Pandemic Management for Diseases Similar to COVID-19 Using Deep Learning and 5G Communications

Ghulam Muhammad, Salman Alqahtani, and Abdullah Alelaiwi

Abstract

The COVID-19 pandemic has had an unprecedented effect on the world. The pandemic has caused considerable death and suffering, triggered economic downturns, and led to significant job loss. Both during and after the pandemic, sophisticated and effective measures must be taken to diagnose COVID-19 patients and mitigate the effects of the virus. Emerging developments in the Internet of Things (IoT), 4G, 5G, and 6G wireless networks, artificial intelligence (AI), and blockchain technology can be harnessed to combat COVID-19. The implementation of IoT in hospitals enables highly integrated digital environments and real-time data collection, which can be utilized to identify clinical patterns, model risk interactions, and forecast effects via AI and deep learning systems. This article emphasizes the potential uses of IoT, AI, and 5G for combating pandemics similar to the COVID-19 pandemic. Then the authors propose a solution that uses federated learning and integrates these three technologies. Experiments were performed using cough sounds and chest X-ray images; the experiments yielded promising results.

Introduction

Beginning at the end of 2019, the coronavirus disease (COVID-19) epidemic sparked a public health emergency across the world. In just over three months, the global number of COVID-19 infections surpassed a million cases. The extraordinary spread of the virus presents an overwhelming challenge for nations across the globe and has shaken the foundations of human society and future development.

Without warning, the number of confirmed COVID-19 cases began increasing rapidly, leaving governments and medical professionals unprepared to cope with the rapidly deteriorating situation. Due to a shortage of test kit materials, many hospitals around the world are unable to identify COVID-19 patients. When diagnosing COVID-19, doctors mainly consider psychiatric symptoms, epidemiological history, favorable computer tomography (CT), and pathogenic examination. Radiological imaging is also a main diagnostic approach utilized by healthcare professionals for COVID-19 diagnosis.

Every day, additional data are being collected on the number of positive diagnoses, patients admitted, accidents, medical beds filled, ventilators needed, and so on. These statistics enable officials and the public to monitor COVID-19 responses, rendering the COVID-19 pandemic a data-driven pandemic. However, these statistics pose a considerable challenge, as decisions based on such data are unreliable and incomplete [1].

The verification and authentication of pandemic-related data and academic scholarship is a necessary prerequisite for devising guidelines and suggestions for the public. The implementation of smartphone monitoring applications is an effective method for halting the spread of the virus. Such applications can also enhance data quality and improve government credibility. Furthermore, producing reliable monitoring data is critical for tracking the spread of the virus. For these purposes, large tech corporations, academics, and health authorities have begun utilizing Bluetooth-based smartphone touch monitoring software solutions. Proximity tracking and geolocation can aid in monitoring the spread of COVID-19 cases.

Due to the worsening pandemic, medical systems are having difficulty providing continued access to vital medical care and supplies as well as medications [2]. Many governments, foreign institutions, and even ordinary people have offered economic assistance to solve such issues, but the main challenge is to maintain adequate delivery of medical services and openness for organizations and contributors.

Several organizations have developed map-based dashboards for tracking the pandemic. In order to understand the nature of the pandemic, sufficient data is needed to predict the spread of the epidemic, the efficacy of interventions, and the effects of the pandemic on people's lives. However, the data available online is not perfect, and it is vulnerable to data theft [3].

Emerging technologies have the potential to improve public health knowledge and public-private collaboration [4]. For example, governments could collaborate with the WhatsApp messaging service to provide reliable alerts about COVID-19 and public services. Various national health departments are utilizing social networking platforms to provide real-time information and correct common misunderstandings. Many facial recognition firms have begun applying thermal face recognition to identify people with high temperatures at multiple screening points in China.

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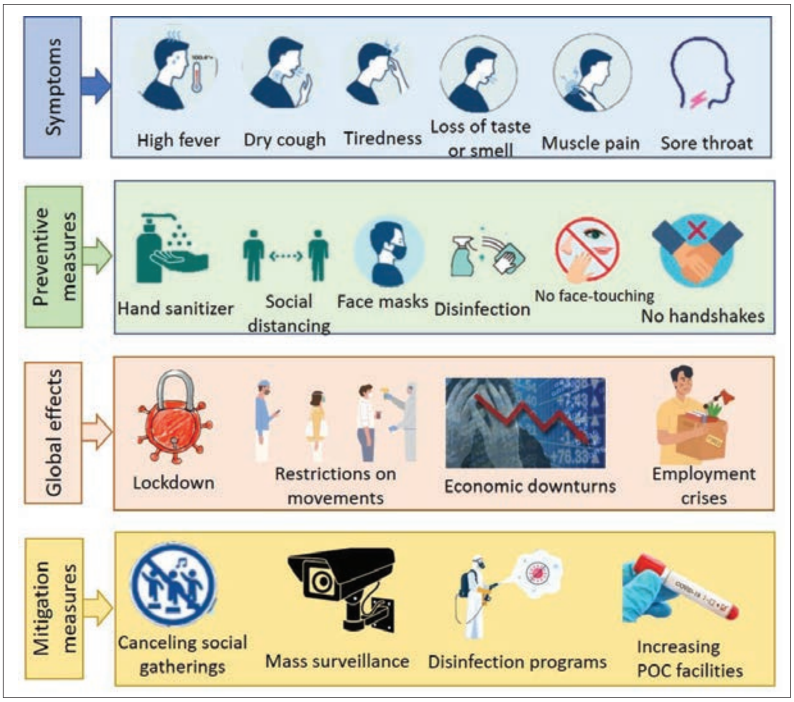

FIGURE 1. A list of COVID-19 symptoms, preventive measures, global effects, and mitigation measures.

Symptoms, Preventive Measures, Global Effects, and Mitigation Measures

There are several known symptoms of COVID-19; some symptoms are more common than others. Some COVID-19 patients, however, have no apparent symptoms. Figure 1 shows a list of COVID-19 symptoms, preventive measures, global effects, and mitigation measures for combating COVID-19.

Some common symptoms of COVID-19 include high fever, dry cough, tiredness, loss of taste or smell, muscle pain, and sore throat. Some patients may present with multiple symptoms; however, the mere presence of any of these symptoms does not guarantee the diagnosis of COVID-19. If COVID-19 symptoms are observed, a patient should undergo laboratory tests [5].

Most COVID-19 patients display similar findings on CT scans, including early ground-glass opacity and late-stage pulmonary consolidation. Patients also display rounded morphology and peripheral lung distribution. Although standard CT images can assist in the early diagnosis of COVID-19, it is impossible to distinguish COVID-19 infection from various forms of viral pneumonia as well as other infectious and inflammatory lung diseases by just evaluating CT images. However, it is important to note that radiologists can discriminate between COVID- 19 and some forms of bacterial pneumonia. A previous study focused on the diagnosis of COVID-19 patients using radiographic images [6].

COVID-19 infection prevention measures include social distancing, using hand sanitizer, face masks, and disinfectant, as well as avoiding face touching and handshakes. Restrictions on social gatherings and indoor crowds at malls should also be implemented. Additional measures include mass surveillance for social distancing monitoring and mask detection, maintaining disinfection programs, and increasing point-of-care (POC) facilities. The global effects of the COVID-19 pandemic have been severe. Some of these global effects include lockdowns, restrictions on movement, economic downturns, employment crises, and a transition to online education.

Healthcare services should develop plans for utilizing emerging technologies. For example, "Internet hospitals" could be established to provide appointments supported by imaging data (e.g., chest X-rays and thorax CT scans) that could be read and interpreted remotely. Such an approach would allow patients to continue to receive standard health treatment while also avoiding the need for patients to gather at medical facilities. The use of digital e-learning systems in primary healthcare operations to reduce the need for physical gatherings is also being explored [7].

The Role of IoT, AI, and 5G in Combating Covid-19

The Internet of Things (IoT) offers public health authorities a database that can provide updates on the current status of the COVID-19 pandemic obtained through surveillance. For example, the Worldometer website presents real-time data on the number of confirmed cases of COVID-19 globally, and provides regular indicators of sickness and domestic spread, as well as the number of recovered, critically ill, and deceased patients. Big data also enables the modeling of infectious disease analyses and can assist public health policy makers in enhancing epidemic preparedness [8].

Artificial intelligence (AI) and deep learning can assist in the identification and diagnosis of COVID-19 patients. The shortage of reliable and low-cost COVID-19 diagnostic tests is a global problem. Therefore, alternative COVID-19 screening and testing methods could be extremely beneficial. Although most patients have only mild COVID-19 symptoms, doctors insist on the importance of all patients adhering to strict isolation, treatment, and monitoring guidelines. AI algorithms can be designed to allow doctors to identify three potential categories of COVID-19 patients: patients with moderate disease (approximately 80 percent of patients), patients with severe disease (approximately 15 percent of patients), and patients at high risk of death (approximately 5 percent of patients). AI could also be used to assist in the production of new COVID-19 drugs. Recently, deep learning models have been designed to be light but highly accurate [9].

Technological innovation is a key component for overcoming the COVID-19 pandemic. New technologies can be leveraged for smart catastrophe management techniques that can be applied to the COVID-19 pandemic. Such approaches could incorporate AI, deep learning, IoT, blockchain, robots, unmanned vehicles, 3D printing, 5G and 6G networks, fog computing, and big data. In particular, the European Parliamentary Research Service (EPRS) explicitly referred to blockchain technology as one of 10 primary innovations for fighting COVID-19.

The COVID-19 virus is spreading rapidly, and governments are facing difficulties identifying positive cases without leaking individuals' private information. Moreover, researchers conducting experiments face obstacles when attempting to exchange data and further develop models. Collecting data from diverse sites presents significant problems that hinder development of AI-based techniques. In addition, difficulties related to teaching deep learning algorithms across a shared network constitute another obstacle. Medical professionals diagnose patients using genome sequences from respiratory tract samples and reverse transcription-polymerase chain reactions. Instead of patients hoping for definitive outcomes from the infection, therapies now cover those accused of developing COVID-19 chest CT scans [10].

Utilizing multiple triage systems that incorporate AI could reduce burdens on physicians. Online chatbots could help patients recognize early symptoms, teach people proper hand hygiene, and inform people about indicators of increasing medical care. A telephone-based program that records and tracks medical details (e.g., daily temperature and symptoms) could eliminate needless doctor visits for patients with moderate flu-like symptoms. This information could also be used to inform COVID-19 AI algorithms. Several hospitals in China have partnered with blockchain firms and pharmacies to bring patients' medications to their doorsteps. By utilizing blockchain, hospitals can ensure prompt distribution of medicine with reliable surveillance.

After recovering from COVID-19, many patients are left with irreversible lung damage. A new study from the World Health Organization suggests that COVID-19, similar to SARS, mainly affects the lungs, giving them a honeycomb-like appearance. Minor lung damage caused by COVID-19 is sometimes overlooked by trained radiologists; therefore, it is important to establish a deep learning model for the automated identification of COVID-19.

In telecommunications, 5G is essential for high-speed communication, in particular for end-to-end networks and uplink connections. It also offers extremely low latency between peers and a high degree of trustworthiness [11]. Moreover, 5G offers considerably quicker and more dependable connectivity and supports far more use cases than WiFi. Furthermore, by using a permitted and non-limited range on low, medium, and high bands, 5G can support more implementations and provide optimized flexibility, wide coverage, and lower latency for end consumers. Figure 2 shows different layers of data sources in a healthcare system, including IoT, edge computing for the preprocessing of data, web applications that act as an interface between the edge and the cloud, and cloud computing for processing data using coordinated deep learning. Data can be obtained from COVID-19 and non-COVID-19 patients, elderly people, and others. Different types of IoT are utilized to capture data. The cloud server can be connected to designated hospitals and medical doctors through a web application. Doctors can assess patients remotely, and hospitals can prepare for potential emergencies [14].

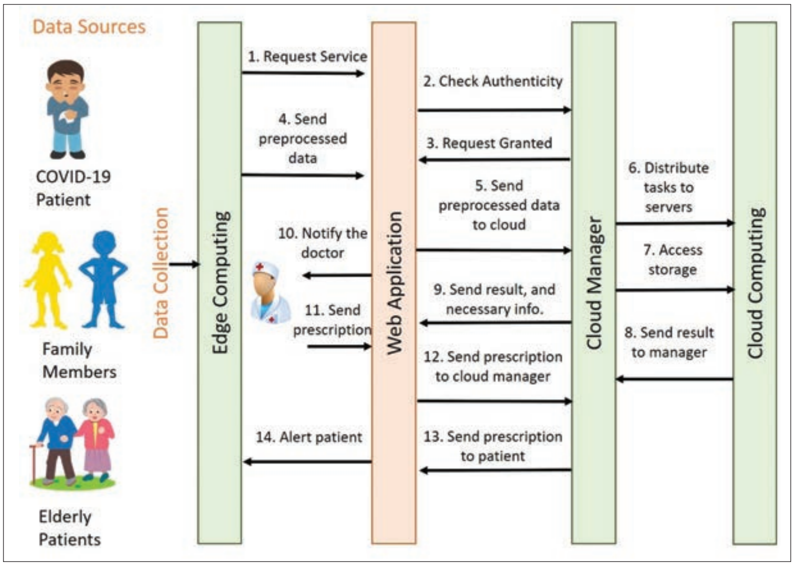

FIGURE 2. Different layers of a healthcare system.

The use of self-driving and unmanned automobiles can minimize human interaction in healthcare systems. The images gathered from multiple cameras mounted on vehicles can be transmitted in real time to control stations for secure remote control. The dispersion of disinfectant by robots could be introduced alongside independent or semi-autonomous transportation systems. Self-driving cars could be deployed to check body temperatures, regulate central intercom touch, and conduct surveillance using facial identification and license plate recognition software. The operation and regulation of self-driving cars requires similar networking specifications to smartphone applications and computer systems, particularly in terms of efficiency and latency.

A 5G network linking the car to the cloud through customer position, similar to a fixed broadband modem, and an operator control and monitoring device is a solution for the implementation, enforcement, and operation of autonomous vehicles addressing end-user and public safety criteria. Moreover, 5G and related technological innovations will attract the majority of investment in fields such as AI development, data center construction, online industry, intra-city train networks, electric car charging centers, and high-voltage electrical networks. By focusing on these areas and structures, countries aim to stimulate economic and social growth, particularly in underdeveloped areas where trade and industry must continue to grow.

By utilizing a global cloud server, countries that have been negatively impacted by the COVID-19 pandemic can take advantage of the current crisis to create infrastructure that can benefit future generations. In addition to helping solve the COVID-19 pandemic, 5G technology enables modern and creative developments based on virtual reality (VR) and augmented reality (AR) as well as the utilization of AI. Moreover, 5G networks would allow 4K and ultra-high-definition video to be streamed instantaneously from a smartphone, smart public transportation-mounted camera, or public surveillance camera. An agent's glasses could receive 4K images over a network.

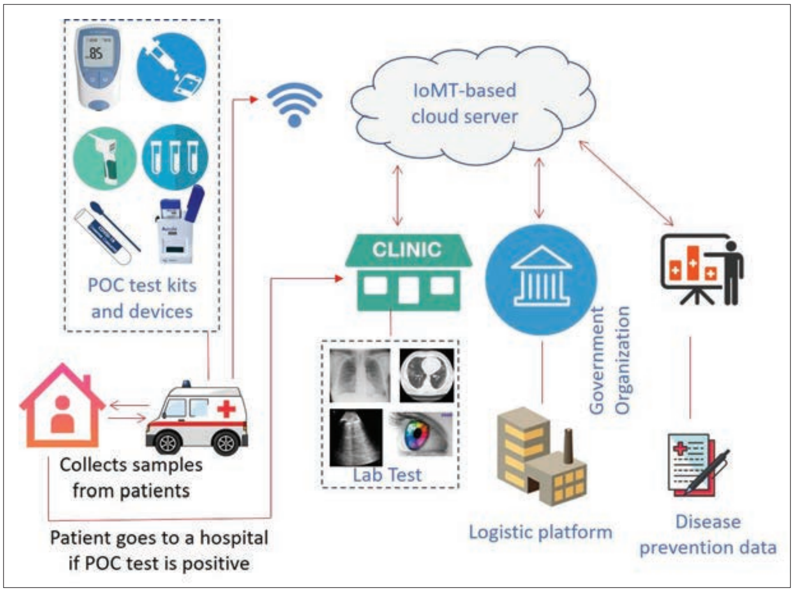

FIGURE 3. A framework for a COVID-19 detection and management system.

The server could create items, compare them to other photographs in a database of faces, and send pertinent information to an agent's glasses. The glasses could display details on a simulated screen in real time so that a perpetrator could be quickly identified.

Federated Learning for Healthcare Systems

Federated learning (FL) is a learning model that seeks to solve the issue of data management and confidentiality by creating machine learning algorithms without sharing data. It was primarily designed for use with smartphones and edge computing; however, it has recently been applied to healthcare systems. FL allows for insights to be extracted cooperatively. For example, in a consensus model, FL can be carried out without transferring patient details beyond the firewalls of the facilities in which patients are housed. Instead, the FL procedure is carried out locally at each relevant organization, and only model characteristics, such as parameters and gradients, are imported, as seen in Fig. 1. Recent research has shown that FL-trained models outperform models trained on centrally hosted datasets as well as models trained on independent single-institution datasets.

Therefore, an effective FL deployment will greatly contribute to enabling precision medicine on a wide scale, as FL creates models that allow for impartial decisions and best represent a person's physiology. FL is also resistant against unusual disorders while protecting privacy. However, FL also necessitates careful scientific analysis to ensure that the algorithm operates efficiently without jeopardizing a patient's privacy or safety. Nonetheless, FL can transcend the shortcomings of methods that depend on a single centralized pool of data.

COVID-19 has profoundly affected our everyday lives. As there is no cure, all measures must be taken in order to prevent infection, including social distancing and self-isolation. Private businesses and institutions such as shopping centers, malls, colleges, clinics, and restaurants must consider the COVID-19 status of travelers, as they can put workers and other customers at risk. One method for identifying people infected with COVID-19 has been thermal or IR cameras. However, these methods fail to identify asymptomatic COVID-19 patients. In addition, authorities and care providers are not required to disclose the status of patients, as health data cannot be exchanged securely. New methods must be developed for securely sharing and storing individuals' COVID-19 status for public health requirements. Recent advances in blockchain, IoT, and social networking technologies have resulted in the creation of new healthcare services [13]. Deep learning frameworks can intelligently train written transactions on the blockchain and off the blockchain.

Deep learning has been extensively used in many applications including speech and speaker recognition, image processing, smart healthcare, security solution, FL, and edge and cloud computing resource distribution [15]. One of the issues of conventional deep learning is the requirement of large training data, which are labeled. Many of the healthcare related data are limited in size, and some of them are not labeled. Therefore, several variants of deep learning architectures are proposed in the literature [9].

The Proposed Framework

Figure 3 shows a proposed framework for a COVID-19 detection and management system. The system uses blockchain to maintain privacy and security. A vehicle carrying POC test kits and devices travels door to door to collect samples. The vehicle collects the samples and either performs simple tests and sends the results to an Internet of Healthcare Things (IoHT)-based cloud server or brings the samples to a designated clinic. At the clinic, additional lab tests, such as chest X-rays, chest CT scans, lung ultrasounds, and ocular surface tests, may be performed. The images are then sent to an IoHT-based cloud server. Then the image samples are first sent to edge computing for processing. A deep-learning-based model is embedded in edge computing and cloud computing. The DL model that is embedded in edge computing can test the image sample but cannot perform training. The DL model in the cloud can be used for training and updating the parameters by using samples from multiple locations. We deployed three existing convolutional neural network (CNN) models as the DL model in the framework. The CNN models are ResNet50, ResNet101, and InceptionV3.

The IoHT sensors shown in Fig. 3 have been chosen to help us control COVID-19 symptoms, carry out evaluations, or handle a pandemic. Figure 4 shows the DL modules of the lab test. In edge computing, there is a dedicated DL module for each test modality. The edge server, where homomorphic processes are executed, may be run by either a local blockchain user or a trusted employee. The edge servers are able to identify signs consistent with COVID-19. First, the edge node connectivity framework safely exchanges secured model and data with the blockchain app. Edge inference enables the data collecting device in the field to provide actionable intelligence using DL models.

This article suggests a holistic approach to the problems of solving the healthcare issue collectively through the development of an enhanced structure that contains implementations for all three of the groups involved, namely COVID-19 patients, health authorities, and stakeholders, which includes states, companies, and other private and public institutions. In this situation, the authorities can allow access to each individual's health status while extending access to the health status of owners (i.e., residents). A QR code-based profile for each visiting subject is created by an approved health agency using a smartphone application. The application enables the uploading of one's COVID-19 health details and biometric data using facial recognition, which the deep learning algorithm analyzes. Transactions are held in the blockchain, and raw data, including facial recognition data, are protected and stored beyond the chain. The medical authorities can review and change the health status of the user at any time. Stakeholders, also known as service providers, may verify the health status of the consumer through the application, which uses subject-specific QR codes and facial scanning data in public places to conduct health checks. The above framework is our proof of concept.

The proposed framework also incorporates a social surveillance system (Fig. 5). The system can monitor social distancing behavior, face mask wearing, and body temperature. For body temperature monitoring, thermal cameras are deployed. For other monitoring activities, surveillance cameras are used. The captured videos are preprocessed in edge computing. The preprocessing includes detecting and enhancing key frames. The pre-processed frames are then sent to the cloud for further processing and classification.

Experiments and Results

As proof of concept, we performed several experiments using cough sounds and chest X-rays. Three existing CNN models were used in the framework. The CNN models are ResNet50, ResNet101, and InceptionV3. Cough sound samples and chest X-ray samples were collected from different sources that were publicly available on the Internet. We collected 200 samples of cough sounds from COVID-19 patients and 200 samples of cough sounds from individuals who did not have COVID-19. In addition, we gathered 500 chest X-ray samples from COVID-10 patients and 500 chest X-ray samples from individuals without COVID-19. Then 70 percent of the samples were used to pre-train the models, and 30 percent were used for testing. For the cough sound samples, we first generated a spectrogram of the sound lasting 50 ms. Samples were processed and analyzed frame by frame. The chest X-ray images were resized to 128 × 128 and fed directly into the CNN. The learning rate and the batch size were set to 0.01 and 5, respectively. Cross-entropy was used as the loss function. Adam optimizer was used to update the parameters of the models. Three performance metrics — accuracy, precision, and recall — were used to measure the performance of the models. Figure 6 shows the accuracy, precision, and recall of the models using cough sounds and chest X-rays. The figure shows that chest X-rays are more reliable than cough sounds for detecting COVID-19. Among the CNN models, ResNet50 performed best according to all three performance metrics. Using ResNet50, the accuracy was 95 percent for cough sounds and 98 percent for chest X-rays. Precision and recall ranged between 97 and 99 percent.

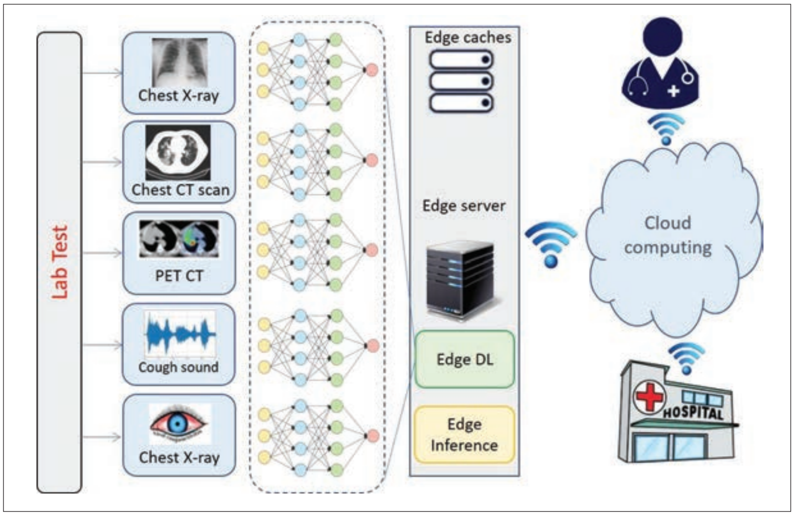

FIGURE 4. Lab test for COVID-19 detection using edge and cloud computing.

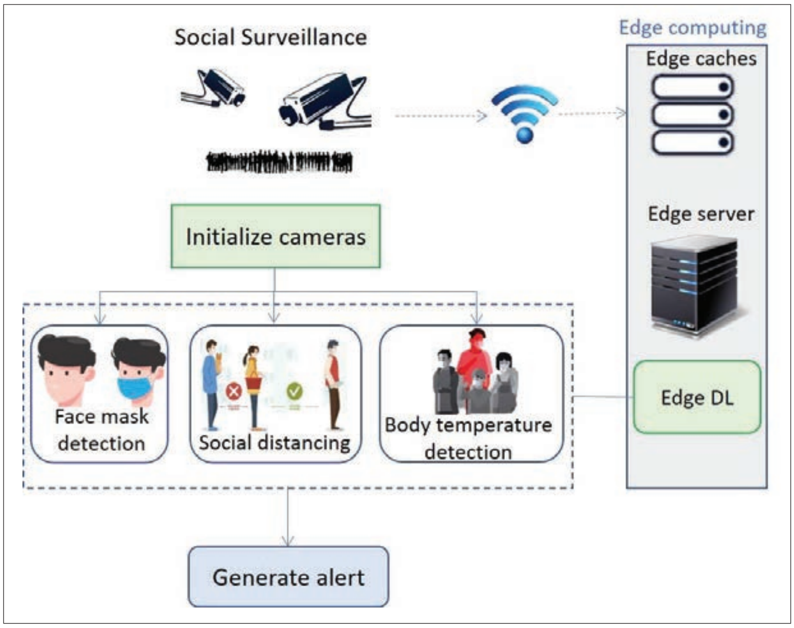

FIGURE 5. A mass surveillance system according to the proposed framework.

Future Work

Currently, there is a lack of multimodal data on COVID-19. For example, it is difficult to find chest X-ray images, chest CT scan images, lung ultrasounds, and coughing sound samples that belong to an individual COVID-19 patient or non-COVID-19 patient. Therefore, all of the existing AI-based screening and detection systems rely on data from a single modality. There is a need to develop a multimodal COVID-19 dataset so that different modalities can be intelligently fused to detect COVID-19 with more accuracy. In this way, the real power of AI, edge computing, and 5G communication can be fully utilized. In addition, tree-based FL models should be deployed to utilize parallel processing with cloud technologies.

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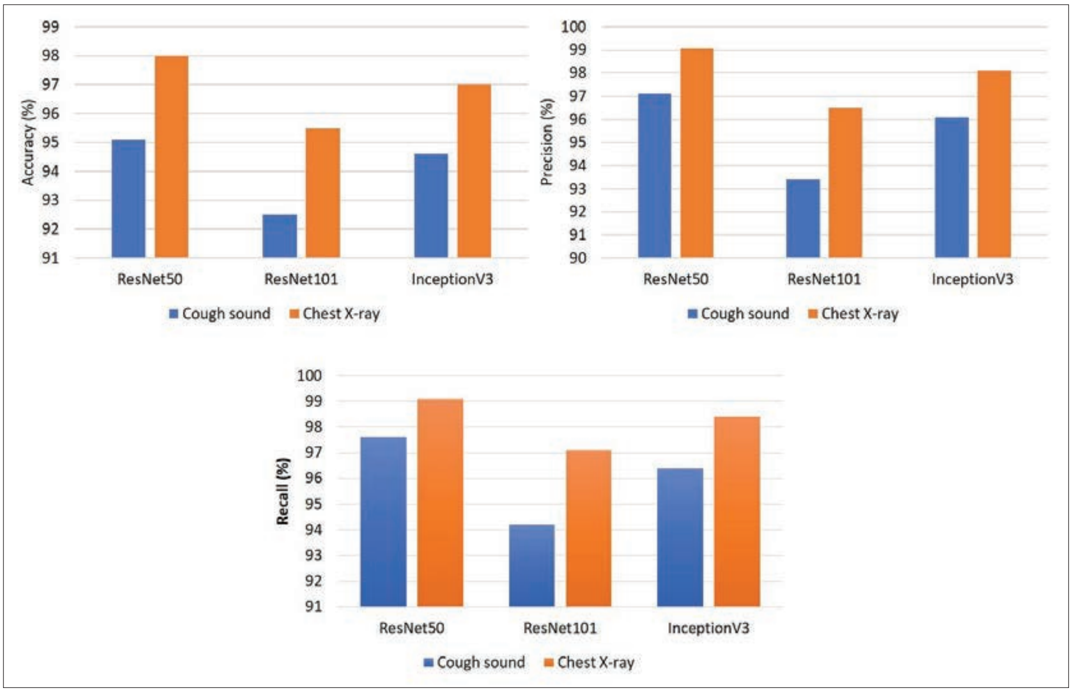

FIGURE 6. Accuracy, precision, and recall of the CNN models in the proposed framework using coughing sounds and chest X-rays.

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