Research Article

Formal Modeling of IoT-Based Drone Network for Combating COVID-19 Pandemic

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Received 2 November 2021; Accepted 21 July 2022; Published 31 August 2022

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Coronavirus biologically named COVID-19 is a disease that is circulating throughout the world due to its viral nature. The interaction of people is a source of spreading of coronavirus. Millions of people have been affected by this virus, and most of them have lost their lives. At present, this viral disease has grown into a worldwide pandemic which is a troubling spot for the whole world. Few technologies are supporting to manage and solve the COVID-19 crisis. In this paper, unified modeling language (UML) will be used to describe requirements and behavior of the proposed system. Unmanned aerial vehicle (UAV) drones are flying mechanical devices without any human pilot that is efficient to reduce the spreading rate of COVID-19. In the proposed IoT-based model, a cluster-based drones’ network will be used to monitor and perform required actions to tackle the violations of standard operating procedures (SOPs). The drones will gather all data through embedded cameras and sensors and will communicate with the control room to operate the actions as required. In this model, a well-maintained and collision-free network of drones will be designed using graph theory. Drones’ network will observe the violation of SOPs in the targeted area and make decisions such as produce alarm sound to alert persons and through communications by sending people warning messages on their smartphones. Further, the persons having COVID symptoms such as high temperature and unbalance respiratory rates will be identified using wearable sensors that are deployed to the targeted area and will send information to the control room to perform required actions. Drones will be able to provide medical kits to the patients’ residences that are identified using wearable sensors to reduce interaction of people. The model will be specified using Vienna Development Method-Specification language (VDM-SL) and validated through the VDM-SL toolbox.

1. Background

The IoT is a network of linked, Internet-interconnected gadgets that can transmit and receive data over a wireless link with no human participation. COVID-19 is a viral illness that can be transferred from one person to another by the close interaction of people in less than 6 feet of distance. The earliest-time coronavirus was discovered in December 2019 in Wuhan located in China; in the past, no one knew about it, but in a short time, this virus has grown into a worldwide pandemic [1]. Unmanned aerial vehicle (UAV) drones play an essential part in dealing with the COVID-19 outbreak although they are flying robots with no human interference, which would help to minimize virus transmission.

2. Introduction

Corresponding to the latest statistics worldwide, 45.8 million people have been affected with COVID-19 and 1.19 million people could not stay alive. In Pakistan, 334K COVID-19 cases are reported and 6,823 people have lost their lives [2]. COVID-19 symptoms include dry cough, headache, and tiredness, but certain patients might experience throat pressure, nasal congestion, and sore throat. The World
Health Organization (WHO) has declared standard operating procedures (SOPs) to reduce transmission of coronavirus. SOPs include keeping a social distance of 6 feet, using a mask, and using sanitizer. To reduce the spread of virus, it is important to maintain SOPs and minimize the interaction among the people.

In this paper, the proposed model includes three modules that are monitoring SOPs, identification of COVID patients, providing them medical services, and the maintenance of drones’ network in case of any failure. The proposed model is cluster-based which includes sensor drones, actor drones, cluster heads, and a control room. By integrating the Internet of Things (IoT), drones can detect SOP violations in the targeted area using embedded sensors and cameras. Our major goal is to keep monitoring of SOP breaches in targeted area and take action while reducing human interaction in order to keep the spread under control. Unified modeling language (UML) is used to develop a model that described the behavior of the system [3]. To make the system understandable, the proposed system is modelled and the functionalities are explained using UML. Graph theory is a data structure that is used to effectively store information [3] which is used to represent the connections and communication between the nodes [4]. In targeted areas, the drones will be able to monitor the violations of SOPs and communicate with the control room in order to perform runtime actions. It is assumed that the control room have details of every person so they can communicate with people when it will be required. In the targeted area, wearable sensors are already implemented to identify persons having symptoms of COVID-19 and inform control room to perform an action. The control room will be able to communicate with drones and people as well, and each drone will be able to communicate with every other drone. It is assumed that every person has done and medical insurance where the drones will deliver medicine and test kits.

Figure 1 illustrates, that when a drone detects a violation of social distancing or missing mask, the drone will perform some actions such as produce alarm sound and spray sanitizer then provides information to the control room, which then takes action by sending an alarm message to the individual.

For any model, maintenance is an essential part that in case of any failure there should be a recovery method for the maintenance of the model. The drones are restricted to their defined zones to avoid the collision. In case if a drone fails due to any technical reason, then for placing new drone, the existing drones will be shifted and cover the place of failed drone and then the new drone will be placed in the space. This procedure will help to avoid the collision of drones during the placement of new drones as shown in Figure 2. The control room is responsible for the charging of drones; it allows drones to charge from time to time and the neediest drones have priority to be charged first.

Wearable sensors are used to identify COVID patients. Wearable sensors are already implemented in the targeted region. Figure 3 illustrates that individual having symptoms of coronavirus (high temperature and unbalance respiratory rates) can be identified and sent a signal to control room. A control room refers a message to persons and also sends a signal to actor drone to provide medical services to the residence of that patient.

The model is specified utilizing formal methods in Vienna Development Method-Specification language (VDM-SL). The formal methods are a software engineering framework that employs mathematical methodology in the development of complex software systems [5]. To describe each process attribute, the method employs a formal specification code. The VDM-SL uses a distinct syntax composed of objects, relations,
and laws. Model validation is done by the VDM-SL toolbox to check the correctness by utilizing facilities available in the VDM-SL toolbox. COVID-19 has become a globally big challenge because people are not taking precautions. We are addressing this issue by making a formal model of a well-maintained drone-based network system that will reduce the interaction of people by providing medical services and network of drones will restrict persons to follow SOPs in targeted area by alerting them. The model is validated and verified by using features of the VDM-SL toolbox. There exists a little research work on COVID-19 and drone system, but there is no work done on drones’ network using formal methods and there exists no complete model that provides SOP alerts and maintenance of drones and medical delivery in a single system.

3. Related Work

In [1], the authors proposed a drone-based architecture to handle the pandemic issues by monitoring people following social distancing. Furthermore, this study was to collect the medical data by using wearable sensors in crowded areas; by processing collected data, the drones become able to take some real-time decisions. In this research, they also restricted drones to their zones to avoid the collision. In [2], the study explores, during the COVID-19 pandemic, drones would improve medicine delivery efficiency. Drones will also contribute to delivering a COVID test kit to the patient’s house and carrying the specimen to a laboratory in this study. The lesser the chance of viral transmission, the less you contact with patients. In [6], the delivery through drones has been discussed in this research; the authors proposed a model in which the drones can deliver multiple packages to the customer as well as the energy drains. The result of the experiments concludes that the number of drones and the speed of drones have an impact value on the objective. In [7], an architecture of a design of a network of drones has been discussed. It consists of coordination and communication with each other by using embedded sensors. They also implemented a multidrone system that can assist in disaster situations such as search, rescue, and monitoring. In [8], the authors present a brief review about cooperative tasks performed by multi-unmanned aerial vehicles. Furthermore, in this research, they have analyzed the importance as well as difficulties of UAV mutual tasks under some complex environment. In [9], the researchers highlighted many technologies which are helping in the fight against coronavirus. They also have discussed the difficulties of using the given algorithms. A model has been presented to recognize the symptoms of the virus which needs some extra accuracy. They determined that many technologies need more development for an efficient model. In [10], a method has been introduced to estimate the location of a drone. For the estimation, they used a double sensor. With the connection of these sensor, they can find the nearest drone and its locus will make a cone which will help to estimate the location of the drone. In [11], the authors discussed about monitoring visitor’s behavior by analyzing zenith images captured by the drones. They also discussed this method of analyzing behavior is way better than the GPS and many more techniques. Furthermore, in this paper, a real-time scenario was discussed to get feedback about crowded place. In [12], an efficient city-based method is introduced which will help to reduce the spread of coronavirus among the medical staff of the hospitals. All the patients will be isolated at their homes. The doctors will deliver the medications with the help of drones. Only those
patients who are more critical will be admitted to hospitals. This method will reduce the interaction of patients with the doctors.

In [13], the innovative fight of Ghana in Africa during coronavirus has been discussed. Africa is deficient in technology as compared to all other regions, but in this breakout, an innovative idea utilizing drones to deliver test supplies is introduced, test samples, medications, and many more effective activities. In [14], this study has proposed an improved multidrone method to handle attacks more effectively. Furthermore, in this study, they have proposed communication between every drone to take a decision against the attack. The results show that this method is more useful than the regular one. In [15], a survey about UAV technology has been taken. They have discussed about the many existing parameters of UAVs like the network and communication. They also highlighted applications as well as the challenges of the technique. In [16], the authors give a review of the existing UAV communication protocols, network architecture. They also discussed some techniques like machine learning, encryption to enhance security and long-lasting communications. Furthermore, in this study, some applications are also discussed. In [17], the authors reviewed the recent issues of the deployment of drones. They highlighted that the drones could inflict many other air objects. So, there is a need of having some more policies to overcome this issue. Furthermore, in this paper, they have discussed about air management. In [18], the authors proposed a framework for some dynamic weather. The candidate drones work for delivery service. The proposed framework allows the drones to make some runtime changes according to the delivery expectations. The results show the efficiency of the framework. In [19], the authors proposed an approach to solving the charging issue of the drones in the network. They proposed a scheduling algorithm that schedules drones with preference like the most needed drone will get the charging slot first. Furthermore, if a drone needs charging, it can request from the station. Game theory approach has been used in it which results in an efficient system of charging.

In [20], the authors proposed a trajectory model in order to minimize the disturbance between normal aircraft and drones. In this model, the positions of drones will be covered
like the initial position, updated position, and different collision zones have been analyzed, and the results show the proposed model can be deployed to evaluate the probability of collision. In [21], the authors proposed a machine learning-based model to predict the threat of coronavirus in the whole world. Cloud computing platform has been used in this model to enhance the accuracy of the prediction. Further, they have provided some useful future directions. In [22], the authors review the role of IoT in combating COVID-19 pandemic as the linked devices and applications which are IoT-based are very useful to handle this pandemic. Further, they have discussed that monitoring of patients and early diagnosis can reduce the spread of coronavirus. In [23], the authors have discussed all the possibilities of the spreading of coronavirus. They have said some disinfection like sodium hypochlorite, chlorine, and bleach solution can be helpful for lower growth of coronavirus. Further, they have discussed principles that can affect the efficiency of system tackling. In [32], the authors proposed a study of smart city technologies such as drones, smart healthcare, and medicine delivery in order to minimize the spread of COVID-19; these technologies will reduce the interaction of people. Further, they have discussed groceries’ delivery essential things and many more tools have played a role in the prevention and treatment. In [31], the authors give an overview of some solutions that already exist for contact tracing. Further, they have discussed principles that can affect the efficiency of the wearable tackling. In [32], the authors proposed a review of the use of unmanned aviation systems (UAS) to handle the COVID-19 issues; further, the authors discussed the innovations in the technologies used during the pandemic. In [33], the authors have reviewed big data, IoT, and AI that play an important role in diagnoses and as the impact of this outbreak on the economy. In [29], the authors proposed a study of smart city technologies such as drones, smart healthcare, and medicine delivery in order to minimize the spread of COVID-19; these technologies will reduce the interaction of people. Further, they have discussed groceries’ delivery essential things and many more important items without any human interaction. In [30], the authors have reviewed the role of many information technologies in the fight against COVID-19 pandemic and the study has concluded that IT such as video calls, drones' big data, and many more tools have played a role in the prevention and treatment. In [31], the authors give an overview of some solutions that already exist for contact tracing. Further, they have discussed principles that can affect the efficiency of the wearable tackling. In [32], the authors proposed a review of the use of unmanned aviation systems (UAS) to handle the COVID-19 issues; further, the authors discussed the innovations in the technologies used during the pandemic. In [33], the authors have reviewed big data, IoT, and AI that play an important role in diagnoses and

```
types
ID = token;
Droneid = token;
Status = <ACTIVE>|<SLEEP>;
EmbeddedSensor = token;
Camera = token;
Energy = <HIGH>|<LOW>;
Alarm = <on>|<off>;
Violation = <SOCIAL_DISTANCING>|<MISSING_MASK>;
ViolationDetection = <DETECTED>|<VNOTDETECTED>;
CRAction = <WARNING_MESSAGE_TO_PERSON>; 
Sdronemode = <IDLE>|<WORKING>;
SdronerAction = <SENSE_VIOLATION>|<INFO_TO_ACTORDRONE>;
Adronemode = <IDLE>|<WORKING>;
ADronerAction = <INFO_TO_CLUSTERHEAD>|<SANITIZATION>|<PRODUCE_ALARM>;
ClusterHeadMode = <IDLE>|<WORKING>;
ClusterHeadAction = <INFO_SENDTO_CR>;
values
Sdinfact: nat =6;
```

Code 1.

```
Sgnl :: received:bool
not_recieved:bool;
Infor :: received:bool
not_recieved:bool;
Database :: ID : token
Pid : ID
person : token
personDetails : token;
Drones :: Sensordrone: set of SDrone
actordrones : set of ADrone
embeddedsensor: Embeddedsensor
camera: Camera
violationdetection:ViolationDetection;
```

Code 2.
Nde::Ndeid:ID
  enrgy:Energy
status:Status
sgnl:Signal
info:Infor;
Edgeess = set of Edgee
inv edg == forall mk_(Ndeid1,Ndeid2) in set edg & mk_(Ndeid2,Ndeid1) in set edg;
Edgee = ID*ID
 inv eg == let mk_(Ndeid1,Ndeid2) = eg in Ndeid1<>Ndeid2;

Code 3.

Controlroom ::cr: ID
db : map ID to Database
drones : set of Drones
info : Infor
craction : CRAction
inv mk_Controlroom(-,db,-,-,-) == forall person in set dom db & person = db(person).personDetails;

Code 4.

SDrone::sdNde: Nde
  sdNdemode: SdroneMode
  sdNdeaction: SDroneAction
  violation: Violation
inv mk_SDrone(sdNde, sdNdemode, sdNdeaction, violation) == sdNde.enrgy = <HIGH>
and sdNdemode = <WORKING> <= sdNdeaction = <SENSE_VIOLATION>
and if Sdinfet < 6 or violation = <MISSING_MASK> then
sdNdeaction = <INFO_TO_ACTORDRONE> else sdNdemode = <IDLE>;

Code 5.

ADrone::actordrone: Nde
  actordronemode: AdroneMode
  actordroneaction: ADroneAction
inv mk_ADrone(actordrone,actordronemode, actordroneaction) == actordrone.enrgy = <LOW> and actordronemode = <IDLE>
and actordronemode = <WORKING> <= actordrone.sgnl.received = true
=> actordroneaction = <SANITIZATION> and actordroneaction = <INFO_TO_CLUSTERHEAD>;

Code 6.

ClusterHead :: chNde : Nde
  sendssgnl : set of Drones
  actdrone : set of ADrone
  chmode: ClusterHeadMode
  chaction: ClusterHeadAction
inv mk_ClusterHead(chNde, -, -, chmode, chaction) == chNde.enrgy = <HIGH> and if chNde.sgnl.received = true then chmode = <WORKING> and chaction = <INFO_SENDTO_CR> else chmode = <IDLE>;

Code 7.
treatment of COVID-19. In [34], the authors propose a study that includes the deep learning edge computing and their role and the challenges of these technologies in the COVID-19 pandemic. Further, they have proposed a system with its issues and scope. In [35], the authors have proposed a study on the integration of technology and the challenges on the integration also have been discussed. Further, they have given a future direction to improve the efficiency of the technologies.

In [36], the researchers identify emerging technology in order to analyze COVID-19 handling. The proposed model could aid in the reduction of coronavirus dissemination. It will also improve healthcare team safety and minimize worker workload. The importance of these technologies in limiting the crisis is also discussed in this study. In [37], the scholars look at several technologies that might benefit in the struggle during COVID-19. The effect of certain technologies is discussed. AI stands for artificial intelligence. The most influenced innovations explored in this paper are machine learning and supply chain. In [38], during the COVID-19 pandemic, the researchers explored the use of drones for food delivery. They have two theories for gathering samples, one before and one after the introduction of this technology. The findings reflect a clear improvement in the regulation of virus transmission. In [31], during COVID-19, the researchers explored the use of wearable monitoring systems. They also explained the concepts of using this tracking and the problems that can arise as a result of using this technology, as well as its reliability. In [39], the scholars provided an analysis of several agricultural technologies such as AI, IoT, robots, and drones. Those would be the agricultural mechanization developments after COVID-19. In [40], the scholars suggested a robotic Internet to support in the struggle next to COVID-19 by capturing medical methods and saving the data on a cloud server where doctors may access it and bring medical instructions via the Internet. In [41], food system of time has contested. Although these herbaceous plants are favorable to the immune system, they are included together with numerous other meals that may be helpful in battling the virus. The report goes through this food chain in detail. In [42], the consideration of AI, which can be helpful in coping with the COVID-19 crisis, has been explored. They also addressed how AI can be educated so that it can spot infected people, which might save lives. In [43], the authors talk about smartphone apps that might aid in the fight against COVID-19. Data may be monitored in

```plaintext
ClusterHead :: chNde : Nde
sendsgn1 : set of Drones
actdrone : set of ADrone
chmode: ClusterHeadMode
chaction: ClusterHeadAction
inv mk_ClusterHead(chNde, -,-, chmode, chaction) == chNde.energy = <HIGH> and if chNde.sgnl.received = true then chmode = <WORKING> and chaction = <INFO_SENDTO_CR> else chmode = <IDLE>;
```

Code 8.

```plaintext
Topology :: clushead : set of ClusterHead
crm : set of Controlroom
clusterr : set of Cluster
edgs : Edgeesss
inv mk_Topology(clushead, crm, clusterr, edgs) ==
forall ch in set clushead & exists crr in set crm & exists cc in set edgs & mk_(ch.chNde.Ndeid, crr.cr) = cc and forall cc in set edgs & exists cl1,cl2 in set clusterr & mk_(cl1.clusterhead.chNde.Ndeid, cl2.clusterhead.chNde.Ndeid) = cc and forall cl1, cl2 in set clusterr & exists cc in set edgs & mk_(cl1.clusterhead.chNde.Ndeid, cl2.clusterhead.chNde.Ndeid) = cc;
```

Code 9.

```plaintext
state SopsMonitoring of
topo : [Topology]
sdrones : set of SDrone
adrone : set of ADrone
clusters : set of Cluster
ch : set of ClusterHead
crom : set of Controlroom
edg : Edgeesss
init sm == sm = mk_SopsMonitoring(nil, {}, {}, {}, {}, {},{})
end
```

Code 10.

```plaintext
operations
SOPsViolationDetection(cluster : Cluster) detected : bool
rd sdrones : set of SDrone
preexists sd in set sdrones & sd in set cluster.sensordrones post detected <== forall sd in set sdrones & sd.sdNde.activated = <WORKING> and
Sdinf < 6 and sd.violation = <MISSING_MASK> and sd.sdNde.action = <INFO_TO_ACTORDRONE>;
```

Code 11.
real time via apps or smartphone dashboards, and in China, there are apps for individuals that are in close contact with a confirmed or accused person. In [44], the authors provide the information about the role of drones in case of any disease crisis breaks like COVID-19. They also said that the drones are used for monitoring the spread of virus, for cargo, or any delivery system during pandemic. In [45], the authors have discussed that the role of drone technology can be very helpful in any crisis like the current COVID-19 pandemic. In the US, there are some programs that have shown drones feasible for these kinds of tasks. In [46], the authors have presented about the role of robotics in handling infectious disease. The robotics include cameras and sensors for monitoring in public areas as well as the temperature and medical conditions can be monitored which can be very helpful for combating virus. In [47], the authors have described the role of information technology application for the management of COVID-19 crisis. The information technologies are categorized into four topics in this paper, the diagnosis of disease and prediction about it and protection. The main motive is to describe the use of technologies to reduce the spread of virus.

In [48], the authors describe the conditions of lockdown due to COVID-19 like restrictions of our home activities and other changes about the society have been discussed and some future issues are also discussed. In [49], the authors have provided their opinions about the challenge’s opportunities and solutions about the post-COVID-19 and also about the agriculture food supply chain. They said in future the new agricultural herbs could be helpful in COVID-19 handling. In [50], the authors have discussed the deep learning applications to healthcare and the importance of deep learning in healthcare. They also discussed use cases of three different countries, and the challenges and issues of deep learning have been discussed. In [51], the authors provide the relation of effective pandemic handling with artificial intelligence. The diagnosis and therapy relationship has been discussed. The future deployment of AI in any pandemic is also discussed. In [52], the researchers have discussed the changes that occurred in our food system due to the COVID-19 pandemic. They also discussed the perspectives from CO+RE.

4. System Model

At present, the rapid spreading of coronavirus has become a global major problem. COVID-19 can be transmitted from one person to another person by human close interaction. When a COVID patient coughs, sneezes, or talks, virus can transmit by their respiratory droplets. In addition, people may become affected by contacting any infected substance and then touching their eyes, mouth, or nose. On a daily basis, millions of people are dying from this virus due to no cure. The vaccination process has started; until process is not done, it is important to minimize the interaction of people. The WHO includes social distancing, wearing mask, and sanitization.

In this paper, a model is presented which uses a cluster-based drone network to monitor the violations of SOPs. This model is designed by unified modeling language and graph theory. The drones will monitor people wearing a mask or maintaining social distancing in the targeted area and send violation information to the control room for performing actions as required.

4.1. Internet of Things. The Internet of Things (IoT) describes the idea of connecting any gadget to the Internet and other devices. It is a vast network of interconnected items and people; all of which store and communicate information about how they are utilized and the environment around them. Devices with embedded sensors are connected to an Internet of Things infrastructure, which gathers data.
from a variety of sources and utilizes algorithms to transfer the most significant information to apps tailored to specific needs. It is an emerging technology; in the future, everything will be connected with the Internet of Things. IoT has made so many tasks easier and saves human time and effort. In our model, we have used drones with embedded sensors and cameras to monitor violations of SOPs and send signals to the control room for performing actions as required.

4.1.1. UML Diagram. The UML is a structured modeling language made up of a collection of standard diagrams that let system and software engineers describe, visualize, plan, and analyze software system elements, as well as advanced analytics and other nonsoftware components. In the proposed model, the UML is used in terms of sequence diagrams. Sequence diagrams are relationship diagrams that show how processes are performed. They track the interaction among objects in the form of coordinated work. Sequence diagrams are time-oriented, and they physically represent the structure of the process by diagram to describe time what messages are received and when.

Figure 4 illustrates the process of monitoring SOP’s violation in the form of a sequence diagram. The sequence diagram included six objects: sensor drone, actor drone, produce alarm, cluster head, control room, and persons.

The process of monitoring SOP’s violation is described in the form of a sequence diagram. The sequence diagram shows the sequence of all the communication between objects. Firstly, the sensor drone senses violation and sends signal to the actor drone; a return message is sent to sensor drone.

```plaintext
ControlroomActions(transmitted : bool)
   ext rd topo : [Topology]
   rd crom : set of Controlroom
pre transmitted = true
post exists cr in set crom &
http://cr.info/.received = true => cr.craction = <WARNING_MESSAGE_TO_PERSONS>;
```

```plaintext
types
ID = token;
Energy = <HIGH>|<LOW>;
InfectCondition = <INFORMATION_SENT_to_SDRONE>|<INFORMATION_RECEIVED>|<NO_INFORMATION>;
PeopleCondition = <NATURAL>|<FATIGUE>|<COUGH>;
SdroneMode = <IDLE>|<WORK>);
Statuss = <ACTIVE>|<SLEEP>;
SdroneAction = <SIGNAL_TO_ACTORDRONE>;
ActorDroneMode = <IDLE>|<WORK>);
ActorDroneAction = <PRODUCE_ALARM>|<SANITIZATION>|<INFORMATION_TO_CLUSTERHEAD>;
ClusterHeadMode = <IDLE>|<WORK>);
ClusterHeadAction = <INFORMATION_SENDTO_CR>;
MedDroneMode = <IDLE>|<WORK>);
MedDroneAction = <DELIVER_KIT>;
Ctrlaction = <ORDER_TO_MEDDRONE>|<MESSAGE_TO_PEOPLE>;
```

```plaintext
Sgnl :: sgnl_recieved:bool;
Information :: Information_recieved:bool;
Database :: peopleid : ID
peopleInformation : token;
BodyBodyTemperature ::bodybodyBodyTemperature:real
natbodybodyBodyTemperature:real;
```

```plaintext
Nde::ndeid:ID
   energy:Energy
statuss:Statuss
sgnl:Sgnl
Information:Information;
EDGSSs = set of EDGSS
inv EDGss == forall mk_(ndeid1,ndeid2)in set EDGss &
mk_(ndeid2,ndeid1) in set EDGss;
EDGSS = ID*ID
inv eg == let mk_(ndeid1,ndeid2) =eg in ndeid1<>ndeid2;
```

After receiving signal from sensor drone, a return message is sent to actor drone. The actor drone will spray sanitizer and produce an alarm sound and then sends message to cluster head. Cluster head will send signal to control room
for performing actions such as the control room sending an alarm message to the person who have violated SOPs; a return message is sent to the control room.

Figure 5 illustrates sequence diagram that describes the process of maintenance of network of drones. This diagram includes three objects: control room, drones, and new drones, and the sequence of communication between these objects is illustrated using diagram.

In case of any failure, the control room will find a failed drone; a return message action performed is sent to the control room. Then, the nearest drone will be shifted to the place of failed drone; the shifting process will continue until there exists a place where a new drone will be placed. The control room sends signal to the new drone as placed new drone, and a return message is sent to the control room.

The shifting of drones will be collision-free as the drones have allotted their zones. Each drone has its zone, and when a new drone will be placed, the nearest drone will shift to the place of failed drone and new drone will be placed to the empty space.

In Figure 6, the sequence of communication of medical delivery service process is described in a sequence.

This diagram includes seven objects that are wearable sensors, sensor drones, actor drones, cluster head, control room, persons, and medicine drone. The sequence of communication between these objects is illustrated using this sequence diagram. Firstly, the wearable sensors will sense symptoms of COVID-19 and send a signal to sensor drone; the sensor drone will send a signal to the actor drone; the actor drone will spray sanitizer and produce an alarm sound to alert the person and then sends a signal to the cluster head. The cluster head will send a signal to the control room for further actions. The control room refers alert to people and gives an order to the medicine drone to provide medical services to the patients’ homes.

4.2. Graph Theory. Graph theory is a combination of nodes and connections, and the communication between them can be represented. In our model, the graph theory is used to represent the whole proposed system by nodes and connections and communication between them.
In Figure 7, the monitoring process of the cluster-based proposed system is described in the form of graphs. Graph theory consists of nodes and edges. Wearable sensor node is connected to sensor drone nodes, and sensor drone nodes are connected to actor drone. Actor drones are connected to cluster heads. Cluster head is connected to the other cluster heads, and every cluster head is connected to control room. These connections of nodes represent communication between nodes and edges during monitoring violations of SOPs.

In Figure 8, the network maintenance of the proposed system is described in graph theory which is composed of
nodes and edges. Sensor drone nodes are connected to every other sensor drone node and also connected to actor drone nodes. The actor drone is connected to cluster head to send a signal to the other cluster head, and every cluster head is connected to the control room. Cluster heads can communicate with each other. In case of any drone failure, the failed drones will be detected; then, the nearest drone will shift to the place of a failed drone, and then, the new drone will be placed in empty space. This shifting process is collision-free.

4.3. Formal Method. Formal methods are procedures for describing complex systems mathematically. By creating a mathematically robust model of a complex system, programmers can not only validate the system’s features more thoroughly but also use mathematical evidence as an addition to system testing to ensure accurate behavior. We utilized formal method for specification in the VDM-SL language. To ensure the system’s accuracy, the validation was carried out utilizing the resources offered in the VDM-SL toolbox.

In given specification, the types of the system are defined; first field is ID with type token. Second field is Droideid defined as a token type; third field is status which is defined as enumeration type which have 2 states active or sleep. Embedded sensors and Camera are defined as token type. Energy is defined as it can be either high or low. The next two fields Alarm and Violation are also defined as enumeration types; both have two states. Every drone (sensor, actor, and cluster head) mode is defined as either IDLE or WORKING. In values, social distancing meaning in feet is valued as Sdfnfeet.

In above specifications, some composite objects are defined such as Sgnl and Info is defined as bool type which means it will be true or false. Database consists of four fields; ID defined as token, Pid as ID type, person, and personDetails is defined as token. In the next line, Drones is a composite object which have five fields; first is Sensor drone defined as a set of SDrone and actor drones defined as a set of ADrone; next is embedded sensor defined as EmbeddedSensor type, camera is defined as Camera, and violation detection is defined as Violation Detection.

In the given specification, the invariant of node describes that every node has a connection with every other node but a node is not connected to itself which means no loop exists. In given specifications, Control room has five fields and the invariant of control room described that the control room has information of every person in the target area.

SDrone is defined as a composite object, and the invariant of SDrone describes that energy of sensor drone is high and mode of sensor drone will be working if and only if sensor drone will sense violation like missing mask or social
distancing less than 6 feet, and then, sensor drone will send
signal to actor drone or no violation found.

ADrone is identified as a composite object. The invariant
indicates that the mode of actor drone is idle at first, and it
goes in working mode if actor drone receives a signal from
sensor drone. If actor drone receives a signal from sensor
drone, actor drone will begin sanitization and send informa-
tion to the cluster head.

Clusterhead is specified as a composite object which
includes five fields, and the invariant describes that the
energy of cluster head is high, and mode of cluster head will
become working if and only if the cluster head receives sig-
nal from actor drone, and then, cluster head will send info
to control room for further operations, or the mode will
remain idle.

In the above specification, Cluster is defined as a com-
posite object which includes four fields which are cluster-
head, sensor drones, actor drones, and egd. The invariant
of cluster describes that every node has a connection, sensor
drone has a connection with other sensor drones, and sensor
drone has a connection with actor drone. Actor drones have
a connection with other actor drones, and every actor drone
has a connection with cluster head.

In the above specifications, the graph theory-based
topology of monitoring is described that includes clusters.

Every cluster has a cluster head, and each cluster head has
a connection with every other cluster heads, and every clus-
ter head has a connection with control room.

The state of the monitoring system is defined which
includes seven fields, and these will be used in the dynamic
part of specification.

In above specifications, the dynamic part of the system is
declared. The pre/postcondition describes that the violations
of SOPs are detected if and only if the mode of sensor drone
is working and social distancing is less than 6 feet and mask
is missing, and sensor drone sends info to actor drone.

A performing actions describes the actions of actor
drones. The pre/postcondition describes that actor drone
mode will be working and will produce alarm sound and
do sanitization and then sends violation information to the
cluster head.

In the above operation, information is now transmitting
to control room for further actions. The postcondition
describes that when cluster head receives information from
actor drone, it will send violation information to the control
room.

The above operation describes the actions of the control
room. The postcondition describes that when control room
will receive information from cluster head, then control
room sends warning message to the person.
Another module of the proposed system is identifying corona patients by using wearable sensors. Formal model of this module is given below.

In the above specifications, all the types are defined that will be used in the next specifications. First is ID defined as token; next all fields are defined as enumeration types that have different states, some have two and some have more than two. Every type of drone has two modes idle or working, and they have different actions. Sdrone has an action of signal to actor drone, and actor drone has actions which are produced alarm and sanitization and sends information to the cluster head. Cluster head action is sending info to the control room, and medicine drone action is to deliver medicine, and control room actions are issuing an order to medicine drone and send warning message to people.

In above specifications, some composite objects are defined Sgnl and Information is defined as Boolean type. The database is defined as a composite object with a peopleId and peopleInformation of token type. Some COVID-19 indicators, such as fatigue and coughing, as well as body temperature, are considered to diagnose the patient.

The invariant describes that any node is connected to every other node; for example, if ndid1 is connected to ndid2, therefore ndid2 is connected to ndid1 and one node is not connected to itself.

WESensor are listed as composite object and of node type. It has five fields: the first is people, which maps id to database, the second is bodyTemperature, which identifies temperature, and the third is rsystem, which identifies respiratory system. The fourth field is pcond and the last is information. The invariant demonstrates the conditions for identifying infected people using WESensor by comparing people body temperature and respiratory rates with natural temperatures and respiratory rates. If the body temperature is higher than natural, the respiratory rate is higher or lower than natural, and the person condition is fatigued or coughing, then sensor’s status will change to active; otherwise, the sensor’s status will remain sleep.

Sdrone have four fields, and the invariant shows that the energy of sensor drone is high and mode is working if the sensor drone has received information; then, action will be sending signal to the actor drone.

The invariant of actor drone shows that mode of actor drone is working if actor drone receives a signal from sensor drone; then, action of actor drone will be to produce alarm and do sanitization and sends Information to cluster head.

The invariant shows that the energy of cluster head is high, and if cluster head received information from actor
drone, then cluster head mode will be working and action will be information sends to control room else mode will remain idle.

The CtrlR is defined as a composite entity with four fields that involve database control room function as control management wearable sensors as a collection of WE Sensor and sgnl. The invariant demonstrates that any user is in a certain domain of the database and has personal information of people.

Medicine drones include two modes: idle and working, and actions include delivering medicines, and not delivering kits. MedDrone is described as a composite object that is used as a Nde type and has the following fields: drone mode and behavior as stated above. The invariants indicate that the mode is idle at first, and it will only work if and only if the medicine drone receives a signal from the control room, at which point the ctrlaction will deliver medication or not.

Cluster is defined as a composite object which has six fields, and the invariant of cluster defines that every node

drone, then cluster head mode will be working and action will be information sends to control room else mode will remain idle.

The CtrlR is defined as a composite entity with four fields that involve database control room function as control management wearable sensors as a collection of WE Sensor and sgnl. The invariant demonstrates that any user is in a certain domain of the database and has personal information of people.

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Cluster is defined as a composite object which has six fields, and the invariant of cluster defines that every node

\[
\text{Clusters} = \langle A \rangle |\langle B \rangle; \\
\text{Drones} : \text{dnde} \text{Nde} \\
\quad \text{zones} : \text{Zones} \\
\quad \text{battery} : \text{BatteryStatus} \\
\text{inv mk_Drones(dnde,)} \\ 
\quad \langle \text{dnde}.\text{voltage} = \langle \text{LOW} \rangle \text{ and} \\
\quad \text{dnde}.\text{status} = \langle \text{FAILED_Drone_Detected} \rangle \\ 
\quad \text{dnde}.\text{link} = \langle \text{LINKED} \rangle \text{ and dnde.condition} = \langle \text{FAULTED} \rangle \text{ or dnde.status} = \langle \text{NOT_DETECTED} \rangle \\ 
\text{Controlroom} : \text{cr} : \text{Nde} \\
\quad \text{charging} : \text{Charging} \\
\quad \text{shift} : \text{Shift} \\
\quad \text{shifted} : \text{Empty_Space_Drone};
\]

\text{Code 33.}

Cluster : \text{clusterhead} : \text{ClusterHead} \\
\quad \text{drones} : \text{set of Drones} \\
\quad \text{edg} : \text{Edgeesss} \\
\text{inv mk_Cluster(clusterhead, drones, edg)} = \\
\quad \text{forall d1, d2 in set drones &} \\
\quad \text{exists c in set edg &} \\
\quad \text{mk_} (\text{d1.dnde.ndeid, d2.dnde.ndeid}) = c \\
\quad \text{forall d1 in set drones &} \\
\quad \text{exists c in set edg &} \\
\quad \text{mk_} (\text{d1.dnde.ndeid, clusterhead.chnde.ndeid}) = c;

\text{Code 34.}

\text{ClusterHead} : \text{chnde} : \text{Nde} \\
\text{inv mk_ClusterHead(chnde)} = \\
\quad \text{chnde}.\text{voltage} = \langle \text{LOW} \rangle \text{ and} \\
\quad \text{chnde}.\text{status} = \langle \text{FAILED_Drone_Detected} \rangle \\
\quad \text{chnde}.\text{link} = \langle \text{LINKED} \rangle \text{ and chnde.condition} = \langle \text{FAULTED} \rangle \text{ or chnde.status} = \langle \text{NOT_DETECTED} \rangle \\
\text{Controlroom} : \text{cr} : \text{Nde} \\
\quad \text{charging} : \text{Charging} \\
\quad \text{shift} : \text{Shift} \\
\quad \text{shifted} : \text{Empty_Space_Drone};

\text{Code 35.}

\text{Topology : clushead} = \text{set of ClusterHead} \\
\quad \text{crm} : \text{set of Controlroom} \\
\quad \text{clusterr} : \text{set of Cluster} \\
\quad \text{edgs} : \text{Edgeesss} \\
\text{inv mk_Topology(clushead, crm, clusterr, edgs)} = \\
\quad \text{forall ch in set clushead &} \\
\quad \text{exists crr in set crm &} \\
\quad \text{exists cc in set edgs &} \\
\quad \text{mk_} (\text{ch.chnde.ndeid, crr.cr.ndeid}) = cc \\
\quad \text{forall cc in set edgs &} \\
\quad \text{exists cl1, cl2 in set clusterr &} \\
\quad \text{mk_} (\text{cl1.clusterhead.chnde.ndeid, cl2.clusterhead.chnde.ndeid}) = cc \\
\quad \text{forall cl1, cl2 in set clusterr &} \\
\quad \text{exists cc in set edgs &} \\
\quad \text{mk_} (\text{cl1.clusterhead.chnde.ndeid, cl2.clusterhead.chnde.ndeid}) = cc;

\text{Code 36.}

\text{state Maintenance of} \\
\text{topo : [Topology]} \\
\quad \text{drones} : \text{set of Drones} \\
\quad \text{clusters} : \text{set of Cluster} \\
\quad \text{ch} : \text{set of ClusterHead} \\
\quad \text{crom} : \text{set of Controlroom} \\
\quad \text{edg} : \text{Edgeesss} \\
\text{init MN == MN = mk_Maintenance(nil, {}, {}, {}, {}, {}} \\
\text{end}

\text{Code 37.}
has a connection; firstly, wearable sensor has a connection with sensor drone and sensor drone has a connection with actor drone and actor drones have connection with other actor drones and with cluster head.

In above specifications, graph theory-based topology is defined which describe the connection of cluster with control room. Every cluster has a cluster head; therefore, one cluster head has a connection with other cluster head and also a connection with control room. The control room has a connection with medicine drone.

The attributes are initialized in the init function, and the system is defined as medical services in state.

IdentifyInfected is an operation that takes wearable sensors as input and returns output in Identified such as True or false is determined. Pre/postcondition: the operation’s pre-condition is true. The postcondition indicates that the patient will be detected if and only if the wearable sensor status is activated and wearable sensors will send signal to sensor drone, and then, mode of sensor drone becomes active and action of sensor drone is send information to actor drone.

In the above operations, actions of actor drone is described which takes input identified and output action; in postcondition, it shows that action is true if actor drone receives a signal from actor drone and mode of actor drone will become working; then, action of actor drone will produce alarm and sanitization and send info to cluster head.

IdentificationReoted is an operation that takes a bool type input. Cr is described as a group of control rooms in the external clause. Pre/postcondition: the precondition specifies that the defined operation must be valid. The postcondition indicates that the identification is reported if and only if cr is in the control room collection and the control room has received the signal.

Pre/postcondition: the precondition is stated as true and in postcondition if the control room receives the info, and then, control room will give an order to the MedDrone for the medical services and sends warning message to the person; otherwise, the mode of MedDrone will remain idle.

Another module of the proposed model is maintenance of drones’ network such as in case of a drone failure new placement drone will be collision-free. Drones will be charged from time to time, and the neediest drone will charge first.

In the above specification, different types of system maintenance are specified and their types are defined.

The invariant shows that each node is unique such as id of one node is not equal to id of other node that means any node is not connected to itself.
Every cluster head is connected to other cluster head, and every cluster head is connected to control room. The connection is showed in form of nodes and edges. 

The State has defined all fields and their types which will be used in the dynamic model of the maintenance. 

Operations are defined in the given specification; first operation is AlotingDroneZone(). Every drone has allotted its zone for designing a collision-free network. 

In postcondition of this operation, it is indicated that a drone is detected by stating that the drone is not linked and the condition of a drone is faulted; otherwise, failure not detected. 

In ShiftingDrone, the postcondition describes that in case of any drone failure, the nearest drone is shifted to the place of failed drone and a new drone is placed at the empty place of that shifted drone. In ChargingDrones postcondition describes that drones are charging from time to time, but the neediest drone which has the lowest battery will charge first. 

5. Result Analysis 

We believe construction of formal models of real-world systems is not sufficient to get full benefits of formal methods. Formal modeling in VDM-SL means that the semantics are very precisely described and can be analyzed using computer tools conforming requirements of the system. The process of analyzing a formal system in this way is termed as validation to insure correctness of a system. Validation and verification are two major principals that play an important role in development of correct systems. Validation addresses whether the produced system really fulfills the system’s requirements. On the other hand, verification attempts to establish whether a particular phase of the software process meets the requirements. In fact, validation of abstract models is a prerequisite for entering of real world of verification. 

In this paper, various facilities available in the VDM-SL toolbox are used for model analysis of the system. Proof obligation and simulation are two main techniques used for the formal analysis. A proof obligation is a logical expression which must hold for internal consistency checking that insures a correct use of language syntax and semantics in the formal specification. The data types and definitions are evaluated to make it sure that it does not violate the invariant or constraints over the data types. The functions are evaluated on the inputs to verify that its output is correct under the assumptions provided in the model. Pre- and postconditions used in the function definitions are checked as part of the proof obligation. 

The VDM-SL toolbox supports the VDM-SL which provides facilities to analyze a precise range of models and ensure its correctness at the initial stages. The tool includes syntax checker, grammar checker, interpreter, and C++ code generator which provide features to validate and verify the model. Syntax checker checks that the given specification is correct and it is according to the definition of the VDM-SL language. If syntax checkers accept the given specification, then it will allow other features. Type checker checks the types are correct and contains no run type or logical error according to the model’s requirements. The integrity checker provides ability of static checking and checks inconsistency of the model which includes integrity violations, type violations, pre- and postconditions. The C++ code generator helps to achieve consistency of the model. The pretty printer is used for the compatible mode of documentation in any software development and converts specifications into a pretty printer version. The pretty printer syntax check shows that no error exists in syntax that violates the syntax of the VDM-SL. Each module of the proposed model has been analyzed, validated, and verified using available facilities in the VDM-SL toolbox. 

Figure 9 illustrates that code is error-free; syntax checker verified that code is conferring to the syntax of VDM language. Type checker checked all runtime and logical errors. C++ helps to achieve consistency of the model. 

Pretty printer is used for the compatible mode of documentation in any software development and converts specifications into pretty printer version that is used for documentation purpose. 

The integrity property window checks inconsistency of the model and shows integrity violation of the code to achieve a consistent model. The integrity property increases static verification and generates a list of probable integrity attributes.
It assures internal inconsistencies and integrity violations in the model definition, such as data type violations, invariants, precondition, postcondition, and map domains. It analyzes the genuine expression; if it analyzes the false expression, there might be an issue.

The analysis of monitoring module shows that the static and dynamic model of this specification is free of any syntax and type violation of the language. Therefore, the correctness is ensured for this module. All the specifications are validated and verified by VDM-SL toolbox checker facilities.

Figure 10 shows that the code of maintenance module is error-free. "S" demonstrates syntax checker; it checks the code that is it according to the definition of VDM-SL or not. "T" represents type checker; it checks logical and runtime errors of the code. C++ helps to find inconsistency of the code.

"P" represents pretty printer that is used to make a compatible mode and can be used for documentation purpose.

The integrity property of maintenance module checks inconsistency of the static model and checks pre- and post-conditions. There exist no inconsistencies in the given specifications.

The given snapshot of this module shows that the model is validated and verified; therefore, the correctness is ensured.

Figure 11 illustrates that the specifications of medical services module are error-free; the syntax check is checked that shows the code is conferring to the syntax of VDM-SL, and type check verifies the runtime and logical errors. C++ is error-free, and pretty printer is used for documentation purpose in the code. This ensures the correctness of the model, and the integrity properties of medical services check the
inconsistencies of the model. These property analyses help to make an error-free specification of this module.

6. Conclusion

The rapid spread of coronavirus has become the biggest problem for the whole world due to its viral nature. There is no proper cure that exists for COVID-19; therefore, it is essential to control the spread of this virus. The World Health Organization (WHO) has set up some standard operating procedures (SOPs) which contain social distancing, wearing a mask, and using sanitizer to control the spread of coronavirus. People are not strictly following these SOPs; therefore, this should be monitored that people are following SOPs or not. If people’s interactions are reduced, the spread of COVID-19 can be managed. Many techniques are contributing to minimizing the spread of virus.

We had presented an IoT-based framework in this paper, which includes a network of cluster-based drones for the monitoring of SOP violations and performs an action such as producing alarm sound and sanitization and sends information to control room for further actions. The network is well maintained; in case of any failure of drones, the placement of new drones is collision-free as every drone has allotted its zone. Furthermore, wearable sensors are used to capture the movement of persons; when drones are monitoring, these wearable sensors are used to monitor people’s temperature and respiratory rates. If any person has high temperature or an unbalanced respiratory rate, the sensors send information to the network of drones for communication and to perform actions such as sanitization and producing alarm sound. The control room then gives a command to medicine drone to provide medical supplies to a person’s home who has been identified infected. Unified modeling language (UML) in terms of sequence diagram has been used to make the proposed model easily understandable by showing the flow of process in a sequence. Graph theory is used to represent the whole system and its connectivity using some suitable topology. The model is specified in Vienna Development Method-Specification language (VDM-SL) and ensured correctness by using the services available in the VDM-SL toolbox.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors would like to acknowledge Taif University Researchers Supporting Project number (TURSP-2020/292) Taif University, Taif, Saudi Arabia. The authors would like also to acknowledge Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2022R193), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

References

[1] A. Kumar, K. Sharma, H. Singh, S. G. Naugriya, S. S. Gill, and R. Buyya, “A drone-based networked system and methods for combating coronavirus disease (COVID-19) pandemic,” Future Generation Computer Systems, vol. 115, pp. 1–19, 2021.
[2] J. Euchi, “Do drones have a realistic place in a pandemic fight for delivering medical supplies in healthcare systems problems?,” Chinese Journal of Aeronautics, vol. 34, no. 2, pp. 182–190, 2021.
[3] R. S. Bashir, S. P. Lee, S. U. R. Khan, V. Chang, and S. Farid, “UML models consistency management: guidelines for software quality manager,” International Journal of Information Management, vol. 36, no. 6, pp. 883–899, 2016.
[4] D. Stahlke, “Quantum zero-error source-channel coding and non-commutative graph theory,” IEEE Transactions on Information Theory, vol. 62, no. 1, pp. 554–577, 2016.
[5] H. Afzaal, M. Imran, and N. A. Zafar, “Implementing partitioning detection and connectivity restoration in WSAN using VDM-SL,” in 2015 13th International Conference on Frontiers of Information Technology (FIT), pp. 71–76, Islamabad, Pakistan, December 2015.
[6] S. Poikonen and B. Golden, “Multi-visit drone routing problem,” Computers & Operations Research, vol. 113, article 104802, 2020.
[7] E. Yanmaz, S. Yahyanejad, B. Rinner, H. Hellwagner, and C. Bettstetter, “Drone networks: communications, coordination, and sensing,” Ad Hoc Networks, vol. 68, pp. 1–15, 2018.
[8] J. Zhang and X. Jiahaoh, “Cooperative task assignment of multi-UAV system,” Chinese Journal of Aeronautics, vol. 33, no. 11, pp. 2825–2827, 2020.
[9] A. Kumar, P. K. Gupta, and A. Srivastava, “A review of modern technologies for tackling COVID-19 pandemic,” Diabetes & Metabolic Syndrome: Clinical Research & Reviews, vol. 14, no. 4, pp. 569–573, 2020.
[10] S. O. Al-Jazzar and Y. Jaradat, “AOA-based drone localization using wireless sensor-doublets,” Physical Communication, vol. 42, article 101160, 2020.
[11] J. A. Donaire, N. Gali, and B. Gulisova, “Tracking visitors in crowded spaces using zenith images: drones and time-lapse,” Tourism Management Perspectives, vol. 35, article 100680, 2020.
[12] M. Angurala, M. Bala, S. S. Bamber, R. Kaur, and P. Singh, “An Internet of things assisted drone based approach to reduce rapid spread of COVID-19,” Journal of Safety Science and Resilience, vol. 1, no. 1, pp. 31–35, 2020.
[13] H. Sibiri, S. M. Zankawah, and D. Prah, “Reponse aux maladies a coronavirus 2019 (COVID-19) : faits marquants de l’innovation et des percees scientifiques et technologique au Ghana,” Ethics, Medicine and Public Health, vol. 14, article 100537, 2020.
[14] A. Y. Husodo, G. Jati, A. Octavian, and W. Jatmiko, “Switching target communication strategy for optimizing multiple pursuer drones performance in immobilizing Kamikaze multiple evader drones,” ICT Express, vol. 6, no. 2, pp. 76–82, 2020.
[15] A. I. Henatti and L. C. Fourati, “Comprehensive survey of UAVs communication networks,” Computer Standards & Interfaces, vol. 72, article 103451, 2020.
[16] A. Sharma, P. Vanjani, N. Paliwal et al., “Communication and networking technologies for UAVs a survey,” Journal of Network and Computer Applications, vol. 168, article 102739, 2020.
[17] R. Merkert and J. Bushell, "Managing the drone revolution: a systematic literature review into the current use of airborne drones and future strategic directions for their effective control," *Journal of Air Transport Management*, vol. 89, article 101929, 2020.

[18] B. Shahzad, A. Bouguettaya, S. Mistry, and A. G. Neiat, "Resilient composition of drone services for delivery," *Future Generation Computer Systems*, vol. 115, pp. 335–350, 2021.

[19] V. Hassija, V. Saxena, and V. Chamola, "Scheduling drone charging for multi-drone network based on consensus time-stamp and game theory," *Computer Communications*, vol. 149, pp. 51–61, 2020.

[20] N. Zhang, H. Liu, B. F. Ng, and K. H. Low, "Collision probability between intruding drone and commercial aircraft in airport restricted area based on collision-course trajectory planning," *Transportation research part C: emerging technologies*, vol. 120, article 102736, 2020.

[21] S. Tuli, S. Tuli, R. Tuli, and S. S. Gill, "Predicting the growth and trend of COVID-19 pandemic using machine learning and cloud computing," *Internet of Things*, vol. 11, article 100222, 2020.

[22] M. Nasajpour, S. Pouriyeh, R. M. Parizi, M. Dorodchi, M. Valero, and H. R. Arabnia, "Internet of things for current COVID-19 and future pandemics: an exploratory study," *Journal of healthcare informatics research*, vol. 4, no. 4, pp. 325–364, 2020.

[23] A. Jayaprakash, P. J. Srividhya Muralidharan, and G. Devendra, "Potent action of disinfectant in targeting spread of COVID-19 using drones," 2020.

[24] W. Power, M. Pavlovski, D. Saranovic, I. Stojkovic, and Z. Obradovic, "Autonomous navigation for drone swarms in gps-denied environments using structured learning," in *IFIP International Conference on Artificial Intelligence Applications and Innovations*, Springer, Cham, 2020.

[25] M. Mohammed, N. A. Hazairin, S. Al-Zuhaidei, S. AK, S. Mustapha, and E. Yusuf, "Toward a novel design for coronavirus detection and diagnosis system using iot based drone technology," *International Journal of Psychosocial Rehabilitation*, vol. 24, no. 7, pp. 2287–2295, 2020.

[26] P. Vaishnavi, J. Agnishwar, K. Padmanathan et al., "Artificial intelligence and drones to combat COVID-19," 2020.

[27] A. Bahabry, X. Wan, H. Ghazzai, G. Vesonder, and Y. Massoud, "Collision-free navigation and efficient scheduling for fleet of multi-rotor drones in smart city," in *2019 IEEE 62nd International Midwest Symposium on Circuits and Systems (MWSCAS)*, Dallas, TX, USA, August 2019.

[28] V. Chamola, V. Hassija, V. Gupta, and M. Guizani, "A comprehensive review of the COVID-19 pandemic and the role of IoT, drones, AI, blockchain, and 5G in managing its impact," *IEEE access*, vol. 8, pp. 90225–90265, 2020.

[29] R. Jaiswal, A. Agarwal, and R. Negi, "Smart solution for reducing the COVID-19 risk using smart city technology," *IET Smart Cities*, vol. 2, no. 2, pp. 82–88, 2020.

[30] E. P. Manalu, A. Muditomo, D. Adriana, and Y. Trisnawati, "Role of information technology for successful responses to Covid-19 pandemic," in *2020 International Conference on Information Management and Technology (ICIMTech)*, pp. 415–420, Bandung, Indonesia, August 2020.

[31] V. Shubina, A. Ometov, and E. S. Lohan, "Technical perspectives of contact-tracing applications on wearables for Covid-19 control," in *2020 12th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pp. 229–235, Brno, Czech Republic, October 2020.

[32] V. Kramar, "UAS (drone) in response to coronavirus," in *2020 27th Conference of Open Innovations Association (FRUCT)*, pp. 90–100, Trento, Italy, September 2020.

[33] M. Tiskala Vafea, E. Atalla, J. Georgakas et al., "Emerging technologies for use in the study, diagnosis, and treatment of patients with COVID-19," *Cellular and Molecular Bioengineering*, vol. 13, no. 4, pp. 249–257, 2020.

[34] A. Sufian, A. Ghosh, A. S. Sadiq, and F. Smarandache, "A survey on deep transfer learning to edge computing for mitigating the COVID-19 pandemic," *Journal of Systems Architecture*, vol. 108, article 101830, 2020.

[35] E. Mbunge, "Integrating emerging technologies into COVID-19 contact tracing: opportunities, challenges and pitfalls," *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, vol. 14, no. 6, pp. 1631–1636, 2020.

[36] M. Abdel-Basset, V. Chang, and N. A. Nabeeth, "An intelligent framework using disruptive technologies for COVID-19 analysis," *Technological Forecasting and Social Change*, vol. 163, article 120431, 2021.

[37] R. M. Elavarasan and R. Pugazhendhi, "Restructured society and environment: a review on potential technological strategies to control the COVID-19 pandemic," *Science of the Total Environment*, vol. 725, article 138858, 2020.

[38] J. J. Kim, I. Kim, and J. Hwang, "A change of perceived innovativeness for contactless food delivery services using drones after the outbreak of COVID-19," *International Journal of Hospitality Management*, vol. 93, article 102758, 2021.

[39] A. Krishnan and S. Swarna, "Robotics, IoT, and AI in the automation of agricultural industry: a review," in *2020 IEEE Bangalore Humanitarian Technology Conference (B-HTC)*, pp. 1–6, Vijayapur, India, October 2020.

[40] E. Leila, S. B. Othman, and H. Sakhi, "An Internet of Robotic Things System for combating coronavirus disease pandemic (COVID-19)," in *2020 20th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*, pp. 333–337, Monastir, Tunisia, December 2020.

[41] C. M. Galanakis, "The food systems in the era of the coronavirus (COVID-19) pandemic crisis," *Food*, vol. 9, no. 4, p. 523, 2020.

[42] W. Naudé, "Artificial intelligence vs COVID-19: limitations, constraints and pitfalls," *AI & SOCIETY*, vol. 35, no. 3, pp. 761–765, 2020.

[43] M. N. K. Boulo and E. M. Geraghty, "Geographical tracking and mapping of coronavirus disease COVID-19/severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) epidemic and associated events around the world," *International journal of health geographics*, vol. 19, no. 1, pp. 1–12, 2020.

[44] M. R. Estrada and M. Arturo, "The uses of drones in case of massive epidemics contagious diseases relief humanitarian aid: Wuhan-COVID-19 crisis," 2020.

[45] B. Skorup and C. Haaland, *How Drones Can Help Fight the Coronavirus*, Special Edition Policy Brief, Mercatus Center Research Paper Series, 2020.

[46] G. Z. Yang, B. Nelson, R. R. Murphy et al., "Combating COVID-19—the role of robotics in managing public health and infectious diseases," *Science Robotics*, vol. 5, no. 40, article eabb5589, 2020.
[47] A. Asadzadeh, S. Pakkhoo, M. M. Saeidabad, H. Khezri, and R. Ferdousi, "Information technology in emergency management of COVID-19 outbreak," *Informatics in Medicine Unlocked*, vol. 21, article 100475, 2020.

[48] J. Zhang, Y. Hayashi, and L. D. Frank, "COVID-19 and transport: findings from a world-wide expert survey," *Transport Policy*, vol. 103, pp. 68–85, 2021.

[49] N. J. Rowan and C. M. Galanakis, "Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: quo vadis?," *Science of the Total Environment*, vol. 748, article 141362, 2020.

[50] S. Bhattacharya, P. K. Reddy Maddikunta, Q. V. Pham et al., "Deep learning and medical image processing for coronavirus (COVID-19) pandemic: a survey," *Sustainable Cities and Society*, vol. 65, article 102589, 2021.

[51] A. C. Chang, "Artificial intelligence and COVID-19: present state and future vision," *Intelligence-Based Medicine*, vol. 3, article 100012, 2020.

[52] S. Bakalis, V. P. Valdramidis, D. Argyropoulos et al., "Current Research in Food Science".