

Examining an Intelligent IoT-Based COVID-19 Contact Tracing System in Nigeria: A Comprehensive Survey and Analysis

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Abstract— The COVID-19 outbreak has highlighted the need for efficient contact tracing methods. This survey reviews scientific research on an intelligent Internet of Things (IIoT)-based contact tracing system in Nigeria. A comprehensive literature review was conducted to evaluate IoT-based systems, focusing on their feasibility, effectiveness, and potential applications. The findings show that IoT technologies, such as sensor networks, data analytics, and connectivity, can enhance tracing accuracy and efficiency. Various system architectures, including centralized and decentralized models, Bluetooth proximity detection, and data collection algorithms, were explored. Performance metrics like accuracy, scalability, and privacy were assessed, alongside auxiliary technologies like mobile apps and cloud computing. While the potential for real-time tracking and quick notifications is promising, challenges such as data security, infrastructure limits, and user acceptance were identified. The study emphasizes privacy-preserving mechanisms, secure data transmission, and adaptation to local infrastructure and cultural contexts. Community engagement and effective communication are critical for system acceptance. Overall, an intelligent IoT-based system can improve COVID-19 management, enhance public health responses, and inform policymaking in Nigeria if challenges are addressed.

Keywords: COVID-19, Internet of Things (IoT), contact tracing, system design, performance evaluation, privacy concerns, data security, Artificial Intelligence

I. INTRODUCTION

A) Background

The emergence of the coronavirus disease has caused considerable changes in lifestyle in communities all across the world (COVID-19). The first instance of the pandemic, which was discovered in Wuhan, China, in December 2019, was caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus. The World Health Organization has received reports of COVID-19 infections and fatalities in more than 180 different countries (WHO). Due of COVID-19's alarmingly rapid global spread, the WHO declared it to be a pandemic.

These force the governments of these nations to take prompt control measures, including isolating severely affected areas, stopping cross-border transportation, and limiting public activities by advising people to stay at home as much as possible. These implemented measures have had a severe negative impact on both social life and the economy.[1].

The societies face a number of challenges in the sectors of manufacturing, supply chain management, travel, tourism, and service provision under the existing circumstances and in a post-COVID-19 future. Overcrowding in hospitals and other healthcare facilities brought on by the rapid increase of COVID-19 patients and the inability to treat normal patients due to limited mobility are two examples of important barriers to the battle against COVID-19 in the healthcare industry. The lack of efficient and automated contact tracing tools further hinders efforts to restrict the spread, as do delays and an increase in resource demand for manual contact tracing.[2]. In order to regulate the current COVID-19 scenario, many parties must act within their power. These parties include students, healthcare professionals, researchers, government officials, technology managers, engineers, and the general public.[1]. For the management and protection of the post-COVID-19 environment, digitalization and the use of information and communication technologies will be essential. A few of the technologies that are assisting the environment in adapting to new protection and economic and social advancements include big data, 5G communication, the Internet of Things (IoT), cloud computing, artificial intelligence (AI), and blockchain. The technicians and engineers will need to overcome substantial challenges and carry out in-depth studies of risk management, resources, cost, scope, and quality in order to implement these potential solutions and benefit from them.[3].

Despite the implementation of all measures put in place to contain the outbreak, coronavirus infections continue to rise globally. The twelve nations throughout the world that are the most severely impacted are listed in Table 1-1 of a WHO report.

Interestingly, the United States of America has held the top spot since the outbreak began at the beginning of this year, and these twelve nations account for a sizable share of all confirmed cases worldwide. Millions of people were being affected by the lockdown that was being extended in numerous nations in an effort to stop the spread of the disease. Initially, experts questioned the viability of this endeavour and issued a warning that some nations ran the possibility of experiencing another SARS-like epidemic. The pandemic looks to be under control in most nations at this point, but there is still opposition to the use of what some have dubbed "draconian" measures to stop its spread.[4]

The COVID-19 pandemic has posed previously unheard-of difficulties for international healthcare systems and highlighted the need of successful contact tracing in slowing the virus' transmission. This scientific and technical study explores the use and possibilities of an intelligent COVID-19 contact tracing system based on the Internet of Things (IoT) in Nigeria. The title of our research, "An Intelligent IoT-Based COVID-19 Contact Tracing System in Nigeria," encapsulates the key terms that define the scope and objective of this study. Contact tracing plays a pivotal role in identifying and managing COVID-19 transmission chains, enabling early intervention, and preventing further infections. Conventional contact tracing methods heavily rely on manual processes, which are time-consuming, resource-intensive, and susceptible to human errors. However, the emergence of IoT technologies offers a promising avenue for developing intelligent contact tracing systems that can overcome these limitations.

Our chosen topic aligns with the burgeoning field of IoT-based contact tracing systems, which harness interconnected devices and data analytics to automate and enhance the contact tracing process. By leveraging IoT technologies such as wearable devices, smartphones, and sensors, coupled with intelligent algorithms and data management systems, a robust and efficient framework for contact tracing can be established [5].

This study's objective is to offer an exhaustive understanding of the feasibility and potential benefits of implementing an IoT-based intelligent contact tracing system specifically tailored for Nigeria by analyzing existing scientific research papers and relevant literature delving into critical aspects such as system design, architecture, algorithms, data collection techniques, and measures for evaluating performance the effectiveness of such a system in the local context.

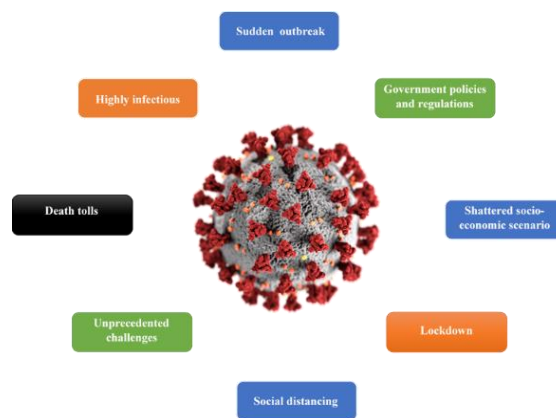


Figure 1 Different characteristics of covid-19 incidents

Our study's geographic focus, Nigeria, offers a distinctive environment for the application of a contact tracing system. The COVID-19 pandemic has had a tremendous impact on the area, as seen by the high number of cases that have been reported. Moreover, Nigeria faces specific challenges related to healthcare infrastructure, population density, cultural norms, and socioeconomic factors. Understanding these contextual factors is essential for designing an intelligent IoT-based contact tracing system that aligns with the region's specific needs and limitations.

The necessity of this research stems from the urgent requirement to combat the Nigeria's COVID-19 outbreak and the potential advantages that an intelligent IoT-based contact tracing system can offer. By leveraging IoT technologies, including sensor networks, data analytics, and connectivity, we can enhance the accuracy, efficiency, and timeliness of contact tracing efforts.[5] This, in turn, can contribute to early detection, swift intervention, and effective control of the virus's transmission within the region.

Furthermore, the successful implementation of an intelligent IoT-based contact tracing system in Nigeria can have broader implications. It can bolster the region's public health response, inform evidence-based policy-making decisions, and contribute to the global efforts in containing the pandemic [6].

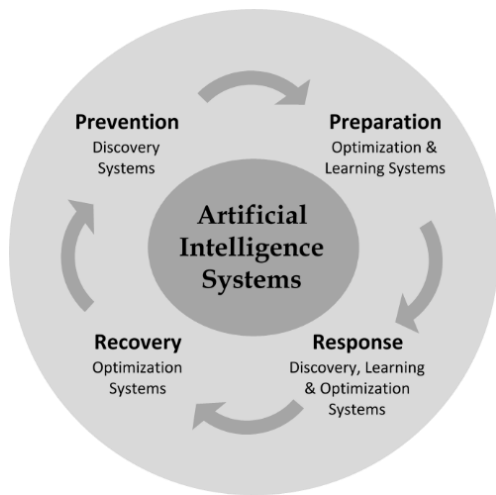


Figure 2 Artificial Intelligence systems for various phasis of pandemics

1) Domestic and Foreign Related Work

a) Domestic Related Work

Within the domestic landscape, several research and development initiatives have been undertaken to explore the potential of IoT-based contact tracing systems. Local institutions, universities, and healthcare organizations have contributed to the field by conducting studies, implementing pilot projects, and proposing novel approaches.

A comprehensive review of domestic literature reveals that significant There has been improvement in the design and implementation based on IoT contact tracing systems. Researchers have explored various architectural models, such as centralized and decentralized systems, each with its own strengths and limitations. These models involve the integration of different IoT devices, such as smartphones, wearables, and environmental sensors, to collect relevant data and enable effective contact tracing.

Moreover, studies have focused on developing intelligent algorithms that can accurately detect and analyze proximity interactions between individuals. Machine learning techniques, such as clustering algorithms and models for deep learning, having applied to identify potential COVID-19 exposure based on contact patterns and epidemiological factors. These efforts have shown promising results in improving the accuracy and efficiency of contact tracing processes.[7]

Despite the progress made, the current domestic work in IoT-based contact tracing systems still faces certain limitations [3]. One key challenge is the system's ability to scale handle a large volume of information produced by IoT devices [6], [8]. As the number of connected devices increases, ensuring efficient data processing and analysis becomes crucial. Additionally, issues related to data privacy and security remain a concern, as sensitive personal information is collected and stored within these systems.

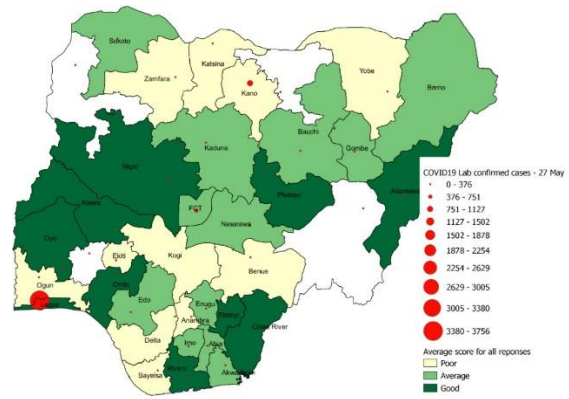


Figure 3 Covid 19 cases as at May 2021 [9]

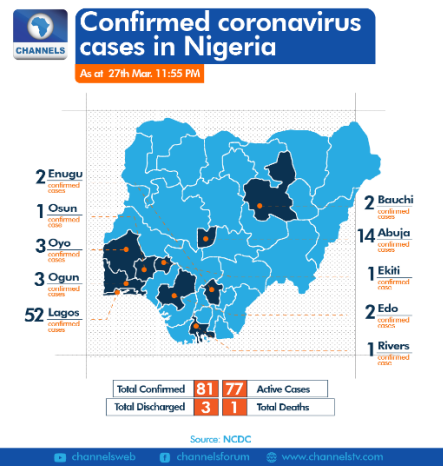


Figure 4 Confirmed Covid-19 cases In Nigeria, March 2023 (https://www.channelstv.com/)

b) Foreign Related Work

International efforts have demonstrated the potential of IoT technologies in enhancing contact tracing capabilities. Countries have explored innovative solutions, such as leveraging Bluetooth technology for proximity detection, integrating GPS data for location tracking, and utilizing data analytics for risk assessment and prediction. These approaches have been implemented in various settings, including urban areas, healthcare facilities, and transportation networks, to keep an eye on and control COVID-19's spread.

Furthermore, foreign research has shed light on the importance of interoperability and standardization in IoT-based contact tracing systems. Collaborative efforts between different stakeholders, including governments, healthcare institutions, and technology providers, have resulted in the development of interoperable frameworks that enable seamless data sharing and integration [7]. These initiatives have paved the way for cross-border contact tracing collaborations and the exchange of valuable insights and best practices.

However, foreign-related work also faces certain limitations and challenges. Similar to domestic efforts, scalability and data privacy remain critical concerns. The

ability to handle large-scale deployments and ensure robust data protection measures is essential for the successful putting in place contact tracing mechanisms based on the IoT. Additionally, issues related to user acceptance, trust, and compliance with privacy regulations require careful consideration to ensure widespread adoption and effectiveness. However, challenges related to scalability, data privacy, and user acceptance persist, underscoring the need for further research and innovation in this field.

B) Motivation

This study's inspiration comes from the pressing need for effective solutions for contact tracing in the COVID-19 pandemic environment. In order to locate and isolate people who may have been exposed to the virus, contact tracing is essential, thereby curbing its spread and protecting public health. Traditional contact tracing methods have limitations, such as manual data collection and delayed notifications, which may hinder their effectiveness in rapidly evolving situations.

To address these challenges, the research will recommend and proposed an intelligent Internet of Things COVID-19 contact tracing system for the Internet of Things implementation in Nigeria. The use of IoT technologies offers the potential to revolutionize contact tracing by leveraging the interconnectedness of devices and the availability of real-time data. By harnessing the power of IoT, the system that can provide timely and accurate information about potential exposures, facilitate prompt notifications, and enable efficient containment measures.

The main research content of this manuscript revolves around the comprehensive examination of an intelligent IoT-based COVID-19 contact tracing system in the context of Nigeria. The survey will delve into various aspects of the

system, including its design, architecture, data collection techniques, algorithms, and performance evaluation metrics. Through a comprehensive evaluation of the literature and analysis of existing scientific research papers, the study will explore the feasibility and efficacy of implementing such a system in a real-world scenario.

Furthermore, this research aims to identify the potential benefits and challenges associated with the Nigerian use of IoT-based contact tracing systems. The research will examine how the system can contribute to mitigating the spread of COVID-19, strengthening public health response efforts, and informing policy-making in Nigeria as well as investigating the specific considerations related to data privacy, security, infrastructure limitations, and user acceptance within the context of Nigeria.

By shedding light on these aspects, our research intends to give insightful information on the deployment and prospects of a COVID-19 contact tracing system based on the Internet of Things in Nigeria. The study intends to add to the body of knowledge already available and provide suggestions for the creation and application of efficient contact tracking tools in the area.

The COVID-19 pandemic context's urgent requirement for practical contact tracking solutions serves as the driving force behind this research. The proposed intelligent IoT-based contact tracing system aims to leverage IoT technologies to enhance the accuracy, efficiency, and timeliness of contact tracing efforts. The subsequent sections will delve into the specific aspects of the system and provide a comprehensive analysis based on the existing scientific literature.

Table 1 2021 COVID-19 Surveillance and monitoring System Summaries for 13 African Countries [10]

Country	Case Notification Right Away	Tracking contacts	Virological Monitoring	Mortality Monitoring	Surveillance of the Serologic	Event-Based Monitoring	Genomic Monitoring	Environmental Monitoring	Participatory Monitoring
Algeria	✓	✓	✓	✓	✓	✓	✓	✓	
Angola	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nigeria	✓	✓	✓	✓	✓	✓	✓	✓	✓
South Africa	✓	✓	✓	✓	✓	✓	✓	✓	✓
Democratic Republic of Congo	✓	✓	✓	✓	✓	✓			
Zambia	✓	✓	✓	✓	✓	✓			
Kenya	✓	✓	✓	✓	✓	✓	✓		✓
Uganda	✓	✓	✓	✓	✓	✓			
Tanzania	✓	✓							
Ethiopia	✓	✓	✓	✓	✓	✓	✓		✓
Mauritius	✓	✓	✓	✓	✓				
Ghana	✓	✓	✓	✓	✓	✓	✓		✓
Cote d'Ivoire	✓	✓	✓	✓	✓		✓		✓

C) Organization of research

The survey is structured to comprehensively examine the implementation and potential of an intelligent IoT-based COVID-19 contact tracing system in Nigeria. The following is an overview of the sections and their respective content:

1) Introduction

An introduction to the survey is provided in this section, highlighting the background, motivation, and objectives of the study. It offers a foundational introduction to the selected topic, "An Intelligent IoT-Based COVID-19 Contact Tracing System in Nigeria," emphasizing the significance of contact tracing in the fight against COVID-19. Additionally, it highlights the potential of IoT technologies and sheds light on the unique context of Nigeria.

2) Related Works

A thorough evaluation of the literature is done in this section to analyze the current state of related technologies and existing work in the field of IoT-based contact tracing systems. Various aspects, including system design, architecture, data collection techniques, algorithms, and performance evaluation metrics reported in scientific research papers, are explored.

3) Analysis of IoT-Based Contact Tracing Systems Analysis

Here, the findings from the analysis of the scientific research papers are presented. The key insights regarding the implementation and potential of IoT-based contact tracing systems in Nigeria are discussed. The analysis encompasses aspects such as system design, data collection techniques, algorithms employed, and performance evaluation metrics.

4) Challenges and Future Works

The possible advantages and difficulties of implementing IoT-based contact tracking systems in Nigeria are examined in this section. The contribution of these systems to mitigating the spread of COVID-19, strengthening public health response efforts, and informing policy-making is examined. Additionally, specific considerations related to data privacy, security, infrastructure limitations, and user acceptance within the context of Nigeria are addressed.

5) Conclusion

The survey's concluding section offers a thorough explanation of the literature-based conclusion. The main conclusions are outlined, the survey's contributions are noted, and suggestions for further study and the creation of contact tracking tools in Nigeria are given.

II. RELATED WORKS

The new coronavirus disease's rapid appearance and spread over the globe in recent years have been observed (COVID-19). The initial COVID-19 outbreak took place in Wuhan City, Hubei Province, China, with fever and cough being the most typical symptoms. In addition to detecting lymphopenia in a large number of cases, chest computed

tomography has established the existence of ground-glass opacities in a significant percentage of laboratory-confirmed patients. The World Health Organization (WHO) was first made aware of the epidemic on December 31, 2019, and on January 30, 2020, it was declared a Public Health Emergency of International Concern. The disease was classified as COVID-19 by WHO on February 11, 2020.[10].

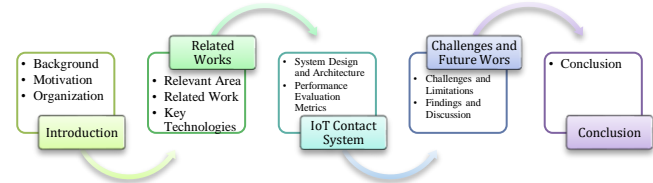


Figure 5 Content Organization

The necessity for creative approaches to combat the disease has been highlighted by the COVID-19 virus' quick global expansion. The use of IoT (Internet of Things) technology, which enables connectivity and data exchange between people and various interconnected devices, such as smart mobile devices, wearable sensors, intelligent cameras, and other interconnected devices, is one area of interest. With the integration of wireless sensing technologies, radio frequency identification (RFID), and artificial intelligence (AI) applications, the use of IoT, also known as MIIoT (Medical Internet of Things), has advanced in the medical industry. [11].

The issues created by COVID-19 in numerous areas, particularly in the healthcare industry, have been met with innovative solutions thanks to the convergence of IoT, AI, and other digital technologies. Early illness diagnosis, treatment monitoring, drug and vaccine development, real-time forecasting, prediction, COVID-19 outbreak prevention, and virtual management via teleconferencing and video meetings are a few of these options. Hospitals, airports, schools, retail malls, factories, hotels, banks, supermarkets, and public transit are just a few examples of the public spaces where these sophisticated technologies might be put into use. However, managing the COVID-19 crisis poses significant challenges, as countries strive to strike a balance between ensuring a return to normalcy and avoiding a resurgence of the epidemic that could overwhelm healthcare systems, potentially necessitating renewed confinement measures. The successful implementation of deconfinement operations relies on specific conditions, protecting people's livelihoods, and facilitating business continuity. Based on the aforementioned situation, this research proposes and analyzes intelligent systems that leverages IoT and AI technologies to provide authorities with an alternative option for managing the COVID-19 crisis.

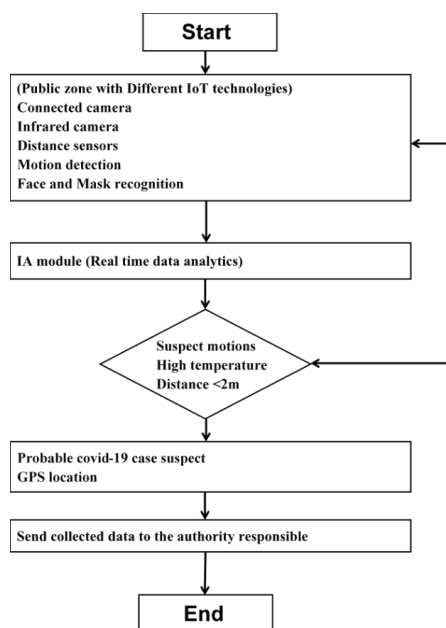


Figure 6 Flowchart of how Contact Systems Operate

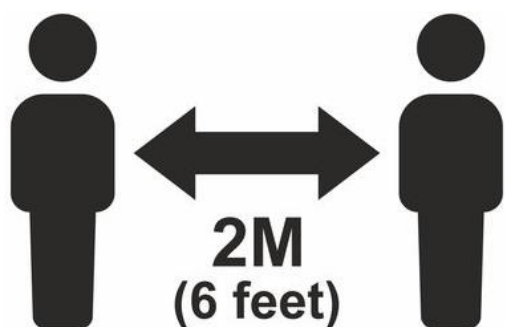


Figure 7 Social Distancing Measures

The subsequent sections of the research will introduce and studies the verse contacts system's and present the proposed/recommend intelligent system's global flow chart (Fig. 2-1). The paper will conclude with final remarks in Section 4.[11]

A. Analysis of IoT-Based Contact Tracing Systems

COVID-19 has prompted the emergence of various solutions in the field and domain of Internet of Medical Things (IoMT), sometimes known as the Internet of Healthcare Things (IoHT) for diagnostic purposes and surveillance of infected patients. IoHT has made significant contributions to preventative measures for serious acute respiratory infections (SARI) and the management of respiratory diseases.

The integration of IoT technology in healthcare has facilitated several initiatives, such as using drones to track people's activities and ensure compliance with quarantine measures. IoT has also played a role in identifying patient zero

and tracking individuals who have come into contact with the infected person. Additionally, IoT has supported healthcare professionals in monitoring patients receiving home treatment.

IoT eHealth provides many services, such as self-testing and telemedicine, which lighten the load on medical professionals and lower the danger of infection. In order to protect patients' privacy and security, these systems give top priority. Body area sensor networks (BASN) are used, for instance, by WISE (Wearable IoT-cloud-based health monitoring system) to gather real-time data on variables like blood pressure, heart rate, and body temperature. Doctors and family members are informed of abnormal fluctuations in these parameters for disease identification, diagnosis, and prediction.

If properly processed, the information gathered from IoT-based smart disease surveillance systems could aid in the prediction and prevention of infectious diseases like COVID-19. Monitoring, tracking, and restricting the transmission of the virus would be made easier by using such data in conjunction with modern technologies.

Another strategy, called Diagnostics using the Internet of Things (IoT), makes use of smart coronavirus monitoring made possible by the IoT. The sensing layer, processing layer, and application layer are the three layers that make up this system. Fuzzy linguistic variables, fuzzy semantic terms, and fuzzy membership functions are used to process and transform input factors like the illness, headache, cough, sore throat, and fever into fuzzy sets. Based on accuracy, miss rate, and the identification of coronavirus sufferers, the system's output assists in estimating the probability of COVID-19 infection.

The nCapp is a system for both diagnosis and treatment implemented through a mobile phone application. It offers eight functions to improve diagnostics, treatment, and the rapid identification and isolation of infected patients, thereby preventing further transmission of COVID-19. The nCapp analyzes user responses to 15 questions and compares them with existing data to classify cases as confirmed, suspected, or suspicious. In confirmed cases, severity levels are also determined to recommend appropriate treatment.

Artificial intelligence (AI) applications have played various roles in managing the COVID-19 pandemic. Quick identification of symptoms and potential matches in patients using AI databases facilitate early diagnostics. Real-time updates on patient status allow physicians to monitor treatments intelligently. AI also aids in tracing infected cases and identifying clusters to halt transmission. Additionally, analyzing collected data helps predict the spread of the virus and accelerates drug and vaccine testing and development.[12] Forecasting models, such as a stacked auto-encoder, have been employed to estimate real-time COVID-19 trends based on data collected from the World Health Organization (WHO). Such models assist governments and healthcare professionals in making proactive decisions.

Monitoring and tracing the spread of COVID-19 has been made easier by Geographic Information System (GIS) technology and mapping dashboards. For instance, the "close contact detector" programme in China uses large amounts of data from public transportation networks to examine people's travels and identify whether they had recently been in close touch with an infected person. There are many difficulties associated with releasing the lockdown procedures put in place to stop the COVID-19 outbreak. Numerous research have shown that responsible exit strategies need to be well thought out. The management of this complex scenario can benefit greatly from new technologies like IoT and AI.

B. Helping COVID-19 patient during self-quarantine phase: The role of AI and IoT

We have been battling the COVID-19 epidemic since 2020 and will continue to do so. Even though vaccinations have been created, it will still take some time to immunise everyone. Bharat Biotech and the National Institute of Virology (NIV) of the Indian Council of Medical Research collaborated to develop the COVID-19 vaccine for India (ICMR).[13]. It is crucial for COVID patients to practise self-quarantine since the coronavirus travels from person to person. However, maintaining a quarantine is difficult since patients must have access to everything without direct touch. Additionally important is remote monitoring.

It is essential to maintain close observation without direct contact during the quarantine period, which usually lasts for at least two weeks. IoT and AI are useful in this situation. These technologies are capable of carrying out activities without human involvement. We can do our work without the assistance of humans by utilising a variety of IoT and AI-enabled gadgets.

Strict observation without direct contact is required throughout the quarantine period, which usually lasts for at least two weeks. IoT and AI both have a role to play here. These tools are capable of carrying out activities without assistance from people. We are able to complete our task without the need for human intervention by utilising a variety of IoT and AI-enabled devices.

C. IoT

By providing contactless medical equipment and systems for the treatment of individuals who are affected, Internet of Things (IoT) gadgets are playing a critical part in this pandemic's fight against the coronavirus. They also aid in limiting the virus's ability to spread through direct contact. By including contactless monitors for body temperature, attendance, and sanitization and more, these gadgets aid in the creation of a new-normal working environment. They are commonly used in workplaces including offices, warehouses, hospitals, and other places. Hospitals can also benefit greatly from facial recognition-based technologies like touch-free drug delivery and touch-free heartbeat monitoring.[14]

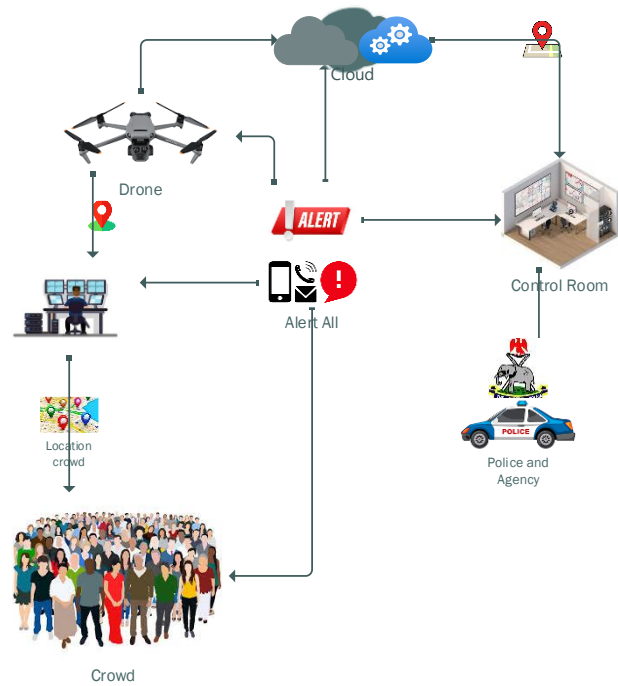


Figure 8 Monitoring and Detection of Social distancing & Digital Forensics via drone

TABLE 2 IoT APPLICATIONS FOR HEALTHCARE SECTOR [15]

SNo.	IoT Applications	Usage
1	Utilising IoT to connect hospitals	To create an IoT-based integrated healthcare network
2	Transparent COVID-19 treatment	To guarantee the COVID-19 epidemic is treated fairly
3	Intelligent patient tracking	To track COVID-19 individuals that are still infected in the early stages
4	Connecting all equipment and devices for medicine	To connect medical instruments and provide real-time treatment information
5	Virus predicting that is accurate	To foresee present circumstances and support medical teams in providing therapy
6	A wireless patient identification system	To identify COVID-19 patients using authentic applications in smartphones
7	Rapid COVID-19 screening	To diagnose infections at an early stage using smart devices
8	An IoT-based home healthcare system	To provide treatment and monitor patients at home using mobile apps
9	Cognitive Internet of Medical Things application	For real-time patient tracking, defence, remote supervision, quick diagnosis, screening, and surveillance
10	Program for Intelligent Diagnosis and Treatment COVID-19 (nCapp)	By transmitting data to clinicians, real-time diagnosis and treatment support is provided.

1) Tracking down the Entities affected by the Corona virus

According to a the Massachusetts Institute of Technology did a study (MIT), IoT, when combined with geographic information systems (GIS), can help epidemiologists determine who has been into contact with contaminated patients.. This

technology enables the tracking of patients who have a high risk of infection, providing valuable data to healthcare staff [16].

2) *Linked Thermometers*

In hospitals, connected thermometers are used to track patients' body temperatures in real time. With the aid of an IoT Access Controller, these systems use sensors to collect and transmit real-time data from patients to a nurse's station, providing round-the-clock monitoring. Daily maps depicting the rise in high fevers across different US counties have been produced using data gathered from more than a million connected thermometers.[17]. Additionally, an Indian team of product professionals has created a contactless fever diagnosis a technology that evaluates the skin temperature remotely using AI-based thermal imaging of people in the camera's field of view.

3) *Smart Wearable*

Researchers at the IIT-Istituto Italiano di Tecnologia have developed sensorized suits that monitor various physiological characteristics of the human body and inform patients when their body temperature hits 37.5 degrees Celsius.[16], [17]. In China, key human body characteristics including heart rate, blood oxygen and temperature levels are also continuously monitored via wristbands and rings synced with artificial intelligence technology.

4) *Button IoT*

The IoT Button, which is being implemented in several Canadian hospitals, is a notable IoT innovation. These buttons allow for quick facility deployment and notify management of any cleaning or maintenance issues.

D. AI

AI is currently a viable area for finding solutions in the fight against the pandemic, particularly in terms of medical advancements. It is used for medicinal operations, timely notifications, data dashboards, and social control.

1) *Using AI, track patients and hospital visitors*

Hospitals all across the world are implementing AI and IoT integrated devices to monitor patients and lessen the spread of the virus through physical contact in response to the epidemic. Hospital visitors are screened using facial recognition scanners with built-in cameras, which also analyse facial features and perform thermal scanning to detect fevers. Numerous people who are infected receive timely treatment thanks to these remedies. A non-contact infrared sensor device created lately by Chinese engineers may detect fever in people even in crowded areas.

2) *Remote Monitoring*

Another essential AI tool that hospitals use to safeguard employees and closely monitor patients even from outlying areas and hospital dorms is remote monitoring. For instance,

sensor technology positioned under a patient's mattress can monitor the patient's breathing, body movement, and heart rate, enabling observation and treatment of COVID patients with a high priority.

3) *COVID Voice Detector*

Technology experts are using AI tools to identify infected people by listening to their speech, breathing patterns, and coughing sounds. In order to ascertain an individual's infection status, data collection techniques including recording speech and coughing are used. In order to forecast outcomes, this data are subsequently put into machine learning and deep learning programming algorithms.

E. Nigeria's Battle Against COVID-19 with AI

Numerous AI and technology businesses have offered their support as Nigeria fights COVID-19. For instance, a robotics start-up in Nigeria has suggested using robots to screen and diagnose patients, gathering crucial data such patient names, symptoms, and contactless confirmation through temperature checks. The diagnostic robot concentrates on people with high body temperatures or indications of the infection and communicates with a doctor in another place via video chat. AI and IoT can be used to identify and track the COVID-19 virus in the current circumstances, which is harming our lives and way of living.

With these technologies, it's important to strike a careful balance between the necessity to fight viruses and the desire to maintain peoples' privacy. While fighting the pandemic is necessary, it's also critical to limit how much time and resources are spent doing so and to maintain each person's right to privacy, non-discrimination, the security of journalistic sources, and other liberties.

F. Techniques for Contact Retrieval and Tracing

A summary of current contact tracing methods for the contagious COVID-19 is shown in Table 2-2. It contains details on the authors, goals, methods, conclusions, and shortcomings of each strategy. The chart demonstrates that COVID-19 contact tracing modelling is still in its infancy and mostly concentrates on confirmed instances with significant human contact tracers.

1) *Typical Traditional Contact Tracing Methods & Techniques*

Finding sick people and then determining who they recently connected with is the basic tenet of contact tracing, but the precise method may differ. Contact tracing is nothing more than old-fashioned detective work.

Backward tracking, which seeks to determine how someone contracted the infection in the first place rather than identifying the people they transmitted it to, is the most widely used and well-known contact tracing technique. Depending on the local capacity for contact tracing, experts may use a hybrid technique that incorporates both forward and backward tracing

to identify the source of infection in epidemics with high levels of infectious variability. Based on a community-based survey, a typical backward contact tracking technique takes the following steps:

- A person will be quarantined and reported to the appropriate public health body after they are found to be infected or a carrier of the virus.
- Contact tracers will speak with the person to learn about their movements and locate any potential infected close contacts.
- Interviews with others who know information about the patient's contacts may also be required by contact tracers. Given the potential for deliberate concealment or the interviewee's poor memory, cross-validation is essential.

Contact tracers will make contact with specified contacts, test them for potential illness, and resume the tracing procedure if the contact is also determined to be infected. Depending on the possible transmission of the virus, broader messages to the public may be sent out in situations where specific contacts cannot be identified.

To keep track of cases and contact tracing operations, contact tracers frequently use case management software during the tracing process. These records are usually kept in a centralised or cloud-based database, making it easy to browse and retrieve information quickly. Additional capabilities of the contact tracing management software may include the ability to email or send SMS notifications to anyone who are believed to have been in close contact with someone who has contracted the infectious disease.

For illnesses including TB, diseases that can be prevented by vaccination (like measles), STIs (like HIV), blood-borne illnesses, Ebola, and novel virus infections, traditional contact tracing techniques have been utilised extensively (e.g., SARS, H1N1, COVID-19). These approaches have severe shortcomings when dealing with widespread outbreaks like the COVID-19 pandemic, despite being beneficial for many infectious diseases. Traditional tracing takes time and resources because it relies on manual interviews and investigations. Furthermore, the conventional approach based on interviews frequently yields insufficient and erroneous information, impeding the tracing process and wasting resources.

TABLE 3 CONTACTS ALERTS AND NOTIFICATION

	Patient's referral	Provider's referral
Process	- The patient index contacts their connections directly.	- The healthcare practitioner gives the partner the information that will be shared by the index patient. - The healthcare practitioner either notifies the contact directly or makes use of another organisation (such as a contact tracer, public health department, or sexual health service) to ensure that contacts are notified. - The index patient's express consent to the healthcare practitioner is required.
Advantages	- People typically prefer to individually inform connections. - Higher level of confidentiality for the index patient.	- Faster and simpler. - Technique of choice in particular circumstances and conditions, as well as when a person fears a violent reaction (For instance, pulmonary tuberculosis, infections brought on by blood transfusions, whenever sex workers or people with intellectual disabilities would be involved.
Disadvantages	- may be appropriate in cases of severe illnesses like HIV where careful case finding is required. - less discretion and confidentiality.	- Patients could make fake contact with partners or may not actually contact partners. - more time and resource requirements and intensive.

As a result, it is crucial to create and implement more effective contact tracing systems that take use of the most recent developments in information and communication technology. These innovations may speed up responses to significant infectious disease outbreaks and increase the efficacy of contact tracing initiatives.

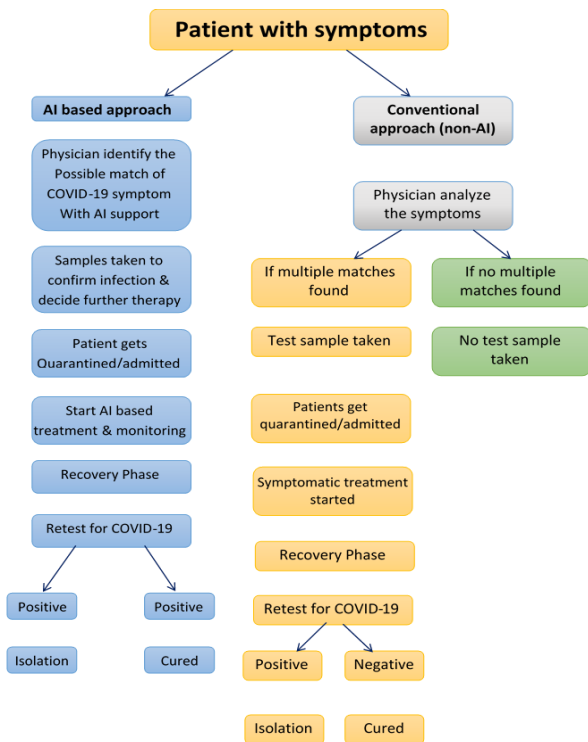


Figure 9 Typical use of AI and non-AI based apps that assist general practitioners in recognising COVID-19 symptoms.[18], [19]

2) Existing Research Implications and Gaps

Considering only confirmed cases or visits has the drawback of enabling the disease to spread quickly. Some of the created models are unique to particular situations and cannot readily be modified for extensive observation. Therefore, it is essential to have a joint effort that includes community reporting, where geographic information like the locations of potential contacts can be gathered in real-time. By specifying the locations of users, spatial models explicitly reflect transmission patterns, helping to capture periodic fluctuations.

While wearable trackers have been used to track potential contagious connections retroactively, the ideal method would incorporate crowdsourcing information regarding close contacts to suspects or diseased people who have disregarded physical/social segregation or safety precautions (e.g., being within a distance of less than 2 metres or for an extended period of time). The spread of epidemics can be greatly slowed down by expanding investigations to include broader people. A speedy reaction to a pandemic can be difficult, though, due to resource limitations. Spatiotemporal modelling has become a practical method for examining real-time data gathered from users' settings when integrated with AI tools. This method makes it possible to examine recurring patterns across time and identify unique patterns. Effective intervention targeting requires an understanding of the mean transmission distances during epidemics. However, a prompt response to a pandemic can be difficult due to resource limitations. Spatiotemporal

modelling has become a feasible option for studying real-time data gathered from users' settings when integrated with AI solutions. This allows for the study of enduring patterns across time and the detection of anomalous patterns. Given that geolocated data has become the standard for studying infectious illnesses, understanding the mean transmission distances during outbreaks might assist target interventions efficiently. Additionally, network models can provide as a unifying framework for both individual-based and meta-population models.[20]

People can use specialised applications that offer extensive location information to make informed judgments about self-quarantining and seeking medical care while governments impose travel restrictions and encourage social estrangement. Applications and dashboards with a map-centric focus have been created to track the COVID-19 pandemic and related occurrences across the globe. To see if the user has recently had any close contact with a confirmed or suspected COVID-19 case, several of these dashboards receive real-time updates of documented cases. [11]

3) Privacy Concerns Issues, Protocols and procedures.

If not carefully handled, some infectious respiratory diseases, such as COVID-19, are very contagious and can spread swiftly. Additionally, those who have the virus can go up to 20 days without showing any symptoms or being recognised, during which time they may have already come into touch with a great deal of other people and spread the illness to them.[21].

Therefore, it is crucial to do contact tracing as soon as is practical and accurately in order to understand the virus's route of transmission and notify anybody who may have been exposed. Utilizing mobile devices and specific contact tracing technology, digital contact tracing is a tool for locating contacts between users and infected patients. Digital contact tracing offers unrivalled advantages for tracking the health of large groups of people, immediately detecting the movement patterns of diseased individuals, and compiling lists of potential contacts. Because of this, it has turned into one of the most crucial technological tools in the ongoing contact tracking activities to thwart COVID-19.

However, users' principal worries when selecting whether to embrace contact tracing technology now seem to be privacy issues. The use of contact tracing technologies is also significantly hampered in many nations by these worries. Digital contact tracking solutions have been developed as a result, and a number of procedures have been proposed and put into place to address and mitigate privacy concerns and preserve or defend users' privacy.

G. Digital Methods for Contact Tracing

The concept of digital contact tracing has been in existence since at least 2007[22], [23], and its effectiveness was demonstrated through empirical investigations using Bluetooth

data in 2014. However, it achieved notoriety during the COVID-19 pandemic when it was initially widely used by numerous governments and commercial COVID-19 apps. Other infectious respiratory disorders can also be treated using the same principles and algorithms used in digital contact tracing.

1) *The overall and General and Architecture of Digital Contact Tracking and Tracing*

Mobile devices, especially smartphones, are often utilised by the general population and are hence the main technology employed in digital contact tracing. Different nations have created a large number of contact tracing smartphone apps, albeit they may differ in terms of data storage, communication protocols, and location systems. Despite these variations, their fundamental functioning principles are still very similar. Figure 2.5 depicts the overall design of mobile contact tracing software designed specifically for smartphones. Different contact tracing applications leverage localization technologies like Bluetooth, GPS, cellular tower networks, and WiFi to gather crucial proximity or encounter data.[24].

The two main user groups in contact tracing apps are the general public (represented by Users A, B, and C in Figure 2-5) and medical and healthcare professionals who are in charge of making diagnoses and doing contact tracing. In this illustration, we'll assume that User A has installed the contact tracing programme and registered to use it, User B has done the same, and User B has tested positive for the infectious disease (e.g., COVID-19).

The following steps make up the general digital contact tracing method using mobile apps:

1. Relevant data, including location and encounter details, is shared when users run into one another and either sent to the backend server or saved in the users' apps.
2. User B uploads the diagnosis data to the server after receiving a favourable diagnosis, either directly or through medical or healthcare experts.
3. The server analyses location and encounter data after receiving the information of a new patient (User B) to find possible contacts (such as User C) based on established rules regarding proximity and duration of contacts. The software then notifies User C, who may then go through any appropriate quarantine or medical tests. Despite having come across User B, User A does not comply with the established regulations and is deemed to pose a minimal danger, therefore they are not informed.
4. Through effective identification and communication of prospective contacts, the digital contact tracing procedure enables quick testing and quarantine actions to stop the spread of contagious diseases.

H. *Technologies for localization services*

Numerous localization solutions have been applied to accommodate the many mobile apps created in response to the COVID-19 pandemic. In this section, we go over a number of significant and generally accepted localization technologies that have been extensively applied for contact tracing, such as acoustic range, Bluetooth, GPS, cellular tower networks, and Wi-Fi. While acoustic range, Wi-Fi, and Bluetooth can all be used indoors, GPS can only be used outside. A comparison of several localisation technologies is given in Table 4.[24].

- a. **Bluetooth:** Bluetooth is a wireless technology that connects two phones and has the benefit of using less power. Due to its ability to track touch devices with a resolution of 1-2 metres, Bluetooth is ideal for recognising near personal contacts that are most prone to spread infectious diseases. The fact that Bluetooth may only capture users' proximity information within a small region is a significant drawback. As a result, while Bluetooth is excellent at creating a list of contacts for contact tracing, it is unable to precisely pinpoint users' physical locations, making it challenging to do more in-depth research and, if required, fully reconstruct peoples' movement trajectories. Additionally, Bluetooth's indoor positioning accuracy is subpar in environments like factories, offices, hospitals, shops, and hotels because of obstructions to the line of sight, absorption, and multi-path reflections.[25], [26].
- b. **GPS:** Contact identification and tracing are made easier by the development of GPS-based location-based technology, which may track users' whereabouts and identify those who have visited the same location as the infected person.[22], [27]. In outdoor settings, GPS often performs well, with an accuracy of 10 to 15 metres. Although most infected interactions take place indoors, GPS signals deteriorate indoors, considerably limiting accuracy. This is a serious restriction for contact tracing. Although GPS usage is more private than Bluetooth, privacy issues can arise. [28], [29].
- c. **Cellphone tower networks:** Location tracking is made possible via cellphone tower networks without the need for users to download and utilise a specific programme. Israel was where this technology was initially used.[28]. If a legal framework is in place, it is non-intrusive and can be implemented without user input. The fact that communication providers currently record and preserve data regarding mobile communication, making the information easily accessible for contact tracing, is one of the key benefits of this technique. Because of this, using this technology has a very low economic cost when compared to other technologies. The position precision is often poor, and the process of locating contacts using these traces can be inaccurate, because the region a cell covers might vary from a few hundred metres to several kilometres. Additionally,

there may be serious privacy issues with this technology. [28].

- d. **Wi-Fi:** As long as the gadgets are logged into the identical Wi-Fi network, Wi-Fi technology makes it possible to identify the identification (MAC address) of nearby devices, allowing the creation of a very accurate list of potential contacts. The RSSI, which can be used to calculate distance, is one piece of information about these nearby devices that mobile nodes can periodically scan and store. Wi-Fi, on the other hand, might not be widely accessible and often has a constrained coverage and range. Wi-Fi, however, is a useful technique for contact tracing indoors. The events logged in the "syslog" file for each device can be used to establish the spatio-temporal mobility trajectory of each device in an enterprise with numerous access points (APs) and ongoing device connections, and a contact graph can be built for contact tracing.[13].
- e. **Acoustic-ranging:** According to this method of sound-based contact tracing, each item generates a random but distinctive acoustic signal that can be used to calculate distances.[30]. This technique precisely calculates the amount of time it takes for sound to travel between two objects and multiplies it by the sound speed to determine distance. High tracing accuracy is exhibited by acoustic range systems. The surroundings can get noisy as the number of devices grows, which makes sound-based contact tracking difficult.

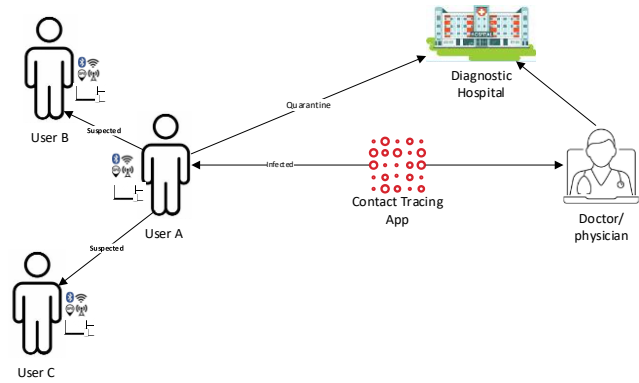


Figure 10 The general and overall design & architecture of digital contact tracing applications.

TABLE 4 EVALUATION OF VARIOUS LOCALIZATION TECHNOLOGIES[21]

Technologies	Data	Accuracy	Battery Usage
Bluetooth	Record the encounter between each device	Able to distinguish between near encounters within 2 metres	Low
GPS	Record and save the GPS coordinates location	Has a higher rate of false positives and is unable to filter for closeness	Medium
Cellphone tower networks	Assemble and save the data from cellular communications	Low level of location accuracy	Negligible
Wi-Fi	Scan and store information about all surrounding devices	Very accurate if users are connected to the same Wi-Fi networks, but has a small coverage area	Negligible
Acoustic-ranging	Sound communication between devices	High accuracy, but decreases with the number of devices communicating	Negligible

III. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

A. Challenges

- a. **Data Privacy and Security:** Ensuring the protection of individuals' personal health information while collecting and sharing data for surveillance purposes.
- b. **Limited Testing and Reporting Capacity:** Overcoming challenges related to limited testing capabilities, delays in reporting, and insufficient data coverage, which can impact the accuracy and effectiveness of surveillance systems.
- c. **Interoperability and Data Integration:** Integrating data from multiple sources and systems to create a comprehensive and unified view of the COVID-19 situation, including laboratory results, hospital records, and contact tracing data.
- d. **Resource Constraints:** Managing limited resources such as healthcare personnel, testing kits, and medical supplies, which can affect the ability to conduct robust surveillance and response activities.
- e. **Technical Infrastructure and Connectivity:** Addressing issues related to inadequate technical infrastructure, internet connectivity, and access to remote areas, which can impede real-time data collection and analysis.
- f. **Misinformation and Infodemics:** Dealing with the spread of misinformation, rumors, and false information that can undermine public health efforts and create confusion among the population.
- g. **Coordination and Collaboration:** Ensuring effective coordination and collaboration among multiple stakeholders, including healthcare providers, public health agencies, government entities, and international organizations, to facilitate data sharing and decision-making.
- h. **Community Engagement and Compliance:** Encouraging community participation, raising awareness, and ensuring compliance with surveillance measures, such as contact tracing, testing, and quarantine, to control the spread of the virus.

- i. Equity and Vulnerable Populations: Addressing disparities and ensuring equitable access to testing, healthcare services, and surveillance efforts among vulnerable populations, including marginalized communities and those with limited resources.
- j. Long-term Sustainability: Developing sustainable surveillance systems that can adapt to changing needs, integrate new technologies and data sources, and continue monitoring and responding to COVID-19 and potential future outbreaks.

These challenges require ongoing attention and innovative solutions to strengthen COVID-19 surveillance and response efforts effectively.

TABLE 5 SUMMARY OF FINDINGS

Topic	Summary
Benefits of IoT-Based Contact Tracing Systems [31], [32]	<ul style="list-style-type: none"> - Efficient and automated contact tracing - Real-time monitoring of infected individuals' health conditions - Early detection and intervention for potential outbreaks - Data-driven insights for decision-making and resource allocation
System Architectures and Data Collection [33], [34]	<ul style="list-style-type: none"> - Centralized architecture with data collected from wearable devices and mobile apps - Decentralized architecture using Bluetooth and proximity-based data exchange - Hybrid architectures combining centralized and decentralized approaches
Techniques [35]	<ul style="list-style-type: none"> - Accuracy of contact detection and tracing - Efficiency of data collection and processing - Timeliness of notifications and alerts - Scalability and adaptability to varying population sizes and geographical contexts
Performance Evaluation and Metrics [36], [37]	<ul style="list-style-type: none"> - Limited adoption and usage of contact tracing apps - Privacy concerns and data protection - Technical limitations such as Bluetooth range and accuracy - Challenges in ensuring compliance and cooperation from individuals
Challenges and Limitations [38], [39]	

Topic	Summary
Privacy and Security Concerns [40], [41]	<ul style="list-style-type: none"> - Protection of personal health data and sensitive information - Mitigation of risks associated with data breaches and unauthorized access
Infrastructure and Cultural Adaptation [42]	<ul style="list-style-type: none"> - Access to reliable internet connectivity and infrastructure - Cultural acceptance and willingness to adopt contact tracing technologies
Community Engagement and Communication [33], [43], [44]	<ul style="list-style-type: none"> - Effective communication strategies to raise awareness and encourage participation - Building trust and addressing public concerns and misconceptions - Collaboration with community leaders and organizations for outreach and engagement
Strategies [45]	

A. Future Directions

Future contact tracing systems are expected to display new traits, which can be summed up using the phrases privacy, intelligence, pervasiveness, scenario customisation, and globalisation.

- *Privacy*: New contact tracing technologies will give enhanced security and better protection of users' sensitive data a higher emphasis. Data gathered and stored in servers and mobile devices, whether in centralised or distributed systems, will be better safeguarded against malicious assaults to prevent the leakage of sensitive information to enemies. In contrast to current structures, new architectures may also develop that promise better preservation of sensitive user data. To more effectively control the use and sharing of user data gathered through contact tracing, nations and international organisations will create pertinent laws, policies, or regulations. These developments will promote wider use and use of contact tracing technologies, which is necessary to stop the spread of the virus.

TABLE 6 SUMMARY OF THE REVIEWED ARTICLES

Paper	Benefits	System Architectures and Data Collection Techniques	Performance Evaluation and Metrics	Challenges and Limitations	Privacy and Security Concerns	Infrastructure and Cultural Adaptation	Community Engagement and Communication Strategies
[46]	Efficient contact tracing	Centralized architecture	Accuracy, efficiency, scalability	Limited adoption, privacy concerns	Data protection, unauthorized access	Reliable internet connectivity, infrastructure	Effective communication strategies
[47]	Real-time monitoring of health	Decentralized architecture	Timeliness, scalability	Technical limitations, compliance	Protection of personal health data	Cultural acceptance, willingness to adopt	Building trust, collaboration with community
[36], [37], [42]	Early detection and intervention	Hybrid architecture	Data-driven insights	Bluetooth range, cooperation	Risks of data breaches	Access to reliable infrastructure	Outreach, addressing concerns
[48]–[50]	Data-driven decision-making	Wearable devices, mobile apps	Contact detection accuracy	Limited adoption, technical limitations	Unauthorized access to sensitive data	Cultural acceptance	Trust-building, addressing misconceptions
[26], [34], [51]	Automated contact tracing	Proximity-based data exchange	Data collection efficiency	Privacy concerns, technical limitations	Data breaches, unauthorized access	Internet connectivity	Collaboration with community organizations
[47]	Real-time monitoring of individuals	Centralized architecture	Timeliness, scalability	Compliance, cooperation	Protection of sensitive information	Infrastructure availability	Community outreach, awareness
[52]	Early intervention for outbreaks	Hybrid architecture	Efficiency, scalability	Limited adoption, Bluetooth range	Risk mitigation, data protection	Cultural acceptance, willingness to adopt	Trust-building, effective communication
[22], [41]	Data-driven insights	Decentralized architecture	Accuracy, efficiency	Privacy concerns, compliance	Unauthorized access to personal data	Access to reliable infrastructure	Collaboration with community leaders
[47]	Resource allocation	Centralized architecture	Scalability, adaptability	Technical limitations	Data breaches, privacy protection	Infrastructure availability	Engaging community leaders, outreach activities
[32], [53]	Prevention strategies	Hybrid architecture	Scalability, adaptability	Limited adoption, technical limitations	Security of personal health data	Cultural acceptance, willingness to adopt	Effective communication, addressing misconceptions

- *Intelligence*: Contact tracing solutions will become more intelligent and provide a wider range of analytical features beyond straightforward tracking as a result of developments in machine learning, big data analytics, and data visualisation. They will be able to derive more value from the enormous amount of user data gathered thanks to these cognitive capabilities.
- *Pervasiveness*: In order to support high-quality contact tracing, contact tracing technologies will proliferate

and become more widespread, providing more detailed data. A multitude of technology advancements, including as increased smartphone usage among the general public, more energy-efficient tracking devices, and more accessible and reliable communication infrastructures, will enable this.

- *Scenario Customization*: Technologies need to be tailored for unique settings by adding pertinent background information and expertise to achieve

optimal contact tracing performance. Their application in a variety of settings, including schools, hospitals, factories, and businesses, will be successful and efficient thanks to this personalization.

- *Globalization*: The geographic reach of contact tracing systems and apps will increase, accelerating or slowing the globalisation of these technologies. Along with this advancement, standardisation of the relevant technologies will inevitably appear, leading to the development of uniform global standards to simplify cross-national contact tracing between various nations.

These future directions aim to improve the effectiveness, efficiency, and acceptance of contact tracing technologies, ultimately contributing to better control and management of infectious diseases.

IV. CONCLUSION

The outbreak of COVID-19 pandemic has brought about significant disruptions across various sectors, necessitating the adoption of innovative solutions. In the post-COVID-19 era, the Internet of Things (IoT) emerges as a crucial enabler in managing the new normal. By leveraging IoT's core functionalities, diverse applications such as patient information interchange, emergency recovery, communication control, power management, supply chain administration, online education, and citizen engagement can be effectively implemented.

The integration of IoT into healthcare systems holds great potential for personalized and efficient patient care. Through IoT-enabled devices and AI-based medical facilities, patients can access personalized therapies, continuous monitoring, accurate diagnoses, and real-time surveillance of their health. Moreover, smart sensors powered by IoT can assist individuals in maintaining social distance and receiving timely alerts within the healthcare system.

The combination of IoT and AI-based healthcare solutions has the capability to revolutionize the management and prevention of diseases like COVID-19. These technologies enable enhanced monitoring, diagnosis, and prevention strategies, playing a vital role in the global battle against infectious diseases. By implementing IoT and AI, we can create a safer and more efficient healthcare system that prioritizes patient-centric care while minimizing the impact of infectious diseases on communities.

The integration of IoT and AI in healthcare offers transformative opportunities to address the challenges and difficulties brought and posed by the COVID-19 pandemic. By harnessing the power of these technologies, we can establish a resilient healthcare ecosystem that ensures the well-being of individuals, while also supporting global efforts to combat infectious diseases effectively.

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