AI and IoT Solutions for Tackling COVID-19 Pandemic

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ABSTRACT

Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has become an unprecedented public health crisis. To tackle this crisis in an effective way different computational solutions involving artificial intelligence and machine learning have been propounded by researchers across the world. Artificial Intelligence has changed the landscape of the healthcare industry and is being used by many corporations and governments around the world to tackle health care issues and hence, it finds applications in these troubling times as well. The internet specially google scholar scoured for relevant and accurate applications of machine learning and deep learning in solving the issues of this pandemic. The different applications include diagnosis, mortality rate prediction, vaccine development, drug development, sentiment analysis regarding COVID-19 comments and misinformation detection. A systematic study presents the best working models in the respective field.

Keywords— Artificial Intelligence, COVID-19, Medical Diagnosis, Drug Development, Mortality Prediction

1. INTRODUCTION

Coronavirus Disease 2019 popularly known as COVID-19 is an infectious and potentially fatal disease that is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The first known case of this disease was identified in December 2019 in Wuhan, China [1]. The death rate according to these statistics is around 3.4%. This disease has spread all around the world as quickly as a wildfire, causing panic and distress among all human beings.

The SARS-CoV-2 virus belongs to the coronaviridae family [2]. The virus infects the body by binding its surface proteins to receptors in healthy cells of the human body. This virus then invades the cell and makes copies of itself and multiplies throughout the body. The virus proteins burst into healthy cells through ACE2 receptors and eventually kill them. The lower airways of the lungs have more ACE2 receptors than other parts of the respiratory system and the SARS-CoV-2 virus is much more likely to go deeper into the lungs than the common cold virus, making it much more dangerous than other viruses [3]. Although, recent research suggests that the lungs seem to be the primary area of focus for this virus, it can also potentially attack the heart, kidneys and different parts of the body. It can also create blood clots in the human systemand potentially kill the patient [1].

The most widely used method of diagnosis of this disease is a real-time reverse transcription-polymerase chain reaction (rRT-PCR) from a nasopharyngeal swab [4]. There are no fixed symptoms of COVID-19 and it varies from person to person. However, the most prevalent symptoms include dry cough, fever and tiredness. Other symptoms that are not so common and may affect a smaller number of people include headaches, nasal congestion, sore throat, diarrhea, loss of taste or smell, discoloration of fingers and toes. Around 80% of the COVID-19 patients recover without needing any medical assistance. Since this disease is communicable, the patients who catch the virus get it from other patients who have the virus in their system. The primary source of transmission of this virus is through small droplets of nasal and mouth fluids that spread when an infected person sneezes, coughs, or speaks.

In modern times, computational solutions have been created to solve many global problems very efficiently and cost-effective [22]. From finance to healthcare and education, AI has revolutionized everything [37]. The rise of Artificial Intelligence and various forms of machine learning has completely transformed the landscape of healthcare systems [12]. Machine learning technologies like Artificial Neural Networks, Convolutional Neural Networks and another state of the art technology is being used in various fields of healthcare like dermatology, ophthalmology, radiology and even genome interpretation [29]. The Internet of Things (IoT) has revolutionized the healthcare industry with products like wearable technologies that monitor a patient's physiological system [24]. Many modern computational technologies like blockchain, Internet of Thing (IoT), machine learning, unmanned aerial vehicles

(UAVs) are being successfully used to tackle COVID-19 problems such as early diagnosis, CT scan diagnosis, contact tracing, vaccine development, remote monitoring, telemedicine, drug development, virus modeling [3]. AI and data science in particular among various modern technologies are being used to mitigate the negative impact of COVID-19.

In this article, different areas are explored in which computational systems have proven to be effective in fighting the battle against COVID-19. In the next section, the most effective computational solutions that are currently being used or will be used in the future in this battle against coronavirus and viruses in general were discussed.

2. RELATED WORKS

A. Diagnosis of COVID-19

The most effective way of diagnosis COVID-19 is through the rRT-PCR test but as the number of cases and potential patients in the world is rapidly growing, the number of test kits is not enough to cater to the demands. Hence, many computational solutions that can accurately diagnose human beings are currently being used extensively. These computational models are much less accurate and unreliable than traditional biological diagnostic systems but in these times of desperate need, they have helped a lot and are more often used as a screening method for further diagnosis [5].

a) Image-Based Diagnosis

Convolutional Neural Networks (CNN) is the most popular deep learning technology that is used for image recognition and classification. CNN has been widely used in the computational healthcare community to diagnose various illnesses using medical imaging. Ardakani et al. [6] have done a comprehensive study where they compare various popular open source CNNs like GoogleNet, AlexNet for the diagnosis of COVID-19 using computed tomography (CT) images of lungs of patients. They made sure that the systems they trained could identify COVID cases with no cases as well as other viral cases. The data set they used consisted of 1020 CT slices from 108 COVID positive patients and also CT slices from 86 non-COVID patients with no diseases or different viral pneumonia. The CNN architecture were studied based on the Xception, AlexNet, ResNet-101, VCG-16, ResNet-50, VCG-19, ResNEt-18, SqeezeNet, GoogLeNet, MobileNet-v2. The highest accuracy was shown by ResNe-101 with an accuracy of 99.51%, specificity of 99.02% and sensitivity of 100%. Another architecture that worked e-Xceptionally well was Xception. Its accuracy was 99.02%, specificity was100%, and sensitivity was 98.04%. In their study, they also tested the dataset on a human radiologist to compare how the CNN models do as compared to human decision-making systems. The human radiologist gave an accuracy of 86.27%, specificity of 83.33% and sensitivity of 89.21%. Thus, they concluded that CNN models are an effective tool for the diagnosis of COVID-19, although a PCR test is to be preferred in a real-life scenario.

Elaziz et al. [7] proposed a machine learning method that is capable of diagnosing COVID-19 based on x-ray images of the lungs of potential patients. They mention that their algorithm requires much fewer data to be trained on and yet gives comparable results to deep learning CNN models. In their proposed method as shown in fig. 1, Fractional Multichannel Exponents Moments (FrMEMs) is used for feature extraction that uses a parallel multi-core computational framework for faster processing. Then further, a differential evolution-based manta-ray foraging optimization technique is used for feature selection after which it's features are fed into a classifier. The classifier

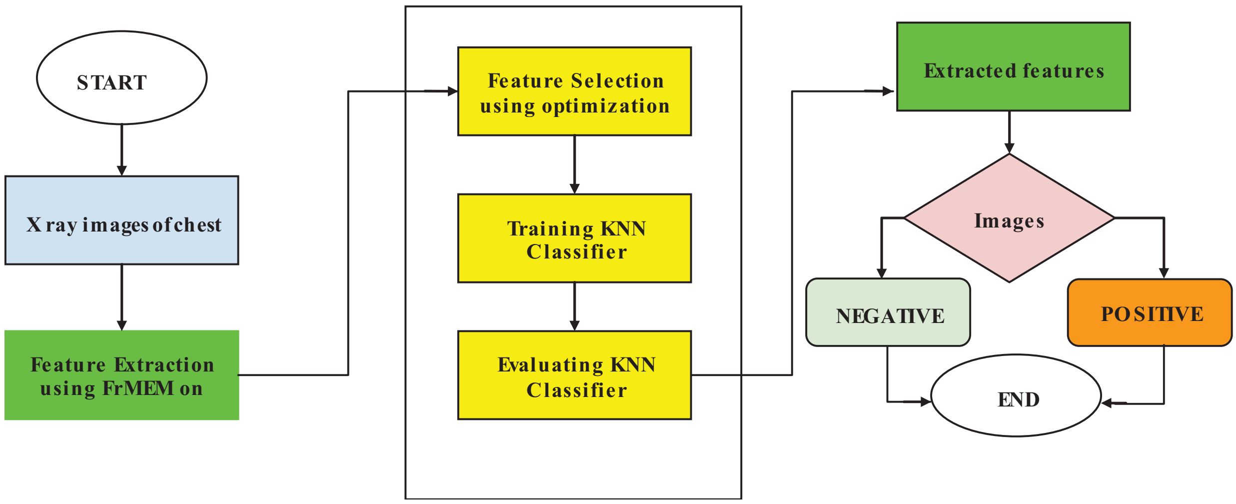

Fig. 1. Flow chart of the proposed model by Elaziz et al. [7]

TABLE I. PROBABILITY RESULTS OF SYSTEM

Event (System Reports)	**Probability**
'COVID-19 likely' when the individual is 'COVID-19 positive'	0.773
'COVID-19 likely' when the individual is 'COVID-19 negative'	1.367×10^{-4}
'COVID-19 not likely' when the individual is 'COVID-19 negative'	0.838
'COVID-19 not likely' when the individual is 'COVID-19 positive'	4.782×10^{-4}
'test inconclusive' when the individual is 'COVID-19 positive'	0.226
'test inconclusive' when the individual is 'COVID-19 negative'	0.161

they have used is the KNN (K-nearest neighbor) classifier. They tested their model on two different open-source data sets. The first dataset consisted of 216 COVID-19 positive images and 1675 COVID-19 negative images and the second dataset consisted of 219 COVID-19 positive images and 1341 COVID-19 negative images. One can observe that the dataset size they have used is fairly low. Their model gave an accuracy of 96.09% on the first dataset and 98.09% on the second dataset.

b) Voice-Based Diagnosis

Several voice-based COVID-19 diagnostic tools have been created in the past few months using cutting edge machine learning and deep learning technologies. A research team at Carnegie Mellon University (CMU) has released an app that can determine whether or not an individual is infected with COVID-19 based on the individual's voice sample [30]. Although, they warn that the app is not to be used as a primary diagnostic tool, but rather as a screening tool so that the most required candidates may get the PCR test done as PCR test kits are limited all around the world.

Imran et al. [8] proposed a computational system named AI4COVID-19 that can diagnose an individual with COVID-19 based on the sound of the individual's cough as shown in fig. 2. It is capable of distinguishing between COVID-19 cough and several other types of cough, even normal disease-free cough. Their proposed system consists of a cough detector and a COVID-19 diagnostic engine. The cough detector is responsible for detecting whether the input sound has a cough or not and the latter system is responsible for detecting the type of cough. The cough detector is trained using a public dataset named ESC-50, which consists of a huge collection of environmental and human sounds. From this data set they used 1838 sounds of humans coughing and 3597 environmental sounds. In this cough detector system, the recorded cough sound's Mel-spectrogram with 128 bands is computed. This is then converted to a grayscale image of dimensions 320x240x1. The resultant image is then fed into a convolutional neural network that classifies the sound as being a cough sound or not.

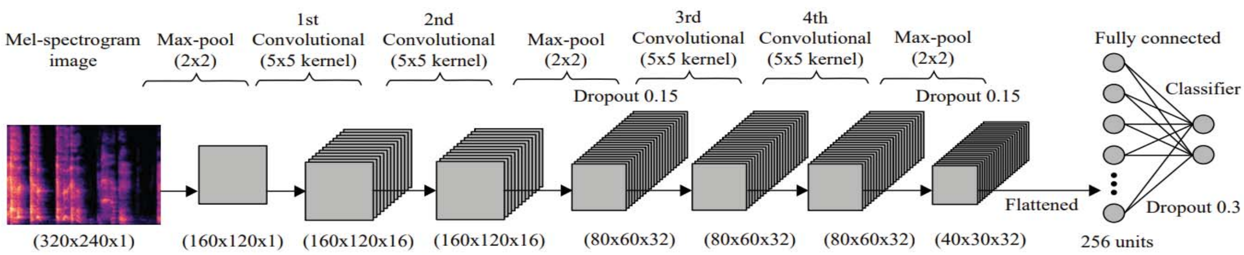

Fig. 2. CNN model of the cough detection system as proposed by Imran et al. [8]

If the sound is detected as a cough then the corresponding image is fed into the COVID-19 diagnosis system. This system is an ensemble of three different machine learning and deep learning algorithms. If all the three algorithms give the same output then only the system gives a valid result and the system reports 'COVID-19 likely' or 'COVID-19 unlikely'. If the three outputs are not the same then the system gives the output 'test inconclusive'. The COVID-19 diagnosis model is trained using a dataset collected by the authors of the paper itself in which there were 247 normal cough samples, 70 COVID-19 cough samples, 96 bronchitis cough samples and 130 pertussis cough samples. The first Algorithm of this module is Deep Transfer Learning-based Multi-Class Classifier (DTL-MC) which is a CNN based model that is similar to the cough detection system. Because of the transfer learning method, this algorithm can have a deep architecture despite the limited size of the data. The second algorithm is classical machine learning based multiclass classifier (CML-MC). In this part, the original cough sound is used instead of the preprocessed Mel-spectrogram. Principal Component Analysis (PCA) is used for feature extraction and then a Support Vector Machine (SVM) is used as the classifier. This part is used to avoid overfitting that may be caused by the deep learning model. The third algorithm used in this ensemble is Deep Transfer Learning-based Binary classifier which is a CNN model similar to the first algorithm but the output is of size 2, i.e. COVID-19 positive or COVID-19 negative. The authors tested their model and gave a bunch of probabilities corresponding to different events such as 'System reports COVID-19 likely and the patient is COVID-19 positive'. Table 1 describes the number representations.

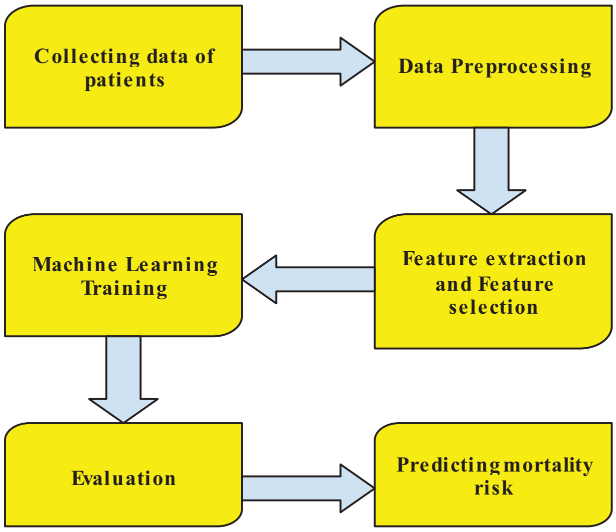

Fig 3. High-level architecture of the system used in the study done by Pourhomayoun et al. [10]

B. *Mortality Rate Prediction*

Machine learning techniques have been used to predict the mortality rate for patients of various diseases as early as the 1990s [9]. These learning techniques have huge potential for predicting the mortality rate among COVID-19 patients so that the patients that have a higher probability of death are given appropriate attention.

A team of researchers at California State University performed a study where they calculated the mortality risk of various COVID-19 patients using traditional machine learning algorithms like Support Vector Machine, Artificial Neural Networks, K- nearest neighbor, Random forest, Decision tree and Logistic Regression [10]. The highest accuracy they achieved was 93%. The high-level system architecture they used in the study is as shown in fig. 3. The dataset they used consisted of 117, 000 lab-confirmed COVID-19 positive patients with an average age of 56. Several different traditional machine learning algorithms were used after thorough feature engineering for the prediction among which the neural network with 2 hidden layers (10 neurons in the first layer and 3 neurons in the second layer) gave the highest accuracy of 93.75%.

Yan et al. [35] did a study in which they used the blood samples to determine the risk of mortality in COVID-19 patients using a machine learning algorithm. They developed a supervised XGBoost machine learning based algorithm that is capable of detecting mortality among COVID-19 patients up to 10 days in advance with an accuracy of 90%. This decision tree-based machine learning algorithm selected three key biomarkers in the blood that determined the mortality rate with an accuracy of up to 90%. The biomarkers were lactic dehydrogenase (LDH), high-sensitivity C-reactive protein (hs-CRP), and lymphocyte.

C. *Curve Prediction*

Many machine learning and artificial intelligence methods have been used to predict important dates of the pandemic, dates like the date on which the number of new cases per day will be the highest. Prediction of the curve is an important application of machine learning because it can enable countries and businesses to make better and informed decisions.

Yang et al. [31] proposed a machine learning and mathematical model that was able to predict the condition of mainland china with regards to COVID-19 cases. Their results seem to be uncannily accurate to a large extent. Strict laws regarding quarantine were enforced in China by January 23rd 2020. Yang et al predicted using mathematical tools and machine learning that the COVID-19 cases would peak by mid-February and extend till late of march in mainland china. They also predicted that if the quarantine was lifted in Hubei back then, the COVID-19 cases mid-march and extend till late-April. This study verily expounds on the importance of quarantine and lockdown. For their study, they used two different models for prediction. First was the modified SEIR, which is a mathematical model that is used to simulate epidemics and pandemics. The second was Long Short-Term Memory (LSTM), which is a type of recurrent neural network that is particularly good at working with time-series data. The LSTM was trained with the data from the 2003 SARS outbreak. According to the LSTM model they used, the number of new cases in China would peak on February 4th. The actual peak was on February 17th which is quite close.

Another interesting study on curve prediction of the pandemic is done by Tuli et al. [13]. The research mentioned above as done by Yang et al. [31] only describes the statistics of the curve for China, however, the study done by Tuli et al describes the prediction for the entire world. They assume that the graph showing the number of new COVID-19 cases per day follows a generalized inverse Weibull distribution rather than gaussian distribution. They use iterative weighting for fitting the generalized inverse Weibull distribution graph which is a machine learning based technique. According to the prediction done by their model the curve would peak around the end of April and 97%of the total number of cases would occur on 11th October 2020. However, according to real data this doesn't seem to be the case. The number of new cases has been rising ever since the end of April 2020.

D. Drug Development

Chemists and biomedical engineers have started using artificial intelligence technologies for drug development for a very long time [14]. Technologies like deep learning have been used for compound property and activity prediction of various biological chemicals. They have also been used in predicting reactions and retrosynthetic analysis. Various efforts have been made to predict the activity of chemicals in the human body using its molecular structures various information [14]. Deep learning and similar technologies can make the process of development of drugs much faster and economical, and they are also currently being used for the development of antiviral drugs against the SARS-CoV-2 virus.

Generative Adversarial Networks (GANs) are most often used to design drugs that are suitable for a given purpose. GANs can be used to generate data that is statistically similar to the training data that is fed into the network [33]. The most important COVID-19 the 3C-like protease for which the crystal structure is known. Insilico Medicine is using a generative chemistry pipeline which is based on deep GANs to design novel drug-like inhibitors of COVID-19 and they have started the generation on 23th of January 2020 [32]. The research done by Zhavoronkov et al. [32] generated various kinds of chemicals. They accessed the similarity of the structures of the different chemicals generated by the network from the ChEMBL database using its search engine. The dataset they used was obtained from the ChEMBL database which is an open-source database of biological molecules with drug-like properties.

In another effort towards drug development for COVID-19, researchers at IBM research used deep generative models to generate different drugs and test them. They propose an end-to-end framework that is called the Controlled generation of Molecules (CogMol) and it can be used to design new drug-like, fairly small molecules targeting many different viral proteins. This model combines a very effective multi attribute-controlled sampling scheme and adaptive pre-training of a molecular VAE (Variational Autoencoder). To generate efficient and effective drug-like molecules CogMol uses a protein-molecule binding affinity predictor that is trained by using embeddings in Variational Autoencoder and protein sequence embeddings. They used 3 target proteins, unlike the above study which used only one. The proteins they used were non-structural protein 9 replicas, main protease and receptor-binding domain of the spike protein. For unsupervised VAE training, they used the Moses benchmarking dataset which includes 1.6 million molecules in the training set and 176,00 different molecules in the test set. According to their results, 90% of the generated molecules are chemically valid, and 95% pass relevant filters. Hence, the model generates very promising drugs to use for further testing to see how effective they are against COVID-19 and how safe they are [17].

E. Vaccine Development

Reverse vaccinology is an advancement in vaccinology that uses the computational field of bioinformatics. The rudimentary idea of reverse vaccinology is that entire genomes of pathogens can be screened using computational methods of bioinformatics to find the appropriate genes [18]. During vaccinations, some antigens (proteins or weakened pathogens) are injected into the human system so that the human immune system can develop an immunity to the particular pathogen. Machine learning and AI technology can be used to predict the different molecules or proteins that can be used as a vaccine.

One such algorithm or model is VAXIGN-ML which is a reverse vaccinology method that uses extreme gradient boosting with mRMR feature selection and hyperparameter optimization to predict the protein best suited as a vaccine [19]. Optimization makes the algorithm more robust [15][16]. Ong et al. [19] have used VAXIGN-ML to predict

SARS-CoV-2 vaccine candidates. The nsp8, nsp3 and S protein present in the COVID-19 causing virus were predicted to be useful candidates for high protective antigenicity. In the VAXIGN-ML tool, five supervised machine learning algorithms were used among which XGBoost gave the highest accuracy. The data used in their study was the protein database in which there were 575 positive samples and 4979 negative samples.

For developing vaccines, knowing the structures of particular proteins is very important. Even after knowing the contents of a protein through different methods, determining the 3D orientation or fold of a protein is a particularly difficult task. Google's Deep mind has released a program called AlphaFold that can determine the orientation of the protein structure. It is currently being used to determine the structures of various proteins that belong to SARS-CoV-2, the virus responsible for COVID-19 [20]. Over the past few decades, various techniques like nuclear magnetic resonance, cryo-electron microscopy and x-ray crystallography have been used to determine the structure or fold of proteins. But these techniques take a lot of time and are very costly. Compared to this, the AlphaFold program is very cheap, computationally fast and easy to use. In the AlphaFold program, the protein structure first goes into a trained neural network which makes distance predictions and angle predictions, and a certain score is associated with the created protein. Then further a generative neural network with gradient descent used to create a protein structure of a higher score [21].

TABLE II. SOME WORKS DONE IN THE DIAGNOSIS, MORTALITY PREDICTION AND DRUG DISCOVERY FOR COVID-19

Authors	Technology	Dataset Used	Use Case	Remarks
Ardakani et al. [6]	Open Source CNN architectures	CT scan slices from the radiologists	COVID-19 diagnosis using CT scans	The RestNet-101 CNN architecture achieved an accuracy of 99.5% on the dataset.
Imran et al. [8]	Deep CNN + Transfer learning base deep CNN	ESC-50 dataset + cough sounds collected in their study	Diagnosis of COVID-19 using cough sounds	The accuracy achieved for cough detection was 95.60% and the accuracy achieved for COVID-19 diagnosis was 92.64%
Pourhomayoun et al. [10]	Traditional ML algorithms like KNN	COVID-19 patients' dataset from labs	Mortality rate prediction of COVID-19 patients	93% accuracy was obtained when tested in the dataset used.
Yan et al. [35]	XG Boost	COID-19 patient's dataset from Tongji Hospital	Mortality Rate prediction of COVID-19 patients	The accuracy achieved was 90% and the results could be known upto 10 days in advance.
Yang et al. [31]	Modified SEIR/ LSTM	COVID-19 statistics in china	Curve prediction	The results showed that the graph showing the number of new COVID-19 cases would peak at February 4th in china.
Zhavoronkov et al. [32]	Generative Adversarial Networks	Data set from Dr Rao's laboratory + ChEMBL dataset	Drug development	GAN was used to generate potential drug -like molecules for fighting COVID-19
Chenthamarakshan et al. [17]	Variational Autoencoder (VAE)	Moses benchmarking dataset	Drug development	VAE was used to generate potential drug -like molecules for fighting COVID-19
Ong et al. [19]	XGBoost	Protein database from NCBI	Vaccine Development	Used VAXIGN-ML Tool to predict potential vaccine candidates.
Andrew et al. [20]	Neural Networks + GANs	Large genomic dataset	Vaccine development	Researchers at DeepMind Google created AlphaFold that determines the fold of proteins. This was used to study SARS-CoV-2 proteins.

3. FURTHER APPLICATIONS AND DISCUSSION

The above section highlighted some important applications of machine learning to tackle the COVID-19 pandemic. Table II gives a brief overview of models that were used to solve different aspects of the pandemic. However, myriads of computational solutions have been devised to alleviate the negative impact of COVID-19 in today's world. Perhaps the most important application of AI in the current COVID-19 situation is diagnosis. AI technology is currently being used for cheap and fast diagnosis of COVID-19 through medical images and voice. Artificial Intelligence and Machine Learning is also being used for very important tasks like the development of drugs that can fight against SARS-CoV-2. Technology is also being used for successful vaccine development among many other important applications. AI is also being used to identify, tackle and forecast outbreaks of COVID-19 in different parts of the world [1].

Internet of Things (IoT) is also playing a major role in solving many problems related to COVID-19. For instance, GPS based wearable systems are being used for contact tracing [34]. Contact tracing is useful because when a certain person gets infected with the disease, then it is more likely that people who came in contact with that person are infected as well and correct precautionary measures can be taken so that the spread of the disease is curbed. To make people more aware of the COVID-19 situation the Indian government launched an app called ArogyaSetu, that is used to connect healthcare services and the people of India so that COVID-19 infected people access treatment more easily. China also launched a mobile app called Close Contact, which tells the user about the closeness of the user to a COVID-19 infected user [25]. The current world is also seeing a rise in the usage of telemedicine services such as virtual consultation for medical services or virtual diagnosis. In the US, in 2019 only 11% of the customers were using telemedicine services but in 2020 due to the COVID-19 pandemic around 46% of consumers have started using telemedicine services [26].

Various NLP techniques are also being used in the battle against COVID-19, specifically in the domain of fake news detection. Such technologies are very useful in solving a wide range of problems from text summarization to sentiment analysis [11]. Jelodar et al. [30] have used deep learning techniques like LSTM for sentiment analysis on COVID-19 comments. They present a systematic framework based on natural language processing to extract and analyze COVID-19 comments on Reddit. They use the LSTM model for sentiment analysis of the extracted comments and uncover meaningful topics that are frequently being discussed on the subject of COVID-19. They found that the most discussed topic was people/infection. Also, they found that the negative comments like someone is dead etc. was discussed more than positive comments like get well soon. Curbing the spread of fake news related to COVID-19 is perhaps the most important area of attention that researchers should be focusing on. Because of various misinformation and spread of social stigma, a father of three in India was reported to have committed suicide after learning that he had been diagnosed with COVID-19 [27]. Also, because of the lack of proper health communication, many people in Nigeria overdosed on chloroquine, a drug that was made popular by the media for being a potential drug for COVID-19 [27]. Serrano et al. [23] used NLP techniques to identify misinformative videos in YouTube. They did so by analyzing the comments in YouTube videos. They extracted information from YouTube using its API. Their data set has 113 videos on misinformation among which they used 32, 273 comments and 67 factual videos from which they gathered a total of 119, 294 comments. They used pre-trained NLP models that were finetuned for their application to get the accuracy up to 89.4%.

Since the beginning of this pandemic, the amount of research done on this topic is immense. There have been hundreds of thousands of research papers published since February on this particular disease and ways to tackle this disease. A vast amount of knowledge has been accumulated in a short period of time. Without coordinated efforts to organize this knowledge, this knowledge can remain disorganized and hidden from individual research groups. To solve this problem knowledge graphs can be used. Many researchers have created many different knowledge graphs. A group of researchers has created a pathophysiology COVID-19 Knowledge Graph, an expansive cause-and-effect network constructed from the scientific literature on the new coronavirus that aims to provide a comprehensive view of its pathophysiology [28].

4. CONCLUSION AND FUTURE SCOPE

Artificial intelligence technologies have been extensively used in healthcare and will continue to do so in the future as well. As artificial intelligence and machine learning have been very successful at tackling the various problems that arise in healthcare systems, it has also been successfully used to tackle the problems arising due to COVID-19. Despite a lot of benefits, there are still many disadvantages of using AI for tackling health care problems, like inaccurate diagnosis. Even though AI systems are currently used for diagnosis, it is not as accurate as a biological diagnosis. Perhaps in the future, AI systems can be so effective that they can diagnose diseases with 100% accuracy. There has been a paradigm shift in telemedicine and similarly, AI can disrupt the healthcare industry with more and more useful technologies coming up. The benchmarks that have been set in various novel research for coronavirus pandemic can also be extended to tackle any likely pandemics that might occur in the future.

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