imposed include maintaining social distance by avoiding mass gatherings and always wearing a mask to prevent transmission and wash one's hands regularly. This strategy was proved to be effective in the 1918 Influenza pandemic as well as [42]. The drastic rise in COVID-19 cases has prompted governments worldwide to make decisions like lockdown and shutdown, restrictions in people's movement, and barring international visitors from blunting the spread of coronavirus. Enforcing such strict measures has a drastic effect on the country's economy and governments around the world are trying to find the right balance between them. Gradually, the norms are being relaxed worldwide to encourage economic activities [5]. The FDA suggested not taking hydroxychloroquine, a drug that was thought to have some effect on the virus unnecessarily without the prescription of the doctors [143] and to use sanitizers which contains 70% alcohol to maintain personal hygiene.

This pandemic has brought new challenges to the world and the world is dependent on technologies to help and overcome these challenges. In this paper, we discuss the possible use case of AI technologies, which helps to overcome the challenges brought by COVID-19.

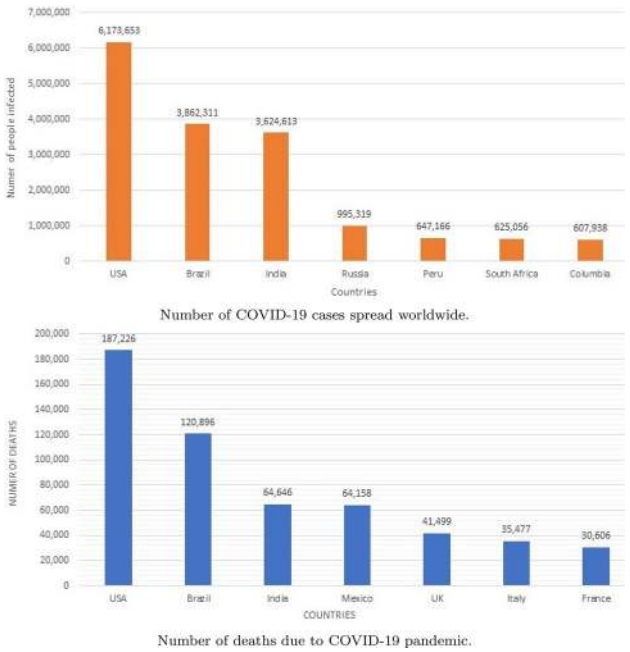


Fig. 2 Effect of COVID-19 in context to the community spread and total deaths [36]

2.3 Potentials of the AI and COVID-19 integration

In this subsection, we explain the potentials behind the AI and COVID-19 integration.

2.3.1 Challenges in COVID-19

In recent years, the prominence of AI is on the rise with its applications in every domain. Researchers have been pondering on the integration of AI and healthcare [56]. The world is in the clutches of the COVID-19 virus, i.e., never experienced before. Its direct impact is on the healthcare sector, economics, and social life [52]. The healthcare sector is facing its greatest challenge to date since due to the exponential rise in the cases, the traditional healthcare infrastructure is not sufficient to accommodate all affected patients due to its capacity and healthcare staff [103]. The same was modeled in [97] and found it was only a matter of a few weeks before all the hospitals get overwhelmed. Most of the healthcare resources and personnel are being allotted towards the care of COVID-19 patients, while the patients suffering from other diseases are being neglected [64]. The medical supply chains are also being overwhelmed at the same time, with the increase in demands of personal protective equipment and ventilators [127]. The manufacturing of drugs for other diseases is being reduced and instead, the resources are being diverted to the developing drugs in support of COVID-19. The quality assurance step in the development of testing equipment and medicines is being rushed, leading to the market being flooded with below par and false products [47, 104]. Healthcare personnel such as doctors and nurses work on the front-line and are directly in contact with the infected patients and they are at the most risk of being infected [77].

Most of the governments around the world have imposed travel restrictions and social distancing rules. Due to this, the revenue in industries such as tourism, aviation, event management, entertainment, and hospitality is almost non-existent. Major sporting events, including the Tokyo Olympics, had to be canceled, which caused billions of dollars to be lost in revenue. Educational facilities worldwide have closed, which led to almost 1 billion people being affected, as estimated by UNESCO. Trillions of dollars have been wiped out of the global financial market since the start of the pandemic. The oil price was the lowest in almost two decades due to the excess supply of oil, but the diminishing demands due to the travel restrictions and the prohibition in the movement of goods [107, 111]. Most of the manufacturing industries anticipate a decline in the turnover for the coming year, with the world economy expecting a negative growth as well [38]. On the other hand, medical and food industries are facing increased demands due to panic-buying and hoarding by the general population. The food supply

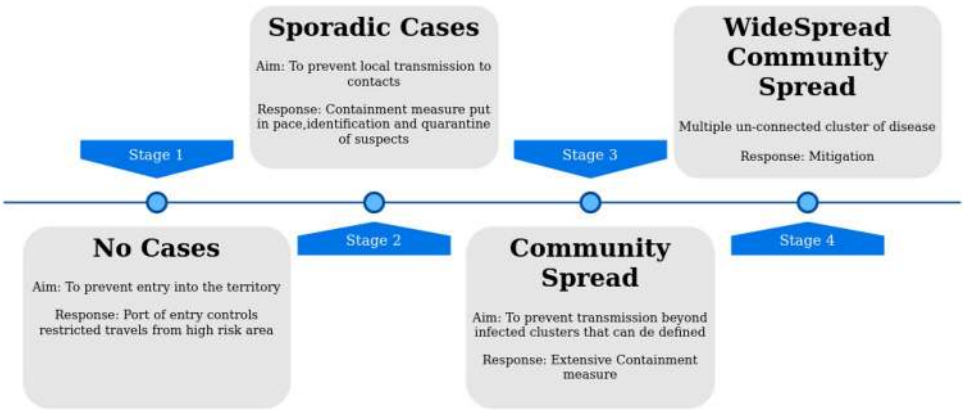


Fig. 3 Stages of COVID-19 transmission

chains must be functioning to avoid mass food shortages [44].

The government's norms have restricted the social gathering of a large number of people, leading to the closure of live sporting events and places of religious importance. Many religious and cultural festivals have not been celebrated this year [40]. Entertainment hubs such as theaters, sports clubs, etc., are closed as well [98]. Students all over the world are restricted to the home, as the educational services are closed. This has lead to the postponement of the examinations and cancellation in some cases as well as [10]. The work mode has shifted to the work-from-home model for most of the employees all around the world [21]. The norms imposed by the government has to lead to distancing from peers and family members, the fear imposed by the pandemic, the negativity that we hear in the news, and the rumors that spread in the social media platforms can make us anxious, staying at home for extended periods can lead to emotional breakdowns especially among the older and younger generations. These have led to stress in the general population and many suffering from mental diseases such as depression [109].

2.3.2 Opportunities brought by AI to COVID-19 pandemic

AI has risen to prominence in the previous few years and it has lead to wide-spread adoption by many industries in various domains. In the times of COVID-19, AI can be a powerful tool in managing harsh situations. Here are some opportunities brought by AI in this pandemic scenario as given in Table 4. The description of each opportunity is mentioned as follows.

- Human detection: The mode of transmission of the COVID-19 virus is via close contact and the governments around the world have taken steps and imposed restrictions on social contacts and gathering. However, the norms are sometimes not followed and the government should take note of this and take necessary actions. Most public places and streets come under video surveillance and AI can easily be incorporated in these systems to ensure that these government rules are being followed. The AI algorithm will monitor the video feeds 24×7, to detect all the violations and take suitable actions. An additional system in the form of mask detection can be incorporated to ensure that people wear a mask in outdoor places [105].
- Pattern recognition: AI can extract information from raw data and identify the trends, outlets, and patterns. Based on the information learned, it can further be used for prediction. As the whole world is engulfed in the pandemic, there is a shortage of trained medical staff. This is where AI can step in, it can identify the patterns in the medical reports such as X-ray, CT scans, or based on the list of symptoms available and can aid the medical personnel in making the decisions [138].
- Number plate detection: Most of the major intersections such as entry and exit points of the cities are under a high-definition video surveillance system which can be re-purposed for this pandemic situation. Contact tracing is the method of recognizing people who have come into contact with an infected person, and it has a vital role to play in the control of virus spread. Number plate detection will help track the movement of infected people

Table 4 Main characteristics of AI techniques and their potentials to COVID-19

AI features	Description	Potential applications to COVID-19 pandemic
Human detection	Locating the presence of humans present in an image or video [118]	Ensures the social distancing norms are being followed or not by detecting the distance between humans
Pattern recognition	Identifying patterns and regularities in data	Detection of COVID-19 infection by identifying patterns in previous medical reports and records and compared them
Number plate detection	Detecting the number plate on the car to recognize its owner [133]	Aids in the contact tracing project, which monitor the movement of infected people and their close contacts
Object detection	Detecting the presence of certain object present in the image or the video frame	Masks must be worn at all times to ensure that infection not spread. AI helps to analyze the video feeds and identify the rule-breakers [73]
Semantic analysis	Analyze the text for its meaningfulness	Rumors are widespread in these pandemic times and AI can be used to dispel them [108]
Classification	Classify the things based on similarity with other things in other groups	Categorize the patients based on their potential severity of infection [32]
Prediction	Using algorithms and modelings the data to make a prediction based on the historical analytics	Predict the number of COVID-19 infections in a particular region [4]
Chatbots	Software applications that stimulate human conversations	Provide emotional support and empathy to people in distress [82] aid the authorities in symptoms monitoring and disseminating the information [93]

and help track the location of people who were in close contact with such people.

- Object detection: As in the case of human detection, AI algorithms can detect the presence of a particular object in the video feed. The spread of coronavirus can be slowed if the general population wears face masks whenever in public. Governments have imposed strict rules for the compulsion of wearing face masks whenever outside the home. AI algorithms can be used to monitor that this rule is being followed and the violators will be noted and later be penalized. Figure 4 shows the captured image of the public place where AI techniques help in identifying the people without masks [37].
- Sentiment analysis: In recent years, powerful NLP algorithms have been developed, which extracts the meaning from text in the same way a human can do. Social media platforms such as Facebook and Twitter are very effective tools for dispelling information among the masses. Sometimes, rumors and fake news are often spread, which can cause mass panic among the general population [110]. These rumors once spread, are difficult to contain and often, such platforms have deployed mechanisms to curb the spread [19]. Sentiment analysis can also be applied to the web scraped data from various news and government bulletins, blogs, and other official sources to extract the information and combine it into one. This all-in-one platform can enable users to stay always informed.
- Classification: AI algorithms as discussed above, can learn the trends and patterns and can make classifications based on it. In the COVID-19 pandemic, the world is lacking hospital resources to accommodate all patients having COVID-19 symptoms. AI can classify the patients based on their medical reports and symptoms list, whether the infection's progression is worse and they would require additional resources such as ventilators. This feature facilitates proper resource management and proper patient care while accommodating as many patients as possible.
- Prediction: Prediction models are used predict the spread of the infection. Traditional prediction models used in pandemic times, such as the SIER model, often have limitations [129]. Today's advanced AI algorithms can model the data, giving better prediction statistics [80]. The algorithms can be used to predict the number of infections in days to come and identify the trends associated with it and can beforehand predict whether a region should be locked down before the situation worsens. These predictions made based on the AI algorithms can help reduce the impact of the COVID-19 if timely actions are taken based on these predictions.
- ChatBots: This pandemic has lead to mass fear and panic among the people. To overcome this fear and panic, the government has set up 24×7 hotlines to help the people with genuine information. However, the hotlines are also overwhelmed due to the rise in the number of cases and they are not able to cater to all. AI can be used to mimic human behavior and help dispel the information on their behalf [137]. The pandemic has also caused mental issues among many and the chatbots can be used as a virtual therapist to help such people [13, 17]. A chatbot can advise on how to protect against the infection, the nearest hospitals' location, the option to report, and how to self-screen [130].

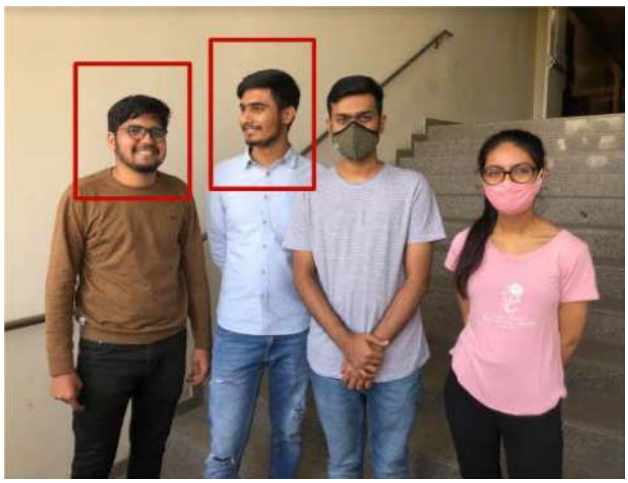


Fig. 4 Face mask detection system in COVID-19 pandemic [37]

3 Fusion of AI techniques in COVID-19

In this global health crisis, the health industry is pursuing new technologies to have proper control over the spread of novel Coronavirus. Among many technologies, AI is one technique that can easily be used, starting from early prediction to diagnosis to treat this virus. The use of AI techniques has been classified into six categories based on the intended use and the Fig. 5 shows each area and the fusion of AI-techniques in the COVID-19 pandemic.

3.1 Early warnings and alerts

The medium of transmission of COVID-19 is from human-to-human, so it is advised to maintain a distance of at least 6 feet from infected people. The spread can be prevented if the general population is alerted about its presence in some regions. Due to early warnings given to the population, they can avoid visiting such virus-infected pockets and reduce the spread of the virus [96]. Predictions can be made regarding the potential spread of the virus to some region, and such predictions can also be presented to the masses as an early warning.

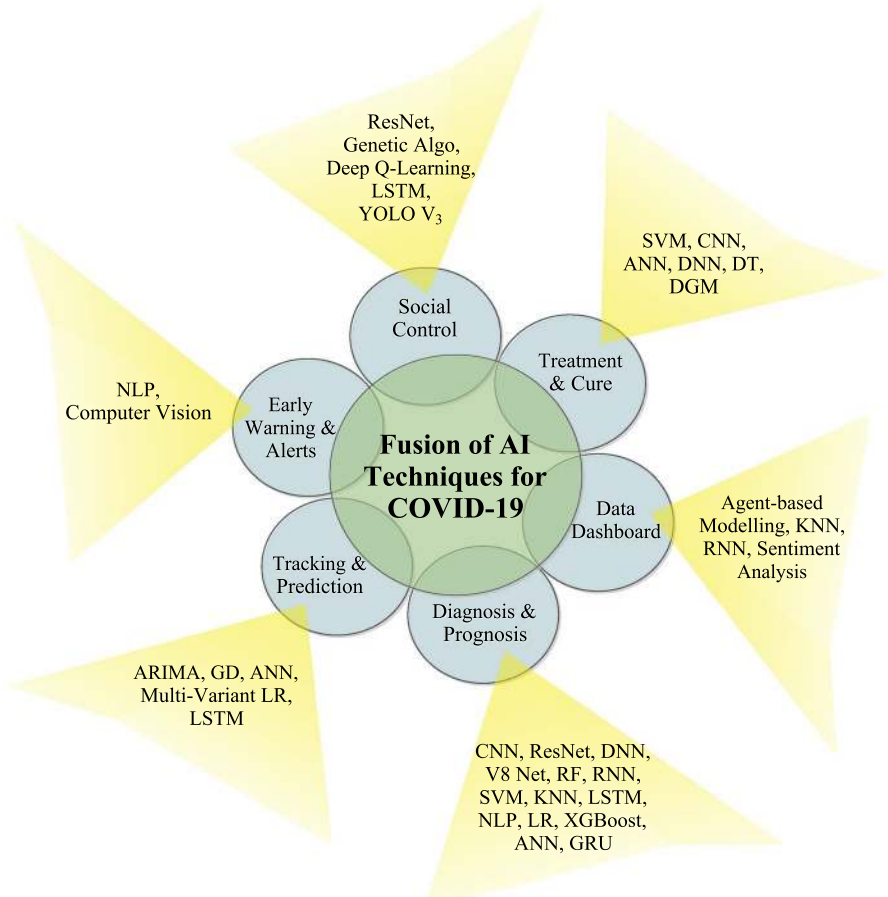


Fig. 5 Fusion of various AI techniques to combat COVID-19 situation

ANN: Artificial Neural Network, ARIMA: Autoregressive Integrated Moving Average, CNN: Convolutional Neural Network, DNN: Deep Neural Network, GRU: Gated Recurrent Unit, KNN: K-Nearest Neighbor, LSTM: Long Short-Term Memory, LR: Logistic Regression, NLP: Natural Language Processing, RF: Random Forest, RNN: Recurrent Neural Network, SVM: Support Vector Machine.

Early warning predictions can be made via AI by modeling the COVID-19 data. Allam et al. [6] discussed two such companies which are working in this domain. Bluedot is a Toronto-based company that gathers COVID-19-related data from all-inclusive sources ranging from over 10,000 official sources, including government sources and information from news outlets to global air travel data. It also employs natural language processing algorithms to extract information from such sources in over 60 languages. Using this wide variety of data, it then applies machine learning clustering algorithms to classify a region as a potential hotspot of the disease. It also warns its clients and sends alerts regularly. The company was able to predict the spread of the Zika Virus in Brazil successfully and also the spread of Ebola in Africa [84].

MetaBiota San Francisco-based company, which works in the same domain. Unlike Bluedot, which relies only on the data from official sources only, MetaBiota utilizes Neuro-Linguistic Programming (NLP) to fetch data from unofficial sources such as social media. Most of their clients are insurance companies, who are more interested in the effects of such pandemics on human behavior. The company uses ML algorithms to make predictions and also estimate the scare level which will cause [6, 41, 150]. LeewayHertz is also a San Francisco-based company, which developed the face mask detection platform that uses AI to detect whether a person is wearing a mask or not. This platform does not require any additional hardware and can be easily integrated with existing IP and CCTV cameras and is suitable for offices to ensure employees maintain safety protocols. The application sends an alert if a user is not wearing the mask, and if the face is not recognized, it is sent to the admin. The same company also developed a social distancing alert system based on AI. Their app maintains a data dashboard that keeps logs of people violating the norms as shown in Fig. 6. When the app finds people in close contact, it alerts the authorities to take appropriate action and ask them to maintain distance. Like the face mask detection system, this alert system does not require any extra hardware to be implemented [37]. Table 5 shows the comparative analysis of various AI techniques designed for early warnings and alerts.

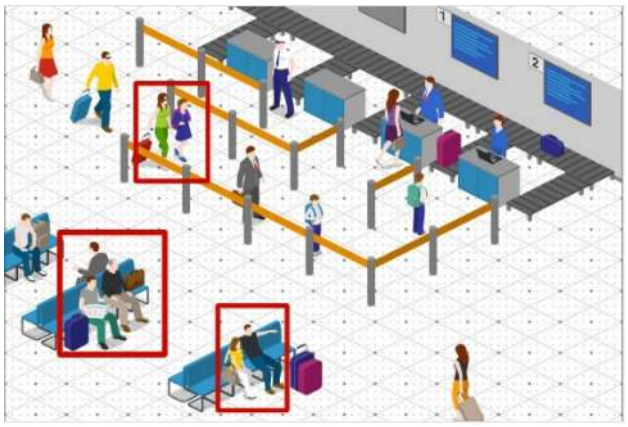


Fig. 6 Social distancing alert system during COVID-19 pandemic [37]

Twitter data were utilized in [70], which mined Twitter data and a fuzzy algorithm was used to detect the outbreak. The data were extracted from Twitter and subjected to text pre-processing, cleaning, filtering, then classification based on it and sending alert messages.

3.2 Tracking and prediction

Due to the complex and non-linear nature of novel coronavirus, we require robust mathematical and automated tracking tools that can help us predict its spread and take necessary actions to prevent further spread. Tracking and prediction tasks can be performed using ML and cloud-computing leverages edge computing technologies as well [50]. A system that can give rapid and accurate predictions can be implemented using the high computation power of cloud-computing along with the low-energy utilization of the mobile computing system. Figure 7 refers to the work done by various researchers in tracking and prediction during the COVID-19 pandemic.

Tuli et al. [154] proposed a machine learning model based on the FogBus framework, which is useful for predicting the change in the number of daily cases and classifying them country-wise. Comparing baseline models and how disastrous it will be affected if the model fits poorly was also explored. For predictions, the official dataset was taken from the WHO website. The inverse Weibull model was selected for the iterative weighted approach as it performed superiorly to the Gaussian model on all 5 datasets utilized [154]. Gupta et al. [46] proposed an AI-based ARIMA model and the exponential smoothing techniques that are the most basic modeling technique for forecasting and analyzing the current situation of India and to predict it for future trends.

Later, Malik et al. [86] proposed a ML approach to predict the number of cases from early infection dynamics. Gradient descent was used to fit the model properly. The parameters of models were taken from different epidemic models such as SI, SIR, and SIS. However, the model was trained considering the COVID-19 data of the USA only, so it can not be fitted for other countries. The exponential rise in the data has also led to a lot of variations and outliers values in the dataset leading to skewed results. ML is preferred more such datasets, as it considers all these factors for prediction. Sina et al. [9] proposed the SIER ML model by assuming that the disease beings its spread by human interactions, and the data were divided into three different classes based on the population: those who are susceptible to infection, those who are infected, and those who had recovered people and trained their mode. The model shows accuracy in places where the government delayed the spread like the United States. However, for countries like Italy and China, the ML-based SEIR model did not show promising outcomes as people were willing to quarantine themselves and restrict them for social contact.

Then, Bennett et al. [16] proposed an AI model that was quite helpful for gene formation in RNA. By identifying similarities between pneumonia and coronavirus, they developed an X-ray image scan with AI, which takes few minutes to detect the patient and recommend the treatment. The primary advantage of this method is its minimum diagnosis time [16]. One of the potential solutions to curb the exponential growth of the COVID-19 is via contact tracing. Governments are now forced to enforce wide-scale surveillance of all the residents who implement contact tracing. It is a process of identifying whether a person has come in contact with an infected person or not. This is a proven method to prevent the spread of such infectious diseases. Previously contact tracing was achieved by relying on the people but nowadays, it is implemented using smartphones to track and trace the users. This approach had been met with criticisms as it violates the privacy of users and has a risk of exposing the person's data [15].

Many challenges in predicting the number of confirmed cases were identified [1], which included the lack of historical data and the different governments' different approaches across the globe. Most of these solutions used hybrid ML models, transfer learning models, and statistics from countries with better facilities and interpolated the results on the ones with limited facilities. Liu et al. [83] proposed a ML algorithm for real-time prediction of COVID-19 based on Internet searches and news alerts. The algorithm could predict 2 days in advance, used clustering techniques, and augmented the datasets from data in small outbreaks. Another method based on utilizing Internet data was proposed by Ayyoubzadeh et al. [11]. LSTM was used to analyze the Google trends and to predict the incidence of COVID-19. It was discovered that the secondary factor next to the previous day's incidence rate was the search for personal hygiene products. Table 6 shows the relative comparison of AI-based

Table 5 A relative comparison of AI techniques used in early warnings and alert

Author/organisation	Year	Objective	AI technique	Merit	Demerits
Allam et al. [6]	2020	To identify the hotspots of the infection based on data	Neuro-Linguistic Programming	Successful presented the hotspots, as well as the scare level of the disease	Data which is being used to predict, is from unofficial sources
Long et al. [84]	2020	The authors proposed a model for detecting as well as preventing COVID-19 spread using AI Technique	Natural language processing(NLP)	Successful to Predict the spread of Zika Virus and of Ebola in Africa	Prediction depends only on Official Sources and they are propagated less frequently
Jahanbin et al. [70]	2020	The authors proposed a model to predict the outbreak using Twitter and web news by using data mining	fuzzy rule-based evolutionary algorithm	Can be integrated with Surveillance for more accuracy	Cannot be applicable where social networks are limited or non-accessible
Bluedot [6]	2020	Developed an application that gave alerts after gathering data from all-inclusive sources include government sources and information from news outlets to global air travel data	NLP	Model helps to identify the Hotspot regions of Virus	Limited availability of data
Meta-Biota [6]	2020	The authors identified hotspots based on the data from all-inclusive sources include government sources as well as from unofficial sources as such social media using AI Technologies	Neuro-Linguistic Programming	Model helps to identify the Hotspot as well as scare level regions of Virus	Limited availability of data
Leeway-Hertz [37]	2020	The authors developed a face-mask detection platform that uses AI to detect weather a person is wearing a mask or not	Computer Vision	Does not require any additional hardware	Individual's Identity or Privacy can be under threat

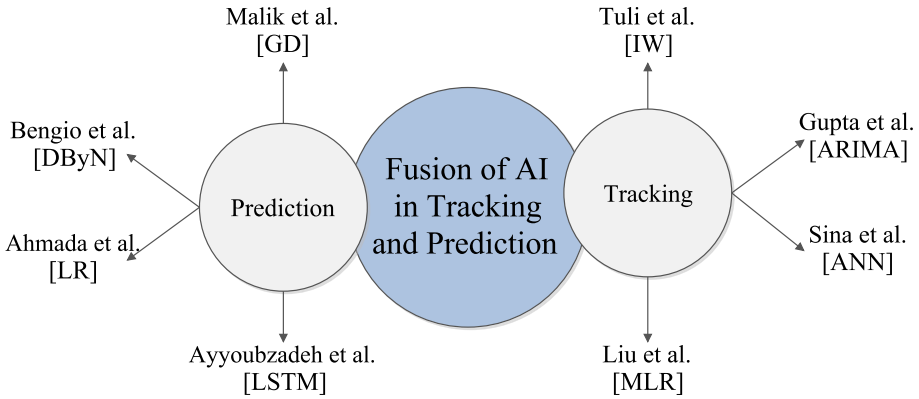


Fig. 7 Fusion of AI techniques for tracking and prediction in COVID-19

ANN: Artificial Neural Network, ARIMA: Autoregressive Integrated Moving Average, DByN: Dynamic Bayesian Network, GD: Gradient Descent, IW:Inverse Weibull, LR: Linear Regression, LSTM: Long Short-Term Memory, MLR: Multivarient Linear Regression

methodologies used to track and predict infected people in the COVID-19 pandemic.

3.3 Data dashboards

Due to the nature of transmission of COVID-19, the people must have complete knowledge of COVID-19 hotspots and be informed of the same at regular intervals. Figure 8 refers to the authors who have contributed to the data dashboards in the COVID-19 pandemic. For instance, Anodot et al., the industry leader in autonomous monitoring, has come up with their COVID-19 dashboard, which uses ML-driven analytics to monitor the number of cases region-wise [146]. The company relies on the WHO and the official Johns Hopkins University databases. It has additional functionality that alerts the user if there is a large spike in the number of infections in their area [35].

Chang et al. [26] proposed an agent-based model dubbed as ACEmod. It is being used in Australia as a data dashboard for each person that categorizes each person by their age, gender, their immunity system, and many more. The model is based on disease transmission parameters to inspect the situation of the COVID-19 pandemic. Also, several interventions were tested, including home quarantine, social distancing, and travel restrictions. The Advantage of this model is its robustness. Then, Maghdid et al. [74, 87] developed a smartphone application that the officials can use to develop the plans for a particular region. The application has contact tracing functionality, which further creates a data dashboard from the contact tracing findings. Also, the k-means algorithm is used to predict whether a particular area will be needed to put under lockdown in the near future based on the registered users' relative positions.

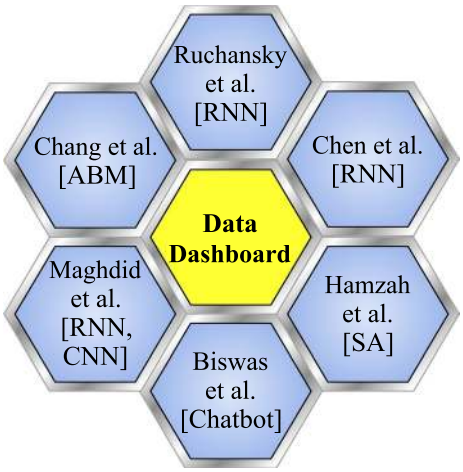
Then, Biswas et al. [18] developed the GO-COVID platform, which is a real-time cross-platform dashboard using data analytics. In addition to displaying information about COVID-19, such as the number of cases and the latest news in the segment, the platform also has an in-build chatbot based on AI for interactive interaction. Hamzah et al. [53] proposed the CoronaTracker platform for the analysis and prediction of COVID-19 outbreak. The website displayed real-time queried data and the SEIR model was used for prediction. Additional functionality included as to fetch the news and classify it as positive or negative. Panic arises among the masses from fake news spreading on social media platforms. To mitigate this issue, a dashboard developed by Depoux et al. [39] to provide real-time alerts of fake news and rumors regarding the COVID-19. Although, the proposed method did not utilize any AI component. Evident from [27, 132], AI can be a powerful tool in debunking the fake information and rumors present in social media. The comparison of various AI techniques used for data dashboards in COVID-19 situations is mentioned in Table 7.

3.4 Diagnosis and prognosis

COVID-19 has infected many people around the world, and due to this, the medical facilities have overburdened [161]. AI can help to save time by accurately predicting the diagnosis and the prognosis of the patients. It can be as accurate as a human, deliver the results faster and cost-effective compared to the standardized tests [22]. Figure 9 shows the fusion of various AI techniques presented by researchers across the globe for diagnosis and prognosis in the COVID-19 pandemic. Table 8 depicts the comparative analysis of various AI techniques for diagnosis and prognosis in tackling the COVID-19 situations.

Table 6 A relative comparison of AI techniques used in tracking and prediction

Authors	Year	Objective	AI technique	Merit	Demerits	Results
Tuli et al. [154]	2020	The authors proposed a model which predicted daily change in cases as well as classifying them using AI Technique	Inverse Weibull function	Shows better prediction result compared to baseline Gaussian model	Major factors like age difference, population density and temperature were not considered	R^2 value is 0.98
Gupta et al. [46]	2020	The authors proposed an AI-based ARIMA model for forecasting the number of cases in India and predicting the future trends	ARIMA Model	Can aid scientists as well as the government agencies to make their plans	The model is not capable to show the output of different regions	Accuracy is around 60–70%
Malik et al. [86]	2020	The authors presented an approach to predict the number of cases from early infection dynamics	Gradient Descent	Easy to implement and works successfully with aggregate data	Changing public health protocols can skew the results	R^2 value is 0.57
Sina et al. [9]	2020	The authors proposed a ML-based SIER model to predict the spread of virus via human intervention	ANN	Shows more accuracy where the government delayed the containment	Skewed results in regions where people are willing to quarantine themselves and restrict social contact	Root mean Square came out to be 1028.98 for logistic model in Italy
Bengio et al. [15]	2020	The authors proposed a model to curb the exponential growth of the COVID-19 via contact tracing	ML	Can give information about the individual risk in a detailed manner	Security breaches can violate the privacy of the users	
Ahmada et al. [1]	2020	The authors identified the number of confirmed cases using AI Technique	Multivariate linear regression	Successfully shows real-time outbreak even with small datasets	Lack of historic data as previous pandemics were different and their results cannot be used here	Models should be based on multiple types of data
Liu et al. [83]	2020	The authors proposed a model for real-time prediction of COVID-19 based on Internet searches and news alerts using AI Techniques	LASSO multi-variable regularized linear model	Able to predict output 2 days prior	Depends upon the geographical location	Normalized root mean square value was greater than 1
Ayyoubz-adeh et al. [11]	2020	The authors analyzed the Google trends and predict the incidence of COVID-19 at different region	LSTM	Very low training errors are discovered	Limited access of Google search at some regions	Root mean square value for LSTM model came out to be 27.187



ABM: Agent-based Modeling, CNN: Convolutional Neural Network, RNN: Recurrent Neural Network, SA: Sentiment Analysis

Fig. 8 Fusion of AI techniques for data dashboards in COVID-19

3.4.1 Diagnosis

Diagnosis is the process of identifying a type of illness by taking into consideration the nature of symptoms.

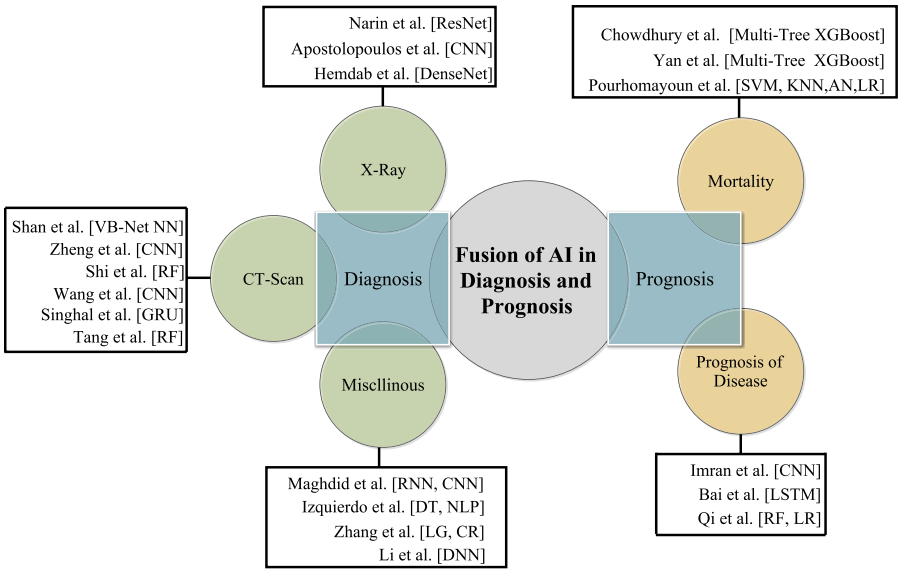
COVID-19 can be diagnosed by reading the chest X-ray of an infected person by a radiologist. AI image processing techniques can also classify the images based on COVID-19 positive and negative with a high accuracy level. Apostolopoulos et al. [8] used CNN along with transfer learning on two datasets of X-ray images containing three labeled classes of data infected with COVID-19, infected with normal pneumonia, and healthy with no infections. The advantage of using transfer learning was that it could detect small abnormalities with good accuracy. The accuracy achieved was 96.78% [8]. COVIDX-Net was a DL approach proposed by Hemdan et al. [58] in which 7 different DL classifiers were used on a dataset of 50 X-ray images out of which 25 were COVID-19 positive. VGG19 and DenseNet showed an accuracy of 90%, although their training and testing time were substantially is higher than others. The only issue with this approach is the small dataset for training purposes [58]. Narin et al. [100, 150] have used three different CNN models on a dataset of 100 X-ray images out of which 50 were COVID-19 positive. All these models were pretrained and out of the three, ResNet50 provided the highest accuracy of 98% which was closely followed by InceptionV3 which gave an accuracy of 97%. The proposed system is end-to-end and to go around the problem of having a limited data set, which reuses a pre-trained model on a new problem [100]. A mobile COVID-19 detection system was proposed by Li et al. [81] dubbed as COVID-MobileXpert used the X-ray images captured by the mobile camera for diagnosis. They created a mobile application and a novel 3-player knowledge transfer and distillation framework. The entire model consists of three networks—the attending physician (extract all the features from the dataset), resident fellow (learns to identify COVID-19 from regular pneumonia), and the medical student network (to perform the on-screen test on the mobile application. An image is taken from the mobile camera, which then screens the image. The snapshots taken can be noisy, so the training method for the Medical student network was implemented [81].

Other than using X-ray images to detect COVID-19 infection, CT images of the lungs can also be used for diagnostic purposes. The diagnosing of CT images also requires a skilled medical practitioner. AI techniques can similarly be used to CT scan images for diagnosis. Shan et al. [136] proposed a DL-based approach, which used the VB-Net neural network to segment the images. To increase the accuracy of the system, the human-in-the-loop strategy was implemented, which increased the accuracy by refining the diagnosis. The model also outputs the rate of infections and can accurately estimate the shape and size of the infection [136]. Zheng et al. [172] proposed a CNN approach dubbed DeCoVNet, which was a weakly supervised algorithm. The proposed algorithm has a peak accuracy of 90.1% [172]. The transfer learning approach was utilized on an inception network in [158], which has an accuracy of 83.9% and when tested on images from external hospitals, it got an accuracy of 73.1%. Shi et al. [139] developed an infection size aware random forest (iSARF) method which used the concept of random forests and decision trees. The images were first classified on the basis of infected legion size using decision trees and then were further classified using a random forest algorithm. The iSARF algorithm got an accuracy of 87.9% [139]. RF was also implemented to estimate the severity of the COVID-19 infection as either severe or non-severe to decide the further course of action [149]. It was found that the RF algorithm with 30 features performed the best with 87.5% accuracy. In this domain Mccall et al. [90] in his paper mention the implementation of the infra-vision AI. He proposed an AI model which will be helpful to diagnose lung CT scan, helpful for measuring the symptoms of coronavirus, it also measures the patient's lungs dimension in terms of its length and to analyze the different lesion of lungs form its pictures, which will be helpful for the doctors to make a decision. The main advantage of this is the doctors would not have to wait for the reports, which will take around 15 min manually. Instead of that, they could get the result in 5–10 s only [90].

Most of the COVID-19 patients show a rapid respiration rate and this was used to diagnose in the method proposed by Wang et al. [159] in their respiratory simulation model (RMS) framework. A depth camera was utilized and a gated bi-directional RNN with an attention mechanism

Table 7 A relative comparison of AI techniques used in data dashboards

Authors	Year	Objective	AI technique	Merit	Demerits	Result
Chang et al. [26]	2020	The authors proposed the ACEmod model which was based on disease transmission parameters	Agent-based modeling	The model shows robustness as it was being used previously	Depends upon the geographical regions	Social distancing is the best measure against COVID-19
Maghdid et al. [87]	2020	The authors developed a smartphone application which the officials can use to develop plans for a particular region	KNN	Helped officers to decide regions required to be contained	Can lead to privacy issue since it monitors User's location	For larger dataset DL can yield better results
Biswas et al. [18]	2020	The authors developed a build-in chatbot based on AI for interactive interaction for the users	chatbot	Very useful for medical emergency	Sufficient amount of data is required based upon different location	Proposed application has more features then most of applications available currently
Hamzah et al. [53]	2020	The authors proposed a SEIR model called Corona tracker platform for the world-wide outbreak analysis and predictions	Sentiment analysis	Transparency in data	It relies more on public reaction and emotion	Accuracy is around 93–95%
Chen et al. [27]	2018	The authors proposed a model for early detection of rumors using AI techniques	RNN	Results are more accurate and speedy compared to other competitors	Large datasets need to be managed manually	Average lag time of 20.47 h
Ruchansky et al. [132]	2017	The authors proposed a model for identification of fake news spreading using AI technique	RNN	Achieved very high accuracy compared to other models	Total output is depend upon all three sub components	*F*-score for twitter and weibo datsets are 0.894 and 0.954, respectively



CNN: Convolutional Neural Network, DNN: Deep Neural Network, GRU: Gated Recurrent Unit, LG: Logistic Regression, LSTM: Long Short-Term Memory, NLP: Natural Language Processing, NN: Neural etwork, RF: Random Forest, RNN: Recurrent Neural Network, SA: Sentiment Analysis

Fig. 9 Fusion of AI techniques for diagnosis and prognosis in COVID-19

was applied to it. Their classifier aimed to classify the breathing pattern in one of the six possible patterns and it was able to do so with an accuracy of 94.5% [159]. A similar system was proposed by Imran et al. [67] in their proposed mobile app called AI4COVID-19. The app is asked to upload their 2-s cough sample to the cloud, where the AI algorithm diagnoses it. It has an accuracy of 90%, which is thought to increase as more samples become available for more training. The proposed system uses three independent classifiers. If all three clusters based on different algorithms returned the same result only then the result is passed or else that sample is labeled inconclusive [67].

A novel framework was proposed by Maghdid et al. [88] in which embedded sensors of the smartphone were used to diagnose COVID-19. Various sensors were used to capture the features. One of the symptoms of COVID-19 is fatigue, so using the camera, videos are captured to detect human fatigue. Fever may spike due to the infection, so on-board temperature fingerprint sensors were utilized. Using the microphone, the sound of coughing was also recorded. To detect the presence of headaches, the posture of the neck was monitored using an inertial sensor. These readings are then uploaded to the cloud, where various ML algorithms were applied and then compiled to diagnose the prediction [88]. Then, Singhal et al. [143] proposed a DL technique for the analysis of respiratory pattern to identify the patient is having coronavirus or not. It was also mentioned how the GRU approach was useful in reading the radiological rays that study CT images to know whether the patient is positive. This method reduces the doctor's time to read the respiratory patterns [143].

3.4.2 Prognosis

Due to the exponential spread of the COVID-19 pandemic, most of the existing medical facilities are overburdened and complete care to all the infected patients may not be possible in some regions. Pourhomayounet al. [120] devised an AI technique to aid the medical staff in the decision-making process. Their proposed model predicted the mortality of a patient with an accuracy of 93% from virus nucleic acid information from a dataset of more than 100,000 confirmed patients worldwide. The patients with higher mortality rates should be given more priority and also be assigned more hospital resources. Many algorithms were unitized and tested, but the neural network approach worked the best performance and accuracy-wise [120]. Multi-tree XGBoost algorithm was proposed by Chowdhury et al. [29] for the prediction of mortality based on the dataset of 375 COVID-19 positive patients in China. The AUC achieved was 96.1% and it was able to identify the ten key biomarkers responsible .

Zhang et al. [169] proposed the use of CT scans for predicting the progression of infection with the help of clinical parameters such as blood and oxygen stats through the LightGBM and CoxPH regression models. It was found that, the presence of lesions on the lungs was an important factor in the prediction of COVID-19 and based on they studied by the model. They classified the patients into low risk, medium risk, and high-risk groups. Then, Bai et al. proposed an AI-based system to identify patients with mild infection with potential life-threatening progression. For training, the dataset of 133 patient's CT scans was taken at the time of their admission to the hospital and when the symptoms

Table 8 A relative comparison of AI techniques used in diagnosis and prognosis

Authors	Year	Objective	Dataset	AI technique	Merit	Demerits	Result
Aposto-lopoulos et al. [8]	2020	The authors utilized AI technologies on X-ray images containing three labeled classes of data	X-ray image	CNN	Technique is capable of ignoring minor positional differences	Dataset used was not very large	Accuracy achieved was 96.78%
Hemdab et al. [58]	2020	The authors utilized AI technologies on X-ray images to identify the infected individual	50 X-ray images	DenseNet	Technique shows good convergence as well as fast running time in processing	Dataset used was not very large	Accuracy achieved was 90%
Narin et al. [100]	2020	The authors diagnosed the X-ray images using AI technologies	100 X-ray images	ResNet50	Less affected by Oscillation compared to other models	Accuracy is low on tested data as compared to train data	Accuracy achieved was 98%
Li et al. [81]	2020	The authors proposed a mobile COVID-19 detection system diagnosed by a novel 3-player knowledge transfer and distillation framework	Images of mobile camera	DNN	No need to come into the contact of individual	Snapshot taken could contain Noise	Accuracy achieved was 93.5%
Shan et al. [136]	2020	The authors diagnosed CT Scan images of lungs for the detection of Covid using AI technologies	300 CT scans images of lungs	VB-Net neural network	Successfully estimate the shape and size of the infection	It exists human intervention	Accuracy achieved was 93.5% in third iteration
Zheng et al. [172]	2020	The authors diagnosed CT Scan images of lungs for the detection of Covid using AI technologies	DeCoVNet	CNN	No need of human intervention	A few small areas of COVID-19 infected is missed	Accuracy achieved was 90.1%
Wang et al. [158]	2020	The authors diagnosed CT Scan images of lungs for the detection of Covid using AI technologies	CT images	CNN	It can distinguished different types of viral pneumonia	Accuracy decreased to 73.1% when tested on external Images	Accuracy achieved was 83.9%
Shi et al. [139]	2020	The authors developed an infection size aware random forest; (iSARF) method to diagnosed CT Scan images	CT images	RF and DT	No human intervention also	Several coronavirus symptoms, as well as possible treatments of Pneumonia subtypes are left in this model	Accuracy achieved was 87.9%

Table 8 (continued)

Authors	Year	Objective	Dataset	AI technique	Merit	Demerits	Result
Tang et al. [149]	2020	The authors diagnosed studied about COVID-19 using numerical data that are analyzed from CT images of the chest	CT Images	RF	Without human intervention, the severity of COVID-19 infection can be measured automatically	Due to very limited data, COVID-19 patient could only be classified into two types	Accuracy achieved was 87.5%
Wang et al. [159]	2020	The authors proposed a respiratory simulation model (RMS) framework used to diagnose COVID-19 patient	Different respiratory patterns	RNN, BI-AT-GRU	Due to limited real world training data, the model generates data	Any activity in human body results into error	Accuracy achieved was 94.5%
Imran et al. [67]	2020	Authors developed a Mobile app known as AI4COVID-19 to diagnose COVID-19 patient	Different cough sample	CNN	It can distinguished different types of viral and non-viral cough	Not effective with limited data	Accuracy achieved was 90%
Maghdid et al. [88]	2020	Authors have developed a framework in which embedded sensors of the smartphone were used to diagnose COVID-19 using AI Technologies	Fingerprints, images of neck postures, recorded audios	RNN, CNN	The Framework do not require any external sensors to diagnose	Limited Network at different geographical location may arise problem	Accuracy achieved was 90%
Singhal et al. [143]	2020	Authors have proposed a framework for analysis the respiratory pattern for the identification of a patient having coronavirus	CT images	GRU	Result can be known without coming to the contact of patient	Reading these radiological rays is difficult for health workers	
Pourho-mayoun et al. [120]	2020	Authors have predicted the mortality of a patient from virus nucleic acid information by diagnosing Covid-19 patient	Demographical data of 117,000 patients	SVM, KNN, logistic regression, ANN	Despite the broad dataset, the techniques produce fast and significant results	Better accuracy can achieve if large dataset is used	Accuracy achieved was 93%
Zhang et al. [169]	2020	The authors predicted the progression of the infected patient from its blood and oxygen stats	Blood and oxygen stats of patients	LightGBM, CoxPH regression	High accuracy	time consuming as well as Lots of Computational is required	Accuracy achieved was 92.45%

Table 8 (continued)

Authors	Year	Objective	Dataset	AI technique	Merit	Demerits	Result
Bai et al. [12]	2020	The authors proposed an AI-based system to identify the patients with mild infection with potential life-threatening progression	133 patient's CT scans	LSTM	The system is easy to use as well as can quickly classify a person's fever	Limitation of data as well as CT data are not with enough detail	Accuracy achieved was 95.4%
Qi et al. [125]	2020	The authors proposed a model to predict the hospital stay of COVID-19 positive patients	CT scans Images	RF, LR	The model is less sensitive and produces consistent results	LR model is more sensitive than RF model	Accuracy achieved was 97%
Yan et al. [164]	2020	The authors proposed a model based on XGBoost algorithms to predict the mortality of the COVID-19 Patients	Blood samples of 404 infected patients	DT,Logistic Regression	Model shows very accurate results for Lactic Acid dehydrogenase test which play's vital role for any person's medical condition	Model is data-driven, hence accuracy will vary much when different dataset will use	Accuracy achieved was 93%
Izquierdo et al. [69]	2020	The authors proposed a model to identify the factors which resulted in the ICU admission of the patients in hospital admission	Electronic health records (EHRs) of patients	Decision tree, NLP	No human involvement is required for linking the variables	Variables used in the model were very less compared to data of actual situation	6% of total hospitalized patients requires ICU admission
Yan et al. [165]	2020	The authors proposed a model based on three clinical features for the prognostics prediction of the COVID-19 infection	Electronic records of 2799 patients	Single tree multi-tree XGBoost	Helpful at the hospitals with less medical equipments and health staff	Limitation of data	F1-score achieved was 0.93

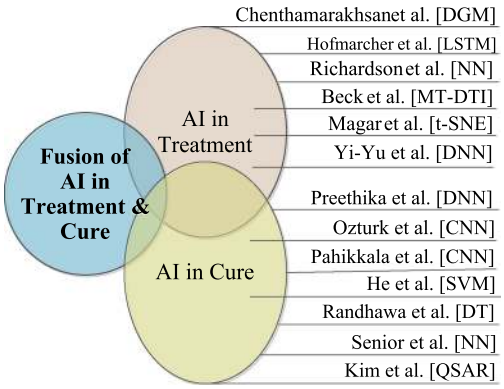
were the worse. LSTM model performed the best with area under curve (AUC) of 95.4% [12]. Later, the authors in [125] have given an innovative machine learning approach to predict the hospital stay of COVID-19 positive patients. The model used the CT scans and classified the patients into two groups, one with a hospital stay of fewer than 10 days and the other with more than 10 days. The data were modeled using random forest and logistic regression, with the latter performing better with 97% AUC.

Yan et al. [164] proposed a DT model based on XGBoost algorithms to predict the mortality of the COVID-19 patients and achieved a peak accuracy of 93%. Huang et al. identified the 17 factors which differed on the admission of patients with mild and severe cases using multivariate LR [63]. Izquierdo et al. [69] used ML and NLP algorithms to identify the factors, which result in the ICU admission of the patients using the data taken from patients on hospital admission. The training dataset was data of over 10,000 patients and used NLP algorithms to mine data from the EHRs [151] and a DT was made for classifying the patients based on admittance to ICU or not. Yan et al. [165] proposed a ML-based model with 3 clinical features for the prognostics prediction of the COVID-19 infection. XGBoost prediction algorithm was used for the same and managed to predict the mortality risk accurately.

3.5 Treatments and cures

The only way to subdue the virus is by devising effective treatment and cure methods. Figure 10 shows various AI approaches for identifying symptoms of COVID-19 and treating accordingly. For example, Yi-yu et al. [76] proposed an AI approach, valid for the identification of therapeutic medicine having a potential effect on the patient suffering from the COVID-19 infection. For these two different databases were used, the first one included the chemicals responsible for the pandemic like the influenza virus, SARS-COV, and SARS-COV-2, and the second dataset for protease inhibitors. After testing many AI predicted drugs in vitro-cell-based against feline coronavirus, eight of them have to show the controlled reaction against the Feline infectious peritonitis (FIP) virus, and the other five medicine was also found active. This model helps to identify old drugs, helpful for the FIP virus, but still, it is remaining to be tested against the SARS-COV-2 [76].

Then, Preethika et al. [122] explored molecular surveillance, which is the mechanism of collecting the genetic sequence of the virus and doing analyses on it. The main advantage of this method it shows the insights of the spread of this virus through the understanding of its pathogens and will be equally helpful for the front-line personnel to tackle this pandemic [122]. On similar lines, Beck et al. [14] proposed a DL model, for drug re-purposing called molecule



CNN: Convolutional Neural Network, DGM: Deep Generative Model, DNN: Deep Neural Network, DT: Decision Tree, LSTM: Long Short-Term Memory, MT-DTI: Molecule Transformer-Drug Target Interaction, NN: Neural Network, QSAR: Quantitative Structure-Activity Relationship, SVM: Support Vector Machine, t-SNE: t-Distributed Stochastic Neighbor Embedding

Fig. 10 Fusion of AI techniques for treatments and cures in COVID-19

transformer-drug target interaction (MT-DTI), which uses an AI-based system in account to predict drug-target interaction on the drugs that are currently available in the market. The model was pre-trained, taking drugs like proteinase and helicase into account, which showed positive results to fight this coronavirus. The decision was taken on the basis of the chemical sequence and amino sequence of these drugs [14]. This approach's advantage is that it does not require any structural data of proteins, which becomes a hindrance for 3D structure-based docking approaches. Compared it through different approaches like deepDTA [112], simBoost [57] and KronRLS [114] MT-DTI approach shows better results [14]. Stebbing et al. [147], collaborating with a startup in the United Kingdom-based on AI technologies also mentioned the drug Baricitinib. They have identified that the drug has a potential against the SARS-COV2 because of less binding with plasma protein and limited interaction with drug transporters. This kind of work illustrates to us how AI-driven production of drugs can be helpful for mankind [147].

AI-based ML technology becomes popular in the research field. Based on that, Magar et al. [85] proposed an ML-based model to predict the total number of synthetic inhibitory antibodies against the coronavirus. To train the model, a dataset consisting of the antibody-antigen sequence against various viruses was used. In total, 1933 samples were collected, which had antibody sequencing for the virus and trained the model. In the end, it was found that a total of eight antibody sequences have the potential to fight against the diseases. The problem with this is quite expensive and time-consuming [85]. Then, Randhawa et al. [126] proposed a model in which ML and a digital image processing technique were used to study the genome of coronavirus. Using

a DT approach over 5000 different genome sequences, the author claims that using this method, he can successfully discover the relationship between different viral genome in few minutes with 100% accurate classification, which will be very useful for the development of medicine [126].

Andrew et al. [135] explored how Google Deepmind uses the protein structure to identify the amino acid sequencing. In this, a NN model was also proposed that can be used to identify the distance between the residual pairs which will be more helpful in knowing information through prediction. This predictive system called Alphafold has achieved a high accuracy without much homogeneous sequence and with a comparatively less complicated algorithm [135]. Richardson et al. [128] proposed an ML-based model called BenevolentAI, in which a knowledge graph was created from the biomedical data coming from both organized and non-organized sources. In this method, different compounds were coupled and their protein sequences were observed in which baricitinib was much effective. The advantage of this model is that, the early prediction of coronavirus is possible by knowing endpoints such as the MuLBSTA score [128].

Chenthamarakshan et al. [28] proposed the CogMol model, which is a deep generative model trained through SMILES VAE embedding and a large corpus. The model also involves silico screening to assess toxicity in parent molecules. The model has tested on three target proteins of SARS-COV-2: the main protease, receptor-binding domain, and non-structural protein. This is the main advantage of this because it is a generic and dynamic method and could provide significant results against the virus. This model's only disadvantage is its less accuracy if some biased data is used to train the model [28]. Then, Hofmarcher et al. [59] mentions a 'ChemAI' a DL technique to identify all the molecules which are effective against the effects of the COVID-19 pandemic. A ligand-based screening was conducted over a database that consisted of 1 billion molecules of the ZINC database. This model predicts up to 6269 outcomes and has accuracy from 69 to 78% when tested by AUC [59].

Later, Kim et al. [78] proposed an AI-based model known as the Disease Cancelling Technology (DCT) platform, which is useful to identify the effectiveness of FDA approved drug against the virus. It was also mentioned that the high-affinity prediction model claims FDA drug which can block the virus by binding it with ACE2 [78]. Han et al. [54] presented an algorithm based on SVM for predicting the growth spectrum of confirmed new cases, deaths, and new cured cases. shiblyet al. [140] used a Visual Geometry Group Network known as OxfordNet along with a convolutional neural network to detect patients with covid by examining their X-ray images. They used 50 chest X-ray images and 25 confirmed COVID-19 cases to validate their findings. The Accuracy achieved was 97.36% with 97.65% sensitivity. Prakash et al. [121] introduced an ML-based algorithm which is the preferred approach for COVID-19 case assessment and laboratory testing of molecules of respiratory tract samples.To evaluate their features and create ML models for performance assessment, the two datasets Covid-19-India and COVID-19-data from Kaggle were used. The accuracy achieved was around 96.7%. Ozturk et al. [113] develop a deep model for early detection and treatment of COVID-19 events. They investigated the DarkNet model as a classifier for a YOLO (you only look once) real-time object detection method. They used 17 convolutional layers then applied various filtering to each one. Accuracy Achieved was 98.08% for binary classification. Jamshidi et al. [71] presented an Artificial Neural network Model for diagnosis and for treatment of COVID-19 diseases. Both clinical and non-clinical datasets were used to estimate desired parameters. The comparative analysis of various AI techniques used for treatment and cures is mentioned in Table 9.

3.6 Social control

The best way to curb the spread of the COVID-19 virus is via the practice of maintaining social distancing. Figure 11 shows the work of various researchers worldwide in the field of social distancing to restrain the effect of the COVID-19 pandemic. For example, Broniec et al. [20] who utilized the VERA model to measure the impact of social distancing on the virus spread by running simulations on a population of 10,000 people. The model has used different values for average contacts per person per day and found that on decreasing its value by a slight amount, the number of days to reach a particular threshold increases [20]. This was further supplemented by the SIRNet framework, which is an LSTM model. It found that mobility of less than 50% will lead to containment of the virus and that of more than 70% leads to an uncontrolled outbreak [145]. These findings speak of the importance of social distancing.

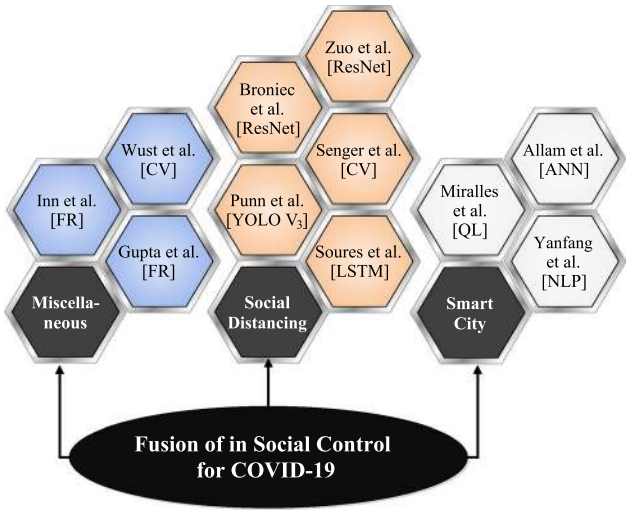
Allam et al. [7] used AI with IoT technology that the government can use with standard protocols to maintain the social distancing and take the steps for virus containment in Urban areas. For example, thermal cameras installed in the street can help the government not only for early tracing. Still, they will help by providing the data for people to make further protocols and decisions for virus containment. Then, Inn et al. [68] explained the potentials of smart cities technologies with the help of the implementation example of China [142]. Infrared cameras and facial recognition systems were utilized, which achieved an accuracy of 95%, even if the person was wearing a face mask. Another implementation example was using robots controlled by AI and equipped with 5G technology along with infrared and face recognition cameras [48]. The robot was capable of scanning up to 10 people in a radius of 5m simultaneously. This

Table 9 A relative comparison of the fusion of AI techniques in treatment and cure

Authors	Year	Objective	AI technique	Merit	Demerits	Results
Yi-Yu et al. [76]	2020	The authors proposed an approach to identify the potential of therapeutic medicine using AI	DNN	Eight of proposed methods have shown the controlled reaction against the FIP virus	Helpful only to identify old drug	Celecoxib and tolcapone were found to have antiviral properties when tested against the FIP coronavirus
Preethika et al. [122]	2020	The authors analyzed the genetic sequence of the virus through molecular surveillance	Multi-task DNN	Helpful to show insights of spread of this virus	Non-existence of proper data warehouse of this disease	This robotic drones were found to be capable of covering large area of spraying disinfectants from the height of 4–300 m
Beck et al. [14]	2020	The authors predicted the potential of DTI drugs available in market against the virus using AI Technique	DL	Shows higher accuracy against deepDTA, SimBoost, and KronRLS	There do not exist a proper evidence that it will be capable for SARS-CoV-2	Without knowing structural information the method able to find binding affinities
Magar et al. [85] T	2020	The authors identified the synthetic antibodies against the virus	ML	Eight potential antibodies were identified	Quite time-consuming and expensive	Accuracy achieved was 90.57%
Randhawa et al. [126] C	2020	The authors studied the genome of COVID-19 using machine learning	DT	It has ability to analyze large dataset in very less time	Bigger dataset should be used	Upto 100% accuracy achieved in some classifications utilized
Senior et al. [135] C	2020	The authors identified the amino acids sequencing	Neural network (NN)	High accuracy	Needs more testing for greater reliability	It has a Templete modeling score of at least 0.7
Richardson et al. [128] T	2020	The authors identified the effects of drugs	NN	High accuracy	Serious side effects of the drug and shouldn't be use unless absolutely necessary	Baricitinib was identified as potential treatment
Chenthama-rakshan et al. [28] T	2020	The authors identified the effect of drugs	Deep generative model	Generic and dynamic method	Low accuracy and tends to be biased	6 AP2-associated protein kinase 1 with high affinity were identified
Hofmarcher et al. [59] T	2020	The authors identified the molecules that are effective against COVID-19	DL	Over 1 billion molecules were considered	Low accuracy in the range 69–78%	The top ranked molecule by ChemAI has achieved the Accuracy of 82.4% with clinical toxicity of 0.06
Kim et al. [78] C	2020	The authors identified the potentials of two technologies to identify drugs	Quantitative structure-activity relationship DL model	Many potential drugs were identified	Validation is still required before taking it to the market	The highest ranked antiviral agents discovered were fosamprenavir, emricasan and glutathione
Ozturk et al. [112]	2018	The authors studied the sequencing of protein for both drug and target and also to predict binding affinities between DT interactions	CNN	Achieved the best Concordance Index performance	Its accuracy is less when compared to MT-DTI model	Concordance Index achieved was 0.718

Table 9 (continued)

Authors	Year	Objective	AI technique	Merit	Demerits	Results
He et al. [57]	2017	The authors identified protein affinities as well as continues values of binding affinities using AI technique	SVM	All performance metrics shows higher accuracy for continues values of data	Not applicable to predict discrete values	Concordance Index achieved was 0.847
Pahikkala et al. [114]	2015	The authors studied the continuous existence of the drug-target interactions for kinase inhibitors	2D CNN	Shows more accuracy compared to DrugBank and TTD	To be tested on data of SARS-CoV-2	Accuracy achieved was 82.9%
Han et al. [54]	2020	The authors predicts the confirmed new cases, deaths, and new cured cases in US	SVM	Method works well for the data which is weak periodical	DataSet size was small	Square correlation coefficient was around 99%
Shibly et al. [140]	2020	Used X-ray images to detect patients with covid-19	CNN	Testing of large datasets is possible	Require the guidance of physicians and radiologists	Accuracy achieved was 97.36%
Prakash et al. [121]	2020	Examine assessment and laboratory testing of molecules of respiratory tract samples	Decision Tree	Testing of large datasets is possible	Less Accurate for different Covid-19-India dataset	Accuracy achieved was around 96.7%
Ozturk et al. [113]	2020	Examine assessment and laboratory testing of molecules of respiratory tract samples	Decision Tree	Helped radiologists to assist in locating the affected areas of chest-X-rays	Require human intervention	Accuracy achieved was around 98.08%
Jamshidi et al. [71]	2020	For diagnosis and for treatment of covid-19 diseases	ANN	Model assist physicians in the training of machines	More Complex	20% of SARS-CoV-2 patients have positive viral RNA in their feces



ANN: Artificial Neural Network, CV: Computer Vision, FR: Face Recognition, LSTM: Long Short-Term Memory, NLP: Natural Language Processing, QL: Q-Learning

Fig. 11 Fusion of AI techniques for social control and cure in COVID-19

reduced manpower as well as preventing infections to healthcare professionals [68].

Gupta et al. [45] explored the smart cities and intelligent transport system (ITS) technologies to sanction the social control measures. ITS and AI systems clubbed together can be used to identify the traffic hot spots of the cities. These are the regions that need the strictest regulations as well as need to be disinfected regularly. Another use-case discussed was tracking the vehicles, just like contact tracing the population. The vehicle will be recognized using an AI-based plate reader and tracked and monitored if it comes from an infected region. Other use-cases discussed included using drones and UAVs to monitor and disseminate large crowd gatherings [91, 117], using AI to assign parking to reduce contact between people, and to route the vehicles though designate testing zone and ensuring that the waiting time is the least for all [45].

An approach to ensure social distancing protocols was proposed by Punn et al. using DL algorithms. Their approach has used the YOLO v3 algorithm for person detection and tracking from video surveillance [115]. This real-time approach will identify the clusters of people and calculate the number of violations and inform the authorities as well [124, 163]. Another approach was proposed in [134], which used the combination of computer vision and DL algorithms. For each person, detected a box was drawn around him/her and its centroid was calculated. The distance between the centroids was considered, and if it was below the permissible limit, then the message was displayed. Then, Wuest et al. explored the potentials of AI in the case of the Manufacturing and supply network in the COVID-19 times. The study included use-cases such as utilizing AI for designing process of products and processes, predicting the demand and possible storage in the future of a product, virtual and augmented reality for remote support, and using wearable devices along with AI-based computer vision system to ensure social distancing norms are being followed in factories or not [160].

Yanfang et al. [167] developed an AI-Driven System that will help areas where there is a possibility of community spread. In this kind of system, α-satellite has been developed to handle risk management and maintain social awareness about the pandemic by collecting a large scale of real-time data heterogeneously from different sources like demographics, the total number of testing, cases, and deaths per million people, Social media, and public health data [116]. The advantage is that it was successfully able to tell the risk at the community level and has been adopted in China as well [167]. Similarly, handling such data that display the output category and mapping data from input to output both are difficult tasks to handle for a model [95]. Miralles et al. [94] presented a novel algorithm based on deep Q-Learning and genetic algorithm to optimize the government actions concerning the pandemic. The actions which the government usually takes, such as isolation, confinement, lockdown, and social distancing, were all evaluated using a reward function. Whenever the government had to impose a lockdown, a heavy penalty was levied upon. The algorithm will present the best course of action, keeping in mind two factors: the number of infections should be minimal and the effect should also be minimal on the economy.

Then, Zuo et al. [173] presented an interactive dashboard using a video feed from various sources for analysis of mobility and sociability trends. The analysis process was completed using the ResNet framework and the platform was deployed on the cloud. A similar platform was developed in [170] which anonymously used mobile device location and give analysis such as the proportion of people staying at home and trip information. Table 10 shows the comparative analysis of various AI techniques used for social control.

4 AI-based suitable vaccination suggestion for COVID-19 treatment and cure: a case study

To demonstrate the usefulness and versatility of AI techniques in the COVID-19 pandemic, we present a case study. In this, we specifically focus on applying AI techniques for the treatment and cure of COVID-19. Since the emergence of COVID-19 in November 2019, scientists worldwide have been collaborating and racing against the time to develop an effective vaccine for immunization against it. Many governments worldwide have approved

Table 10 A relative comparison of AI techniques used in social control

Authors	Year	Objective	Merit	Demerits	Result
Broniec et al. [20]	2020	The authors identified the impact of social distancing on the virus spread by running simulations	Conceptual Modeling is followed instead of Mathematical Modeling	Results shows variation according to data taken into account	Graph shows flattening of the curve in the number of people infected vs time from the first infection
Soures et al. [145]	2020	The authors identified the importance of Social Distancing using SIRNet framework	The model successfully fit into the data collected from 28 different countries	It only reflects about the nominal mobility	Mobility grater than 0.7 results in an uncontrollable epidemic whereas mobility 0.5 results in local virus removal
Allam et al. [7]	2020	The authors identified the use of AI along with IoT technology for virus containment in Urban areas	With the help of IoT devices, direct communication with healthcare worker can be possible	People's privacy is under threat	As early detection and management is dependent totally on technologies of smart cities it makes the system non-productive
Inn et al. [68]	2020	The authors developed a facial recognition system through Infrared Cameras using AI Technologies	Many smart apps are capable of GPS tracking, monitoring people, particularly those on self-quarantine, and allowing them to report symptoms and status updates	Lots of time as well as data and resources are required	Accuracy of 95%
Gupta et al. [45]	2020	The authors developed a model which uses Intelligent transport system and AI together	Monitoring of large gathering and smart parking cab be carried without human intervention following the social norms	Lots of time as well as data and resources are required	Accuracy of 95% was achieved
Punn et al. [124]	2020	The authors developed a model for ensuring social distancing protocols through video surveillance	Total time is much less than the time taken by Faster RCNN and SSD	People's privacy and their individual rights are under threat	Accuracy around 74% was achieved
Sengar et al. [134]	2020	The authors proposed a framework to monitor the distance between individuals through CCTV camera by utilizing AI technology	Much easier to manage the crowd without human intervention	Using only one camera will not give correct results	Accuracy for detecting object was achieved around 74%
Wuest et al. [160]	2020	The authors explored the potentials of AI in case of manufacturing and supply network in the COVID-19 times	Measures ensure that the economics of the country is not affected while taking care of the safety of the workers	Still in the research and development phrase	
Yanfang et al. [167]	2020	The authors developed a System which will be helpful for the areas where there is a possibility of community spread	It is successfully able to tell the risk at the community level and has been adopted in China as well	Handling and working with huge data sets is very difficult	Graph shows exponential increment in risk index
Miralles et al. [94]	2020	The authors presented an algorithm for the optimization of the government actions concerning the pandemic	DQL approach more accuracy than GA	The results can be skewed in the presence of other viral agents affecting the residents	
Zuo et al. [173]	2020	The authors developed a platform which anonymously used mobile device location and gave analysis	No human intervention	Depends upon the geographical location as well depends upon the network signal of the mobile	Model can find density, social distancing compliance rate and many other parameters

fast-track approval of vaccines based on clinical studies [31]. This has led to the development of vaccines with accuracy as high as 95% [24].

The development and approval of vaccines have led to kick-starting of mass-vaccination drives around the globe and ramping up the manufacturing facilities. This has led to over 350 million vaccine shots administered worldwide [60]. Since these COVID-19 vaccines were developed using fast-track procedures and tested on a smaller set of participants, some cases have been reported that the patient develops side-effects after administration of the vaccine and some of these side-effects have adverse effects and were permanent [30].

Most countries offer multiple vaccine options. AI techniques can be utilized to predict which vaccine will have the best efficiency and the least adverse effects on the patient. We can feed in details such as age, gender, comorbidities, etc., into the model and the model will return ranked order of all the vaccines available in the country. The patient based on the suggestion of the model should be given that particular vaccine. The AI model will have access to all the live data of the vaccine drives going on around the country and the patient details and the side effects that we experienced by the patient. As the training data increases, the accuracy of the model will increase.

In addition, researchers can also utilize various ML and DL techniques for the drug development and re-purposing of the currently available drugs at the molecular level. Alafif et al. [3] have discussed various algorithms that can be used for the same. Some of these experimental treatments can also be utilized for faster recovery of the user.

In addition to using AI, other state-of-the-art technologies to increase its effectiveness. These include-

1. Blockchain: It offers several benefits such as anonymity, decentralization and autonomy. They can be helpful to preserve the users' privacy, ensure that data integrity is maintained, and prevent unwanted disclosure of data [89].
2. Cloud computing: It offers virtually unlimited space for storage and computation power that can be used to run the AI algorithms leading to faster outputs [65].
3. Robotics: Due to the nature of the spread of the virus, robots can reduce human contact with the patients, leading to the safety of the medical staff.

5 Challenges and future directions

This section discusses about the challenges and issues which are prevalent in the current work of AI to tackle COVID-19 and also about the performance and accuracy of AI models.

5.1 Challenges of the AI and COVID-19 integration

Research is being carried out on the possibility of AI and healthcare integration by researchers worldwide. They have highlighted the advantages that AI brings to the table. We analyzed and examined the literary works in this domain that we deem necessary for the fight against the pandemic. The majors sub-domains that AI will be advantageous include early warning and alert systems, diagnosis and prognosis and social control.

AI has many promising features such as detection, pattern recognition, classification, prediction, etc., which make it a perfect fit for complete integration with the healthcare domain. The foremost challenge that the existing healthcare systems face in these pandemic times is the lack of skilled manpower and hospital infrastructure to cater to all those in need [49]. This calls for the necessity of using AI for automating some of the decision-making processes while maintaining human-like accuracy. AI can further help in ensuring that the government rules and restrictions are being followed as well as in tracking and prediction of the patients.

Although most of the out surveyed literary works are currently in the research phase and still have a long way to go before wide-scale use, some have shown great promise. These include the models given by companies such as Bluedot and MetaBiota and the models' superior accuracy in the diagnosis and prognosis domain. No Doubt that AI can potentially counter this pandemic, but it is still at a preliminary stage to be implemented in the real world and for the current scenario.

5.1.1 Insufficient data

The use of AI is constrained because of the insufficient amount of datasets as well as models to be work on. In any work to fight against the pandemic, whether it is research work or any collaborative work, historical data in large amounts must be needed to enhance the functionality of AI. All tracking, prediction, and virus diagnosis with the help of AI are done using data only. Also, Most of the publication and organization who has released out the data are limited. Most of them are samples are china-based, which makes it very difficult for AI models to be trained to be worked on any types genes or people of different origin [101]. Hence developing an accurate model with sufficient data is a challenging task for the researchers.

5.1.2 Data privacy

Not only limited data but privacy is also a primary issue with AI. Video Surveillance System is one of the systems where

AI is used for tracking as well as social control between individual by the government, may create some consequences in the near future which can violate human rights [66].

5.1.3 Unbalanced binary classification problem

Some of the diagnostic problems are Yes or No form of problem known as Binary classification problem. For example, the main objective of the diagnostic problem is whether a person is infected. For this form of AI model, data must not be biased to either of the classes, i.e., should be proportionate to both classes to make the model work. From the comprehensive analysis, we found that it may affect AI model efficiency if the dataset is not balanced. It is to note that various types of sampling techniques can solve such type of data imbalance problem.

5.1.4 Accuracy metrics

Nearly in all research papers, whether the model is fit or not is determined solely by its accuracy, which is not enough to evaluate the model's performance. Metrics like precision, sensitivity, F1 Scores, Specificity which are equally important for the efficiency of the model are not considered. Also, the AI model, which are employed for diagnosis and treatment of Virus or in any healthcare system sensitivity, as well as specificity as a parameter, is equally important [2]. At the same time where researchers maximize their accuracy, they must also need to minimize misclassification.

5.2 Future research directions

Motivated by our extensive survey of research studies on AI and COVID-19 pandemic convergence, we point out possible directions for research that should be included in future works.

- For the diagnosis of the infection, medical imaging technologies such as X-ray and CT scans are required. However, these technologies work based on radiation, and the radiation dosage for each patient should be the minimum. AI can be utilized to calculate the dosage requirements for each part of the body based on thickness. This can ensure only the necessary dosage of radiation is used [138].
- Most of the data sets available in the medical imaging domain often have inaccurate labels and for such scenarios weakly supervised deep learning models such as deep-transfer models,self-supervised models, deep metric learning, and meta-learning [33, 138, 157].
- Robotics is another interesting field that is gaining prominence. Due to the nature of transmission of COVID-19 which is human-to-human, AI-powered robots can be used for automated blood collection from patients using ultrasound to pinpoint the nerves of the hand, social robots can be deployed to provide company, robot-assisted surgeries can be realized with the advent of superior network capacity, robots can be used to transport food and medicines to and fro form patients in isolation and robots can disinfect themselves very quickly which can help it cater to more patients and the medical personnel [166, 168].
- Blockchain is another interesting upcoming technology that can be leveraged along with AI for its characteristics such as security and transparency. In these COVID-19 times, data sharing among hospitals is necessary and it must be done in a secure mode. A hybrid model consisting of federated learning and blockchain can be used for such purpose [79].
- Companies and organizations across the globe are adopting cloud computing technologies due to their superior characteristics such as scalability and efficiency over maintaining their own infrastructure. Cloud platforms can help in the collection of data from various distributed agencies. Cloud platforms further can perform data analytics and display the end result to the user [154, 162].

6 Conclusions and discussions

AI can be a valuable tool in combating the effects of coronavirus. AI can provide early warnings and alerts to people along with the tracking of the pandemic along with its high accuracy prediction of the numbers in the following days. AI can work side-by-side with the medical personnel in the decision-making process along with providing consistent treatment. It can recognize the patterns and predict the course of the infection and the symptoms in the patient. This can help in the judicious allocation of hospital resources. The development of a vaccine is being conducted as well, which can be accelerated with the help of AI. AI can be scaled up easily and integrated with the existing surveillance technologies which ensure that the government rules and norms are being followed. In this paper, we explore the possible implications of AI integration in the healthcare domain, keeping in mind the current COVID-19 pandemic. The impact of AI is profound in every domain and it can be expected that it will be a game-changer in the combat against the once-in-a-lifetime pandemic. We proposed an AI-enabled solution taxonomy for combating the crisis, which utilizes various AI technologies starting from its application in the early warning and alert system and going all the way up to ensure social control. Finally, we explored the possible shortcomings and implementation issues in such integrations and the future research directions possible in this direction.

Research on applying AI for the pandemic is still in the genesis phase. But given the rise and use of AI in recent years, it is obvious that AI will significantly uplift the shape and experience of the future to handle COVID-19. In the future, we would like to conduct a detailed survey on the AI techniques currently deployed and used around the world to tackle the COVID-19 pandemic.

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