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Integrating emerging technologies into COVID-19 contact tracing: Opportunities, challenges and pitfalls



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ABSTRACT

Background and aims: With no approved vaccines for treating COVID-19 as of August 2020, many health systems and governments rely on contact tracing as one of the prevention and containment methods. However, there have been instances when the infected person forgets his/her contact-persons and does not have their contact details. Therefore, this study aimed at analyzing possible opportunities and challenges of integrating emerging technologies into COVID-19 contact tracing.

Methods: The study applied literature search from Google Scholar, Science Direct, PubMed, Web of Science, IEEE and WHO COVID-19 reports and guidelines analyzed.

Results: While the integration of technology-based contact tracing applications to combat COVID-19 and break transmission chains promise to yield better results, these technologies face challenges such as technical limitations, dealing with asymptomatic individuals, lack of supporting ICT infrastructure and electronic health policy, socio-economic inequalities, deactivation of mobile devices' WIFI, GPS services, interoperability and standardization issues, security risks, privacy issues, political and structural responses, ethical and legal risks, consent and voluntariness, abuse of contact tracing apps, and discrimination.

Conclusion: Integrating emerging technologies into COVID-19 contact tracing is seen as a viable option that policymakers, health practitioners and IT technocrats need to seriously consider in mitigating the spread of coronavirus. Further research is also required on how best to improve efficiency and effectiveness in the utilisation of emerging technologies in contact tracing while observing the security and privacy of people in fighting the COVID-19 pandemic.

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1. Introduction

The outbreak of coronavirus disease in 2019 (COVID-19) caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has caused detrimental effects in many health systems globally [1]. The spread of COVID-19 overwhelmed health sectors globally and continue to affect all aspects of life including education, entertainment, businesses, tourism and manufacturing. As of August 12, 2020, there were 20, 542, 758 confirmed COVID-19 cases, 746,337 deaths and 13, 460, 643 recoveries [2]. COVID-19 is contagious and spreads rapidly from person-to-person, physical contact with infected objects [3] and aerosols transmission [4] among others. Some infected persons show symptoms while others are asymptomatic and pre-symptomatic. It is often difficult to detect COVID-19 in asymptomatic individuals hence the need to

keep registers of affected persons' contacts. World Health Organization declared COVID-19 a pandemic on January 30, 2020, because of high COVID-19 transmission and death rates [5,47]. With no approved vaccines, COVID-19 paralysed many health systems while governments implemented prevention and containment methods such as case management, surveillance, infection prevention and control. COVID-19 infection prevention and control strategies include maintaining physical distancing (individual and community), contact tracing social distancing, use of personal protective equipment (PPE) to reduce exposure, decontamination and disinfection of contaminated areas and objects using sanitizers, restrictions on travelling, closure of schools and universities [6]. Since there is no approved COVID-19 vaccine, health systems rely on case management which involves contact tracing, quarantine, self-isolation of infected and suspected individuals. The dynamic nature of people movements within their communities makes it difficult to achieve accurate contact tracing. This presents unprecedented opportunities for research activities, collaboration and

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integration of modern technologies to strengthen contact tracing efforts. Studies by Wang [7] Ting [8], Vaishya [9], Iyengar [10], Vafea [11], Mohd [12] and Elavarasan [13] shows that emerging technologies including 5G technology, artificial intelligence (AI), big data, Internet of Things (IoT), blockchain, Geographical Information Systems (GIS), Internet of Medical Things, additive manufacturing, robotics and nanotechnologies can play a paramount role in tackling COVID-19 pandemic. Therefore, this study aimed at analyzing possible opportunities for incorporating emerging technologies to enhance COVID-19 contact tracing activities. Also, the study identified the challenges of integrating emerging technologies into contact tracing activities.

2. Contact tracing

Contact tracing is an important control measure to break chains of COVID-19 person-to-person transmission [14]. Since COVID-19 symptoms are nonspecific, asymptomatic and sometimes undetected in many people, testing alone does not stop the spread but requires contact tracing to speed the discovery of an affected person's contacts to prevent further transmission. To effectively enhance contact tracing, the World Health Organization recommends a combination of measures such as rapid diagnosis and immediate isolation of cases, rigorous tracking and precautionary self-isolation of recently exposed close-contacts [15]. To prevent onward transmission, the person who tests positive for COVID-19 is either quarantined or self-isolated. After that, the person's close contacts are followed up and advised to go into precautionary self-isolation. This process is called contact tracing, and its purpose is to prevent possible transmission chains. Contact tracing as a control measure identifies exposed contact-persons that need 14 days of precautionary self-isolation [16]. A close contact or contact-person is a person who had face-to-face contact with an infected person or confirmed case [17]. Implementation of contact tracing activities requires collective efforts from the health workers, community, researchers, telecommunication companies and government authorities.

Currently, contact tracing activities rely on the memory of COVID-19 infected person to provide a list of contact-persons to the healthcare professionals or COVID-19 response team. However, Ahmed [18] highlighted that there have been instances when the infected person cannot remember his/her close contact-persons and does not have contact details of the contact-persons [18]. For example, the infected person might have had contact with

unknown persons in the retail outlets which might be difficult to trace contacts. In cases like this, technology-based contact tracing applications can facilitate and automate the process, enabling contact tracers to inform users who a COVID-19 victim's contact persons are. This can be enabled by using global positioning system (GPS), Wireless Fidelity (Wi-Fi) technology Bluetooth technology, Social graph, network-based API, mobile tracking data, card transaction data, and system physical address [15].

2.1. Opportunities for integrating contact tracing with emerging technologies

Emerging technologies are highly interlinked and could be utilized for tracing and tracking COVID-19 pandemic as shown in Table 1. With the rapid increase in COVID-19 cases and deaths in affected countries, the integration of emerging technologies into contact tracing activities is inevitable. Integration of COVID-19 contact tracing activities with technology is not new, countries like South Korea, Germany, Singapore, Australia, Colombia, Australia, Egypt, Ghana, Austria, Israeli among others have launched aggressive technology-based contact tracing applications. These countries use several devices communicating together through Bluetooth technology, Global Positioning System (GPS), wireless technology, mobile phone applications, wearable technology and sensors. For instance, Germany implemented a contact tracing application that executes on smartwatches and screens the user for COVID-19 using pulse, temperature, and sleep pattern [19]. The data from the contact tracing application is mapped to the country's interactive map for further analysis and allocation of resources. Singapore implemented a Bluetooth-based mobile phone application, TraceTogether to boost COVID-19 contact tracing efforts. TraceTogether mobile application works by pushing notifications and location permissions to devices in close-proximity as two meters apart and sharing information [20]. TraceTogether mobile application can store data for up to 21 days and transfer it to the national health information systems. More examples of contact tracing applications are depicted in Table 2.

2.1.1. Digital Contact tracing applications (apps)

Several contact tracing apps have been developed in many countries as shown in Table 2 and in articles written by Samuel [15], Vinay [21], Cho [22], and Ahmed [18]. However, none of the apps have been reported for South Africa as one of the most COVID-19 affected countries. Russia launched Moscow's patient-tracking

Table 1
Opportunities for integrating contact tracing with emerging technologies. Digital Contact tracing applications (apps).

Emerging technology	Possible activities of COVID-19 contact tracing applications
Artificial intelligence	<ul style="list-style-type: none"> •Regular check body temperature if integrated with smartphones, smartwatches, smart thermometers •Initial screening of COVID-19 suspected individuals using body temperature among others •Have a "chatbox" for real-time communication, education and remote monitoring of individuals
Internet of Things	<ul style="list-style-type: none"> •Allow authorities to have real-time access to COVID-19 data for contact-persons •Remote monitoring of COVID-19 patients in quarantine centres and or self-isolation
Geographical information systems	<ul style="list-style-type: none"> •provide a real-time tracking map for COVID-19 patient or contact-persons •Scatter contact-persons' mobility patterns •Spatial modelling of the affected populace using GPS coordinates •Track COVID-19 patients and contact-persons' activities
Big data	<ul style="list-style-type: none"> •Be connected to national health information systems (HIS) and store data (mobility patterns) on a real-time basis for further analysis. This helps health policymakers to effectively monitor COVID-19 and allocation of resources •Raise awareness, education and communication •Support video conferencing activities
Blockchain technology	<ul style="list-style-type: none"> •Authenticate and validate COVID-19 patients before the provision of counselling services and administering patients' medication in quarantine facilities •Encrypt health data as it moves from one node to the other in a peer-to-peer architecture
5G Technology	<ul style="list-style-type: none"> •Increase bandwidth size, perceived quality of service and data transfer rate to ensure real-time access to data •Facilitates teleconsultation between healthcare professionals and COVID-19 patients and contact-persons

Table 2
Selected Approved Digital Contact tracing applications.

Contact Tracing Apps	Country	Tracing Technology	Description
TraceTogether App [22]	Singapore	Bluetooth technology (BlueTrace protocol)	The app provides little to no privacy for infected individuals; after an infected individual is compelled to release their data [22]. No privacy as Infection status is shown to all tokens, and all contact tokens revealed.
BeAware App [28]	Bahrain	Bluetooth and Global System for Mobile Communications technology	The mobile app that sends notifications and SMS messages to individuals who may have come into contact with active cases, requesting them to be tested. The app assists to contain the spread of COVID-19 virus.
CoronApp [29]	Colombia	Global Positioning System technology	It is a free app that facilitates real-time monitoring of COVID-19 data and helps to detect affected areas
COVIDSafe [15]	Australia	Bluetooth (BlueTrace protocol)	It is a contact tracing mobile application developed based on Bluetooth protocol called BlueTrace protocol to help to minimize the spread COVID-19 pandemic
Aarogya Setu [25]	India	GPS coordinates	The contact tracing app that stores details of contact-persons. Once the contact-persons test positive, the other people in contacts are alerted immediately and proactive medical interventions are administered
GH COVID-19 Tracker [30]	Ghana	GPS and GIS	The app uses geospatial data to track mobility patterns of the population
Stopp Corona [31]	Austria	Bluetooth technology	It is an open-source contact tracing app developed using Bluetooth technology to fight against COVID-19
HaMagen [15]	Israel	Bluetooth and GPS technology	It is a contact tracing app that notifies people about people diagnosed with COVID-19 and their close contacts with 14 days before the patient's diagnosis
StayHomeSafe	China	Bluetooth, GPS and WiFi	The contact tracing app is applied to self-quarantined people staying at home through.

app that uses mobile network operators and GPS coordinates to track patients who have tested positive for COVID-19 and who have chosen to undergo treatment at home has been implemented in Moscow [23]. The app is not yet rolled out nationwide, as some populace are monitored using digital travel permits. In the United States of America (USA) development of contact tracing apps is decentralized to states in collaboration with Apple and Google because of security and privacy issues [24]. Contact tracing apps in the USA are still at the pilot phase and not yet rolled out and connected to health systems [25]. With the growing number of COVID-19 cases and deaths, India launched the Aarogya Setu contact tracing app that uses mobile phones' Bluetooth and location data to track users [26]. India made it mandatory for government and employees to use the Aarogya Setu contact tracing app despite the security and privacy issues to boost contact tracing activities [26]. Instead of implementing contact tracing apps, Brazil adopted surveillance technology that uses geolocation tracking to minimize COVID-19 transmission chains [27].

Contact tracing is highly effective in the early control of COVID-19 but places a heavy burden on the health services because each case would require an average of 36 individuals to be traced. Cho et al. [22] also state that contact tracing apps are vulnerable to security and notions of privacy from snoopers, and authorities.

2.2. Challenges of integrating emerging technologies into COVID-19 contact tracing activities

While emerging technologies such as artificial intelligence, big data, Internet of Things, geographical information systems and mobile technology have been recognized as paramount technologies in developing COVID-19 contact tracing apps, their adoption in COVID-19 contact tracing is limited owing to the following challenges:

2.2.1. Asymptomatic individuals

Asymptomatic individuals transmit COVID-19 though they do not possess symptoms of the disease. This poses infection and control challenges yet their contribution is not well-known [32]. This means contact tracing emphasizing more on close contacts is unlikely to be sufficient unless clinical testing is done. Hellewell [14] state that contact tracing becomes less effective especially when dealing with asymptomatic individuals since symptom

checkers and apps rely on the pulse, temperature, and sleeping patterns.

2.2.2. Surfaced significant technical limitations

Setting-up contact tracing apps require highly skilled manpower to develop, deploy, configure, and maintain the system. Integration of blockchain API, BlueTrace protocol and other security algorithms requires experts to ensure that data is secured and encrypted. Such experts are scarce in many parts of the world.

2.2.3. Lack of supporting information and communication technology (ICT) infrastructure and electronic health policy

Integration of emerging technologies into health systems is still nascent in some countries. There are no guidelines or policy on electronic data protection in COVID-19 pandemic policy [20]. Countries like Chad and the Central African Republic with poor ICT infrastructure find it hard to deploy limited resources toward technological innovation as part of their COVID-19 pandemic response plan [33]. Also, setting-up health information systems as a response to pandemics including national health information systems, electronic health records and telemedicine require an ethical framework for digital epidemiology and technological interventions to boost trust and expedite the adoption of emerging technologies in health systems [34].

2.2.4. Socio-economic inequalities

Integrating technology into contact tracing activities requires internet connection and computing devices which can be expensive. Due to the digital divide and health-care disparities especially in developing countries, integration of emerging technologies into contact tracing might be threatened. Even in developed countries, high-risk groups might not have full access to broadband signals, smartphones, or wearable technology such as smartwatches [20]. To address this challenge, network service providers together with the affected government can zero rate COVID-19 contact tracing applications or reduce the cost of internet data or develop unstructured supplementary service data (USSD) based contact tracing applications that do not require internet access. USSD-based contact tracing apps can also assist people living in unnetworked rural areas to disseminate COVID-19 information and connect with health workers instead of excluding them.

2.2.5. Deactivation of mobile devices' WIFI, GPS services.

The existing contact tracing apps rely on Bluetooth protocols, WIFI and GPS technology to monitor movements of infected people and contact-persons. These technologies facilitate location-based services which can be interrupted by the proximity, heterogeneity of protocols, and spoofing of GPS signal. Since people have rights to configure their mobile devices 'connection settings, contact tracing apps might fail to track COVID-19 patients and contact-persons if they deactivate WIFI and GPS connection [20].

2.2.6. Interoperability and standardization issues

Contact tracing apps operate and embrace the Internet of Things concepts whereby data from COVID-19 patients and contact-persons is transferred immediately on real-time to the national health information systems. These contact tracing apps are custom-made and not standardized globally, which means each country develop contact tracing app that has its Internet of Things infrastructure, devices, APIs, and data formats leading to interoperability issues [35]. Interoperability issues include heterogeneity of networking standards and communication protocols, data semantics and ontology, data formats, diverse operating systems [36] and diverse programming languages among others. Data formats and structure should be standardized across all platforms to avoid incomplete and noisy data, thereby improving data quality. Therefore, contact tracing apps should be easily integrated into health information systems and facilitate real-time data sharing regardless of platform and communication protocols.

2.2.7. Security risks

Contact tracing applications violates COVID-19 patients and contact-persons' data security, confidentiality, integrity, availability of data and sometimes bridge ethical and privacy of patients which might cause mental health problems such as stress, anxiety, depression among other [18]. There is a great need to protect against health data loss and unauthorized access when implementing emerging technologies in tackling Covid-19. Most COVID-19 contact tracing apps such as *TraceTogether*, *COVIDSafe* and *BeAware App* support concurrent access of health data and remote monitoring of COVID-19 infected people and suspects in self-isolation (or in isolation centres), which poses serious security threats to public health data. Effective database management, including encryption and automated backup procedures, needs to be implemented to enforce data security. Also, Dubov & Steven [34] recommend health systems to store aggregated and anonymised data when the person test positive to COVID-19. Such information should be only shared upon granted ethical clearance and approval. These are the ways to protect data security.

2.2.8. Privacy issues

Tracking COVID-19 patients and contact-persons' activities could entail a breach of their privacy. Safeguarding privacy is the core concern of the health systems, however, an individual's privacy has not been considered in devising some contact tracing solutions. COVID-19 mobile apps impinge on people's privacy as they collect, analyze and have access to personal health data such as health behaviour, status, travelling history, household coordinates positions and location. However, privacy issues vary depending on the purpose and data types used by emerging technologies. For instance, Cho [22] states that contract tracing apps should enforce the privacy of data from snoopers, contacts, and unscrupulous health agencies. Enforcing privacy protects patients misuse while maintaining patients' confidentiality.

2.2.9. Political and structural responses

Obasola [37] states that lack of political-will and involvement of

state and local governments severely affects the adoption of electronic health interventions despite the influx of ICTs. In some developing countries, improving healthcare service delivery through integrating ICTs is not prioritized [38]. This could be attributed to cost associated with setting-up, integration, and maintenance of emerging technologies; intermittent network connection [39] and power outages as well as over-reliance on non-governmental organizations (NGO).

2.2.10. Ethical and legal risks

There are four types of COVID-19 digital applications namely; contact tracing tools, symptoms checkers, quarantine compliance tools and flow modelling tools; developed for pandemic management, quarantine control, tracking and contact tracing, symptoms testing, and flow modelling (track people's movements in specified geographic regions) [40]. These digital applications compromise basic principles and moral considerations of public health ethics and data ethics by providing little to no privacy for infected individuals; after an infected individual is compelled to release their data [22]. Such an act might pose ethical and legal challenges when dealing with people and their health data. For example, contact tracing tools track infected people and their close contacts for precautionary self-isolation. Gasser et al. (2020) also highlighted that Singaporean COVID-19 mobile app called *TraceTogether* uses Bluetooth connections to log other phones nearby and alerts infected person's close contacts about his/her COVID-19 positive status [34].

2.2.11. Symptoms checkers

Symptoms checkers such as smart and digital thermometers have been frequently used as symptomatic surveillance tools that collect, analyze, interpret, and disseminate health-related data, especially body temperature. Symptoms checkers are cost-effective methods of screening COVID-19 suspects during triage and disperse populations. Symptoms checkers such as *CoronaMadrid* symptom checking app allows the government of Spain to collaborate with medical professionals and citizens to remotely monitor and control COVID-19 pandemic [40]. Unlike Spain's *CoronaMadrid* symptom checking app, digital smart thermometers paired with mobile apps are enabling healthcare professionals to collect temperature data from people and provide real-time insights into emerging COVID-19 hot spots.

2.2.12. Consent and voluntariness

Contact tracing application should allow individuals to practice consent withdrawal. This occurs when a person voluntarily stop participating in data sharing [18]. Data sharing based on consent mitigate privacy risks. However, there are highlighted impediments associated with implementing consent procedures such as language barriers, lack of customizable contact tracing apps, lack of comprehension and absence of choice to deny consent [34]. Also, it is difficult to balance contact tracing activities with consent withdrawals. The more people practice consent withdrawal the more the risk of transmission chains. Therefore, there has to be a balance between consent withdrawal and COVID-19 containment.

2.2.13. Abuse of contact tracing applications

Since most contact tracing applications use GPS and Bluetooth technology, malicious users can use these technologies for stalking and unauthorized access to other files stored in the mobile device. Another challenge is that people share smartphone which might result in sending misleading information to health authorities and health workers. Therefore, contact tracing applications should incorporate gait recognition and other activity recognition methods that utilize biometric authentication [41].

2.2.14. Discrimination

Contact tracing apps pose a high risk of discrimination especially the affected populace. Specifically, IoT-based contact tracing apps collect data for the entire population on real-time which further analyzed to map COVID-19 hotspots. Such data can include, ethnic information (race, clan, region), demographic details (gender, age, level of education, marital status) and socioeconomic status which can influence the allocation and distribution of COVID-19 resources and ultimately lead to discrimination and riotous [42].

2.2.15. Digital divide

In some continents including Africa, the digital divide remains a challenge in many health systems [10]. The integration of contact tracing apps assumes that the whole population has access to modern technologies, yet the gap still exists between ICT access and utilisation amongst the population. For example, Jubie et al. [43] state that 51% of the world's population does not have internet access. This means that in some resources constrained areas, people do not have mobile phones, no or inconsistent electricity supply and access to network signal which makes the use of contact tracing apps threatened [44,45] and inevitable consequence of fuelling health inequality amid COVID-19.

3. Discussion

Many contact tracing applications rely on Bluetooth and GPS technology to track infected persons and contact-persons. These technologies have drawbacks, for example, the proximity of Bluetooth technology is very short which can be obstructed by buildings and walls hence affect its adoption rate. Also, Bluetooth technology consumes a lot of smartphone battery power. On the other hand, GPS technology is not secure and is vulnerable to spoofing attacks [43,44]. With the rapid increase of COVID-19 cases and deaths especially in severely affected countries such as the United State of America, Brazil, India, Russia and South Africa [45,46], integration of emerging technology into contact tracing activities is inevitable. However, security [48], privacy [51], consent, health policy among other issues should be critically observed in the development of contact tracing apps and data sharing stage.

4. Conclusion

Integrating emerging technologies into COVID-19 contact tracing is seen as a viable option that policymakers, health practitioners and IT technocrats need to seriously consider in mitigating the spread of coronavirus. Further research is also required on how best to improve efficiency and effectiveness in the utilisation of emerging technologies in contact tracing while observing the security and privacy of people in fighting COVID-19 pandemic.

Declaration of competing interest

None.

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