Artificial Intelligence Technologies for COVID-19-like Epidemics: Methods and Challenges

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Abstract

The outbreak of coronavirus COVID-19 not only brings great disaster to the people of the world, but also brings heavy burden to the medical and health network system. Massive network data traffic and resource optimization requests make traditional network architectures unable to calmly deal with the impact of COVID-19. Artificial intelligence (AI) can effectively raise the upper limit of the medical and health network, as evidenced by the ever-increasing restorative clinical data. In addition, the development of next-generation network (NGN) technologies based on machine learning (ML) has created unlimited possibilities for the emergence of emerging medical methods. In order to reflect the effective results of the current application of AI technologies in the fight against the COVID-19 epidemic and provide a reliable guarantee for subsequent diagnosis and treatment of COVID-19 epidemics, a series of AI technologies which can be used in the diagnosis and treatment of COVID-19 are systematically summarized and analyzed. Based on various AI technologies and methods, we try to propose an AI-based medical network architecture. The architecture uses AI technologies to quickly and effectively realize the monitoring, diagnosis and treatment of patients. Finally, we rationally analyzed the technical challenges and practical problems that may be faced in implementing the architecture. The purpose of this article is to inspire scholars and medical researchers to carry out the latest research in response to the COVID-19 epidemic and make breakthrough medical technology progress.

Introduction

The COVID-19 outbreak caused by the SARS-CoV-2 virus has caused a global crisis, and the lives and property safety of people around the world have been greatly threatened. Since the outbreak of COVID-19 in Dec. 2019, the total number of confirmed cases worldwide has reached 51 million at present. Although more than 35 million patients have recovered from the virus, it is important to note that the number of confirmed cases is still increasing significantly every day [1]. The COVID-19 epidemic has brought unprecedented severe challenges to the global health system. All information related to COVID-19 patients should be recorded in time, including activity trajectories within two weeks, people in close contact, body temperature changes, and clinical treatment records. Since the modern medical system (prevention, monitoring, treatment) is largely implemented by network technologies, one issue worthy of attention is that with the increasing number of confirmed patients, massive network data traffic and resource requests have brought a heavy burden to the network system. How to improve the performance of the network to effectively respond to COVID-19 and even other global epidemics has become a key issue considered by researchers.

Due to the continuous and rapid growth of medical data, the pressure of traffic and resource request brought by network big data is the primary problem faced by the current network community. What is exciting is that artificial intelligence (AI) has successfully attracted the attention of scientific researchers and medical experts. They start an attempt to combine AI with existing network to deal with the COVID-19 epidemic [2]. AI technology has been widely used in clinical treatment. It not only has higher accuracy in epidemic prevention and diagnosis, but also plays a great role in improving drug development and production efficiency. More importantly, it is possible to use AI big data technology to sample viruses on a global scale and accelerate the study of virus activity modeling on a national scale to effectively predict and respond to large outbreaks of similar epidemics [3]. For example, in the medical image diagnosis, the artificial neural network (ANN) technology in AI can accurately identify the image, so as to effectively diagnose COVID-19. To a certain extent, it avoids the production of redundant medical information and relieves the network burden. In order to further realize the efficient application of AI in the medical network system, this article investigates the latest development of AI in response to the COVID-19 epidemic. On this basis, we propose an AI-based medical network architecture and rationally analyze a series of difficulties that may be faced by the implementation of AI.

The COVID-19 outbreak has accelerated the research and development process of AI-supported network technologies in academia and industry. Since the AI-supported medical and health network system can effectively deal with the harm caused by COVID-19 and even other epidemics, this technology has attracted the attention of the people of

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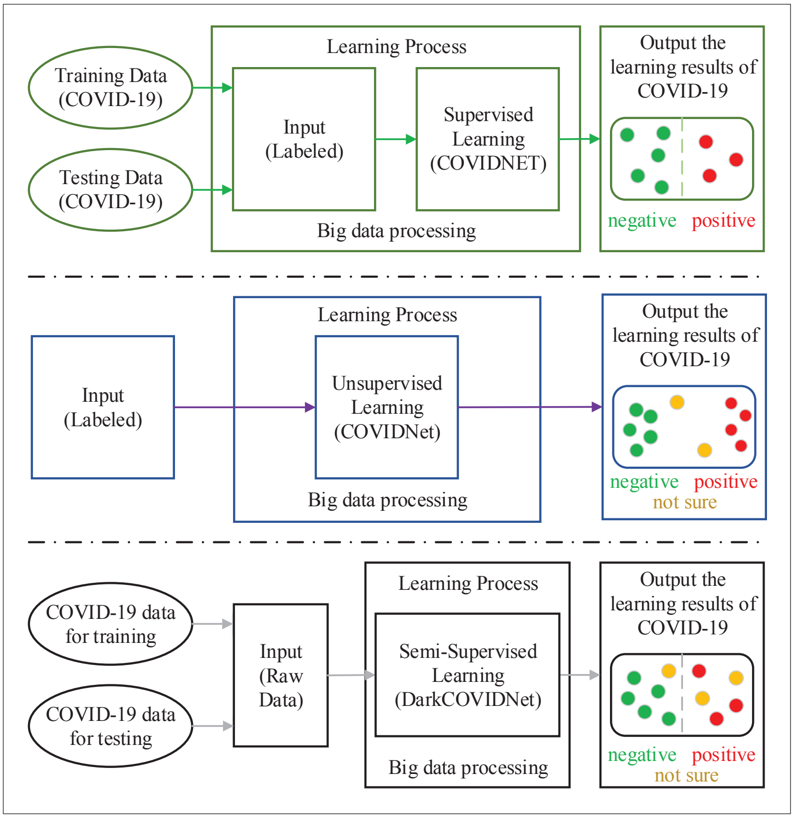

FIGURE 1. Three typical AI technologies application instructions. From top to bottom are supervised learning, unsupervised learning and DRL.

the world, especially the medical community. Most of the existing researches are from the perspective of combining medical technology with machine learning (ML), deep learning (DL), data sets and cloud computing. We will summarize relevant research and try to propose a modern medical network system architecture based on AI.

The organization structure of the article is arranged as follows. In the following section, we summarize typical AI technologies to deal with COVID-19 and give a comparison between them. We then present the general process of AI's response to the COVID-19 epidemic. After that, we propose indicators to evaluate the performance of AI-based medical technologies. Following that we show the AI-based medical network architecture we try to propose. We rationally analyzed a series of challenges that this technology may face. The last section summarizes the full article.

COVID-19 and Artificial Intelligence Technologies

The role of AI in the modern medical network system should be to fully train the data generated in medical experiments, including monitoring and diagnosis, case analysis, and treatment recovery. Especially in the fight against the COVID-19 epidemic, AI has played a vital role in computer tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and optical and digital microscopy imaging. The above phenomena show that radiology based on AI technologies is an important aspect of diagnosis and treatment of COVID-19, among which deep neural network (DNN) is the most widely used AI technology. DNN is essentially a neural network with more layers. Whether it is a biological neural network or an ANN, when they have more layers, they can all be called DNNs. An important function of DNN model is image recognition. Medical researchers can train the COVID-19 data set using the DNN model obtained from World Health Organization (WHO). The accurate recognition of lung scanning images can prove that AI can obtain optimal results in epidemic diagnosis, which is difficult for doctors to achieve by relying on human resources. In order to clarify the role of AI in responding to COVID-19-like epidemics, the following will introduce typical AI learning techniques.

The AI learning technologies that can be used and proven to be effective against COVID-19-like epidemics mainly include supervised learning, unsupervised learning, reinforcement learning (RL) and DL. Since RL and DL are usually closely related, we call them deep reinforcement learning (DRL) for a unified description. Supervised learning is one of the earliest and most widely used AI technology in medical and health system. Supervised learning obtains an optimal model by train ing the existing training samples (diagnosis data of patients), and then uses this model to map all the inputs to corresponding outputs, and finally judges the output to achieve the purpose of classification. These algorithms can provide a standardized platform for programmatic observation and prediction of COVID-19, with an accuracy rate of up to 90 percent. Unsupervised learning needs to classify (cluster) the sample set according to the similarity between the samples, the purpose is to minimize the gap between classes and maximize the gap between classes. DRL has both the perceptual ability of DL and the decision-making ability of RL. Its main feature is continuous learning in the interaction with environment, which is used to solve decision-making problems in high-dimensional space. DRL can play a pivotal role in the early prediction and monitoring, diagnosis and treatment, and social control of COVID-19. The simple application of the three AI technologies is shown in Fig. 1. We provide a detailed comparison of the three AI technologies in Table 1.

Due to the urgency of diagnosing and treating COVID-19 patients, the above mentioned AI learning technologies have begun to try to apply in the medical network system. With the help of network technologies driven by AI and ML (5G, Beyond Fifth Generation (B5G) and even 6G), some researchers have developed high performance medical network architectures from the perspectives of prompt energy efficiency, regional traffic and spectrum efficiency to assist in monitoring, diagnosing and treating patients with COVID-19. For example, the authors of [4] realized that the existing DL algorithms had two major flaws. First of all, the model training need a large number of COVID-19 data sets, which was often difficult to obtain and manage. Another point was that DL algorithms were usually developed and used by scholars, and they were often difficult to be recognized by health care personnel or even the public. The author proposed a B5G framework with low latency and high bandwidth performance based on the distributed DL paradigm. In this framework, each edge COVID-19 node used

–	Definition	Problem	Data	Training	Method	Strategy	Limitations
Supervise learning	Train the labeled data to derive the function.	Regression, classification.	Labeled.	Supervision.	The mapping of labeled inputs to known outputs.	Rely on algorithm and data.	Large data sets and high precision problems are not applicable.
Unsupervise learning	Lack of prior knowledge, training unlabeled data.	Clustering, association.	Unlabeled.	No supervision.	The sample set is classified according to the similarity between samples.	Rely on classification and data.	Unmarked data can make the model worse.
DRL	Learning agent interacts with environment to accumulate rewards.	Decision making.	No predefined data set.	No supervision.	Training, iteration and gradient.	Experience.	The sampling efficiency is low and the reward function is difficult to set.

TABLE 1. Comparison of AI technologies.

the local DL framework for training, and the data set was also obtained from the edge. The use of edge data sets avoided the difficulty of obtaining large-scale data sets. It cannot be ignored that this method of data set acquisition is likely to cause the drawbacks of not extensive sampling and omit some COVID-19 pathological information. The authors of reference [5] did a similar work. On the basis of the former, the authors also developed a large-scale monitoring system under the B5G framework to monitor the social distance of the crowd, whether to wear a mask, and body temperature.

In addition, some researchers have combined AI technologies with different medical methods. Crowd tracking is an effective way to control the spread of COVID-19. At present, some countries have taken relevant measures to track the crowd. The common way is to install applications in mobile phones to monitor personal behavior. Marotta et al., [6] deployed a hybrid distributed program within the campus to monitor the crowd at a certain place at a certain time. The application can use WiFi signal to sense and locate the location of personnel, and it will send a reminder once there is a reported case in the surrounding environment. The authors of references [7] and [8] mainly introduced the clinical features and prevention methods of COVID-19, and provided diagnosis and treatment methods based on DL. The above contributions all have great limitations in the use of AI technologies. Hossain et al., [9] suggested using DL to intelligently allocate wireless resources for 5G networks. The author proposed a framework for predicting future traffic congestion composed of a deep tree model and a long short-term memory (LSTM) network. The result proved that the framework can guarantee a lower packet loss rate and a higher throughput rate. Li et al., [10] proposed a framework for DNN collaborative reasoning using device edge and edge computing. The framework can adaptively divide the calculation between the device and the edge, which can further reduce the delay in calculating the correct size of the DNN. In addition, the authors also considered the potential risk of network fluctuations in actual deployment. In order to cope with this problem, the authors designed the framework to be suitable for the conversion between static and dynamic network environments. Jiang et al., [11] proposed a comprehensive CT image processing method based on a conditional generation confrontation network to deal with the difficult problem of COVID-19 data collection. The results showed that this method can effectively generate high-quality COVID-19 CT images for medical use. The above studies inspire researchers to try to deploy COVID-19 treatment sites on edge servers to improve the efficiency of COVID-19 treatment and reduce mortality. In order to reduce the difficulty of manually segmenting the pathological features of CT images, it is necessary to automate the processing of COVID-19 abnormal images. For this reason, Paluru et al., [12] proposed a convolutional neural network based on deformed deep embedding to segment abnormal features in COVID-19 CT images. The results showed that the lightweight network can effectively reduce the training parameters of the network model and improved the efficiency of image diagnosis. In Table 2, we summarize the relevant references on the response to the COVID-19 epidemic and give their technical comparison.

Reference	A	B	C	D	E
Singhal *et al.*, [7]	✓	✓	×	✓	×
Sohrabi *et al.*, [8]	✓	✓	×	✓	×
Jiang *et al.*, [11]	✓	✓	×	×	×
Paluru *et al.*, [12]	✓	✓	×	×	×
Hesamian *et al.*, [13]	×	✓	✓	✓	✓
Nardelli *et al.*, [14]	×	✓	×	✓	✓
Jiang *et al.*, [15]	✓	✓	✓	×	×

Note: A-machine learning; B-deep learning; C-quality of service; D-robustness; E-algorithm.

TABLE 2. Comparison of technologies used in existing studies.

Methods of Artificial Intelligence Dealing with COVID-19

At present, there are some general AI strategies which are suitable for modern medical system. Through these strategies, a set of methods that can support the worldwide medical and health systems to fight COVID-19-like epidemics can be summarized. These AI methods are constantly updated on the basis of sufficient COVID-19 related information. Figure 2 shows the general process of applying AI methods to combat COVID-19-like epidemics. The first step is to provide data input for AI system, which usually contains medical information such as medical record

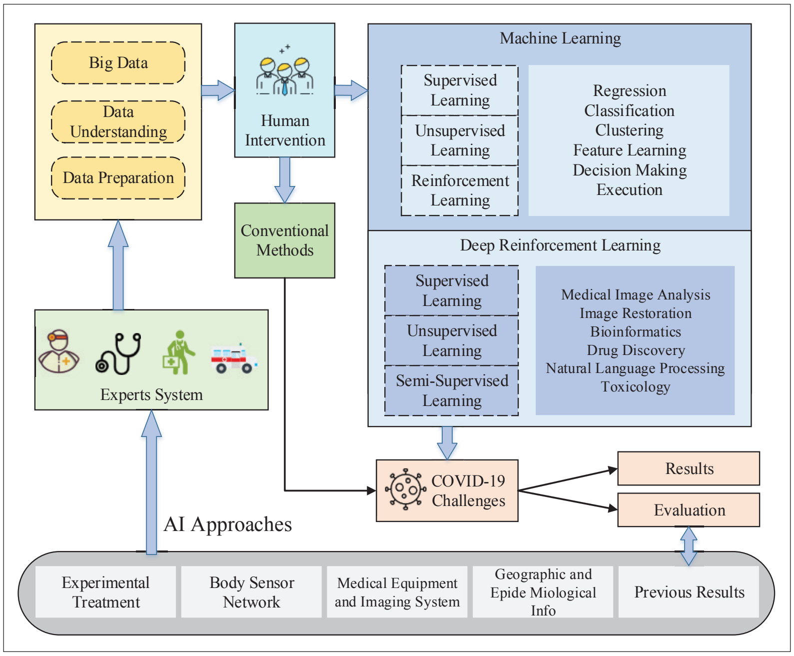

FIGURE 2. The typical process of AI technologies against COVID-19-like epidemics.

report, medical record and medical image. These data should be transformed into a format that can be understood by medical devices through special processing. In the process of data transformation, data is formatted, and different big data sets are formed through aggregation, classification and other processes. This stage is mainly carried out under the operation of ML. Researchers can intervene in this process in order to extract the best structured and representative data information and reduce the interference of poor quality data. As mentioned above, the main AI methods include supervised learning, unsupervised learning, DL and RL. As a representative ML method, DRL algorithm can deal with large scale data sets far beyond human understanding ability, which is usually composed of multi-layer algorithms.

AI technologies can be tried and widely used to combat COVID-19-like epidemics thanks to its ability to provide relatively accurate prediction methods, and it can also finely identify the differences in gene sequences of different viruses. In addition to the several general AI technologies mentioned in the previous section for diagnosing and treating outbreaks of epidemics, there are several other AI technologies that have proven effective in clinical applications.

Support Vector Machine (SVM): SVM is a linear classifier that uses supervised learning to classify sample data. Typical applications in the medical field include the use of SVM to distinguish imaging markers of mental and neurological diseases, to evaluate and determine the malignant growth of tumors, and to combine with other measurement equipments to predict Alzheimer's disease early et al.

Neural Network: Neural network include ANN and biological neural network. Neural network realizes the purpose of information processing through complex basic neuron connections. It is widely used in medical fields such as diagnosis of stroke, analysis of malignant tumors, and analysis of Parkinson's disease et al.

Natural Language Processing (NLP): The essential purpose of NLP is to realize effective natural language communication in computer systems. The medical data faced by modern medical treatment is redundant and has complex annotations, and some valuable data needs to be extracted from it. Typical applications include analyzing chest X-ray diagnostic reports and distinguishing the causes of cerebral aneurysm diseases in detail et al.

The role of AI in COVID-19-like epidemics is mainly reflected in three aspects, including high-risk population monitoring, epidemic outbreak and control, disease treatment and diagnosis. As a hot field of AI research, ANN has solved the difficult problems of modern computers in the medical field. Especially in the field of image recognition and analysis, ANN seems to be spe cifically designed for the COVID-19 epidemic. We present a schematic diagram shown in Fig. 3 to demonstrate the role of ANN in combating COVID-19-like epidemics. The schematic diagram is divided into five layers. The input layer is used to receive various medical data from the database, and the two are tightly coupled by high-speed channel. Using a large number of microprocessors with high-performance database processing software, the database can transfer a large number of data packets to the input layer. The selection layer designed based on the ANN intelligent selector adopts the top imaging technology according to the system experience. If the imaging technology is approved by medical experts, then the third layer of imaging layer will take the required medical images. Commonly used imaging techniques mainly include the aforementioned CT, PET, optical and electron microscopy imaging, and so on. The optimization layer is mainly used for image adjustment and improvement, which will directly determine the doctor's intuitive judgment. In order to clearly distinguish different types of epidemics, this layer often uses DL technology and uses ResNet to extract image features. The final output layer mainly saves and outputs the diagnosis results. The database information of the input layer can also be directly transmitted to the optimization layer and the output layer, so that the diagnosis efficiency can be improved by comparing with the original data directly. At the same time, the diagnosis information of each layer can be fed back to the input layer to enrich the disease information in the database, so as to facilitate the diagnosis and treatment of subsequent diseases.

In the field of AI, the performance of the AI technologies used is usually evaluated. Similarly, when using AI technologies to combat COVID-19-like epidemics, corresponding evaluation indicators should also be provided. In the diagnosis and treatment of COVID-19-like epidemics, the evaluation indexes of AI based medical technologies mainly include accuracy, sensitivity and specificity. The accuracy rate mainly focus on the four possible manifestations of the observation object, which are true positive (COVID-19 patients are diagnosed as positive), false positive (non COVID-19 patients are diagnosed as positive), true negative (non COVID-19 patients are diagnosed as negative) and false negative (COVID-19 patients are diagnosed as negative). The ratio of the sum of true positive and true negative to the sum

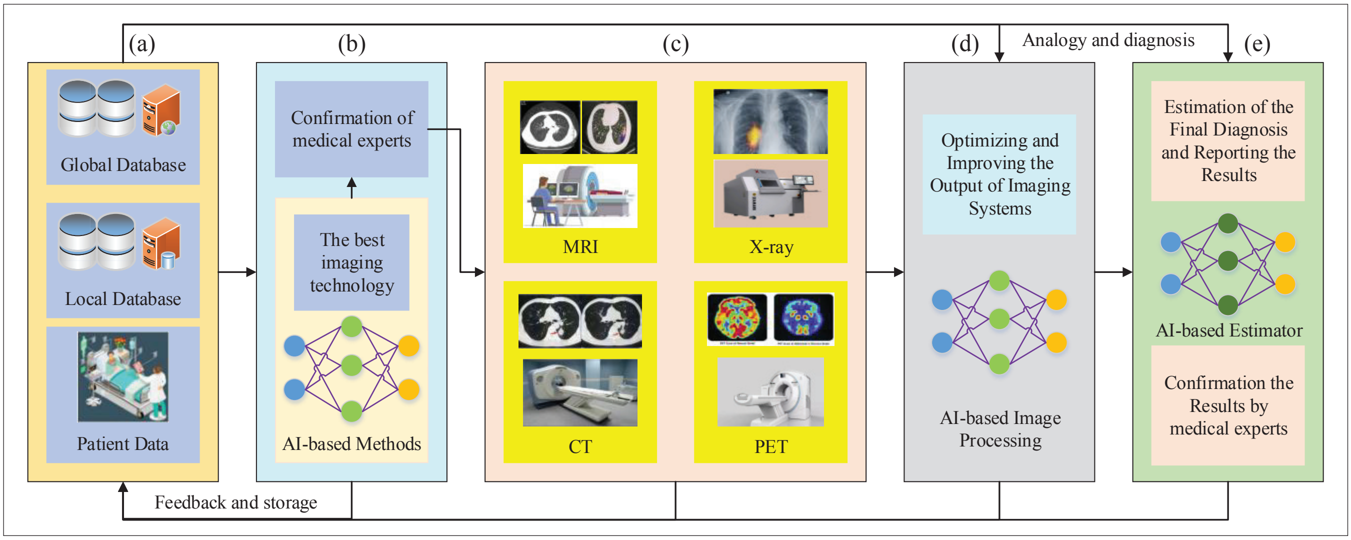

FIGURE 3. ANN diagnosis of COVID-19-like epidemics flow chart: a) input layer; b) selection Layer; c) imaging layer; d) optimization layer; e) output layer.

of the four is the final accuracy rate. Sensitivity means how many correct results can ultimately be determined. The ratio of true positives plus true positives and false negatives is the sensitivity of this AI technology. Specificity refers to the estimated repeatability or predicted correct number, which can measure the proportion of so-called healthy people in all truly negative people. The final specificity is calculated using the ratio of true negatives to the sum of true negatives and false positives.

A Proposed AI-Based Wireless Network Medical Framework

The social trend of using AI technologies to solve medical problems is irresistible. Considering the global and rapid spread of the COVID-19 outbreak, it is necessary to establish a global intelligent medical network system. Medical terminals all over the world simultaneously request a large quantity of medical network resources from the central server, and at the same time upload local patients information to the central server. While massive network traffic and resource requests put tremendous pressure on wireless channel transmission, they also bring severe challenges to the traditional Internet architecture. It shows that the centralized traditional network architecture is not suitable for the modern medical system with extremely high requirements for ultra-low delay and high bandwidth.

What is exciting is that driven by AI technologies and ML, the next-generation network (NGN) technologies have become more mature and can be widely used. Representative advanced technologies include 5G, B5G, cloud computing, edge computing and even 6G. Therefore, it can consider using the above technologies to design a new network architecture for modern health care. We envision a modern medical network framework based on edge computing and 5G to deal with the COVID-19-like epidemics. The framework is designed based on a distributed network architecture. Medical terminals scattered around the world can use local DL models to train medical data sets in local databases. After the training results are approved by medical experts, the edge medical node will upload the data set and DL model to the central medical node. The central node will train according to the received local models and data sets, and obtain the aggregated global models and data sets. Finally, the global model can be applied to each local medical node to test its accuracy. When the accuracy reaches the prescribed standard, the model can be used as a general model to diagnose and treat epidemics.

The modern medical network architecture based on edge computing and 5G we plan to propose is shown in Fig. 4. Assume that mobile edge nodes (medical equipments that can use DL for local training) suitable for this framework are deployed in each hospital. The mobile edge node can download the global training model from the central node through the high-speed 5G base station. The 5G base station has the characteristics of large-scale machine-type communication, ultra-reliable low-latency communication and enhanced mobile broadband. The architecture adopts a distributed design mode. Patient information in different regions is calculated and stored in different edge nodes. At the same time, each edge node can upload local information to the global controller for sharing, which can avoid the huge amount of information transmission. Network overhead can improve the efficiency of network processing information, thereby further improving the quality of medical services. An important function that the framework can achieve is the global sharing of important pathological information. Take the use of X-ray to diagnose COVID-19 patients images as an example. Local medical equipment uses the DL model to train the X-ray data set of COVID-19 patients. Authoritative medical institutions or medical experts analyze and appraise the training results. If the results are approved by experts, the pathological information of COVID-19 will be uploaded to the global server for global sharing. Medical institutions around the world can download this information through 5G base stations.

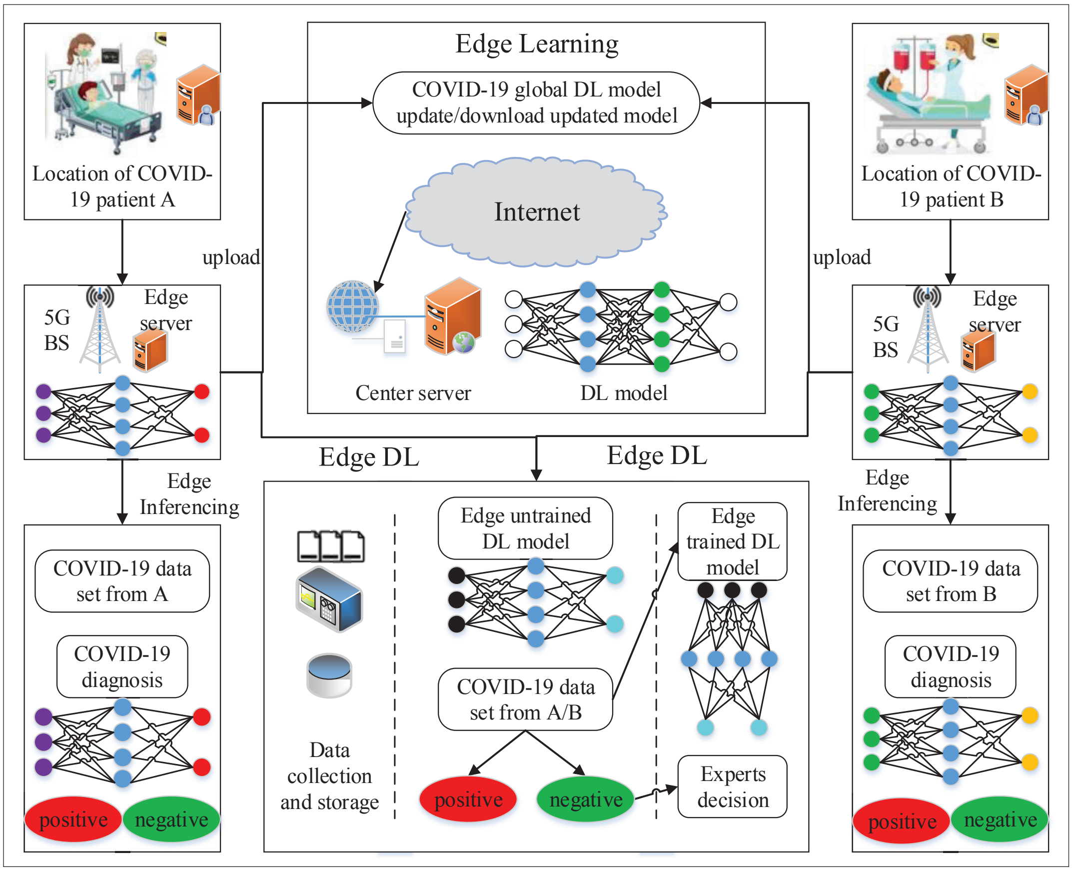

FIGURE 4. Proposed modern medical network system architecture based on AI technologies.

The COVID-19 epidemic caused by SARS-CoV-2 virus spreads faster, covers a wider range and causes more serious life and property safety than the previous worldwide outbreaks (e.g., A H1N1) [2]. Even more terrifying is that the COVID-19 virus is mutating, making vaccine development more difficult. In order to better contain the continuous spread of COVID-19 and thoroughly treat the infected, it is necessary to find effective treatment methods based on a full understanding of the infectious disease. Therefore, strong data set support is extremely necessary. There are currently several officially released COVID-19 data sets that have been widely adopted by researchers. The first is the COVID-19 Open Research Dataset (CORD-19) released by Microsoft and the White House. The data set collects relevant information on more than 40,000 academic articles, including approximately 29,000 articles on COVID-19, SARS-CoV-2 and coronavirus. This data set is freely accessible. The second is the wuhan2020-timeline. The data set uses the timeline as a clue to sort out the epidemic information released by official media, private media and self-media, effectively presenting the whole story of COVID-19 in Wuhan. The other is the new type of coronavirus pneumonia characteristic analysis data. It is the largest COVID-19 epidemiological characteristic analysis released by the Chinese Center for Disease Control and Prevention. Its original data are from over 70 thousand cases reported in mainland China in February 11, 2020. Other popular data include the chest radiography dataset-CheXpert, the Korean COVID-19 chest radiograph image dataset, and the British coronavirus tracker. Although relevant research and institutions have published some data sets on COVID-19, this is still far from enough. In the world, the situation of virus infection in some countries and regions is still uncontrollable, and the virus even mutates. Medical institutions around the world also need to work on the acquisition and management of a large number of COVID-19 data sets.

Due to the huge destructiveness of COVID-19, the complete realization of the modern medical network system based on AI technologies still faces a series of difficulties.

Lack of Data Sets: There is currently a lack of sufficient COVID-19 data sets to support the training and learning of DL models. In addition, the problem of low data quality also caused a waste of model efficiency.

Low Training Quality: The results obtained by DL models trained on inferior data sets are often far from the correct results, which can easily mislead the judgment of medical personnel.

Information Disclosure: DL model training has no special confidentiality mechanism. A large amount of medical information is transmitted on the network channel, giving criminals and malware enough time and space to steal this information.

Ethics: It is difficult for patients to accept the ethical impact brought by AI treatment technology in a short time. Some doctors may also be skeptical about the diagnosis and treatment results of new technologies.

Even though the difficulties may be far more than these, we hope and believe that the AI-based medical network system can play a key role in fighting the COVID-19-like epidemics. Relevant experts and medical personnel also need to further improve the ability to use new technologies to treat different epidemics. All in all, AI-based medical technologies can be further improved and has broad development prospects.

Conclusion

The outbreak and pandemic of COVID-19 have brought huge disasters to people all over the world, whether in terms of declarations or property. In order to effectively deal with the crisis brought by COVID-19-like epidemics, researchers have started new attempts from different aspects such as advanced medical technologies and advanced network technologies. With the development of NGN technologies driven by AI and ML, it is possible to use AI technologies to fight the COVID-19 epidemic. This article first summarizes a series of AI technologies that can be used to fight COVID-19 and fully affirms their contributions. After that, we give the general process of applying AI technologies to diagnose COVID-19-like epidemics and use accuracy, sensitivity and specificity to evaluate its performance. In order to achieve reliable medical technologies, we try to propose a modern medical network architecture based on AI technologies, which fully embodies the superior performance of AI technologies. Finally, we rationally analyze a series of challenges that may be faced by the application of AI technologies. The AI technology-based treatment of COVID-19 is still a new topic, and there are still many limitations in the deployment and implementation. First of all, there is no special security mechanism in the designed network architecture. How to ensure the security of user information privacy is a problem worthy of consideration. Secondly, how to verify the effectiveness of the system for other types of COVID-19 epidemic. Finally, the actual deployment of the system. The above problems will be studied as a part of future work.

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