Towards QR Code Health Systems Amid COVID-19: Lessons Learnt from Other QR Code Digital Technologies

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Abstract The novel coronavirus disease (COVID-19) continuously crippling healthcare systems globally and disrupting movements of people which led to the temporary closure of schools, colleges, universities, industries, and businesses. To reduce the catastrophic impact of the new variant of COVID-19, governments in collaboration with World Health Organization (WHO) emphasize on vaccination of populations. However, several countries witnessed a rapid increase of new infections and deaths which are linked to relaxation of regulations, fake COVID-19 certificates, resistance to adoption of health digital technologies, overburdened health system, lack of personal protective equipment, social risk behaviors, poor policies and standards for immigrants and lack of standardized and synchronized regional and international health information system that facilitates the regular sharing of COVID-19 data, test results and vaccination certificates. Also, accessing COVID-19 data and patient health history data remains a challenge for many health systems. Therefore, we propose the use of secure regional and international quick response code-based health systems to monitor the migration patterns, validate COVID-19 test results and vaccination certificates to facilitate safe regional and international movement of people during the pandemic.

Keywords Quick response · COVID-19 · Health information systems · Digital technology

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1 Introduction

In December 2019, a new infectious respiratory disease emerged in Wuhan, Hubei province, China and was named by the World Health Organization as coronavirus disease 2019 (COVID-19) [1]. The outbreak of COVID-19 continues to burden health systems, globally, disrupting movements of people exacerbated by the temporary closure of schools, colleges, universities, industries, and businesses. As part of the response to reduce the catastrophic impact of COVID-19 and emerging variants, governments in collaboration with World Health Organization (WHO) implemented infection control and preventive measures such as social distancing, face masking, regular temperature checking, contact tracing, quarantine and self-isolation [2]. This follows enacted stringent COVID-19 restrictions and guidelines such as maintaining social distancing in public spaces, wearing of face masks, recursive national lockdowns, and regular checking of temperature in strategic entry points [3]. More recently, several countries started loosening travelling restrictions to allow the swift reopening of economic activities after the successful development of WHO approved COVID-19 vaccines [4], which subsequently intensified the vaccination of populations [5]. Unfortunately, some countries like India, United Kingdom and South Africa witnessed COVID-19 surge partially linked to relaxation of regulations [6], resistance to adoption and use of health digital technologies, overburdened health systems [7], social unrest, poor sanitation [8], poor adherence to COVID-19 preventive measures, poor vaccines efficacy, insufficient vaccines, fake COVID-19 certificates [9] and dearth of medical equipment such as the testing kits, personal protective equipment, masks, and ventilators [10].

To alleviate these impediments, several digital technologies have been implemented to monitor, trace, track people and enhance the implementation and adherence to COVID-19 infection control and preventive measures. Digital and emerging technologies such as big data, cloud computing, geographical information systems, Internet of Medical Things (IoMT), 5G technology, blockchain [11], artificial intelligence, Internet of Things (IoT) and fog computing have been adopted to develop social distancing applications (apps), contact tracing apps among others to fight against COVID-19 pandemic [12]. However, despite relying on emerging digital technologies, several countries developed varying applications for surveillance, screening, quarantine, and self-isolation which led to varying data formats, data management, security, and privacy. This has led to data synchronization and standardization problems [13] which subsequently affect international and regional sharing of COVID-19 data.

1.1 Contribution of the Study

COVID-19 brought transformative shifts in healthcare service delivery by integrating digital technologies to promote effective sharing of health information, remote monitoring, and virtual care. Among digital technologies, quick response code has been extensively adopted in developing COVID-19 contact tracing applications and vaccination certificates or immunity passports. This has been necessitated to alleviate issues emanating from paper-based vaccination cards. Notably, the authenticity and reliability of COVID-19 test results, immunity passports or vaccination certificates are vulnerable to forgery [14], counterfeits, issued corruptly and they can easily tear [15], get lost and potentially violate individual's privacy [16]. Despite all these challenges, vaccination certificates or immunity passports and negative-COVID-19 test results are slowly becoming mandatory for travelling, therefore, there is a need to synchronize, authenticate, sharing and provide remote access to vaccination information. In such circumstances, the adoption of QR code health systems amid pandemics like COVID-19 is inevitable. Such QR code health systems may be used to validate COVID-19 certificates and accessing COVID-19's patient history remotely as well as vaccination information and subsequently facilitate contact tracing and improve healthcare service delivery. Currently, individual's COVID-19 history data is not easily accessible regionally and internationally as people travel from one place to the other [17]. However, the recent advances in QR code technology in health systems could alleviate such impediments. Therefore, this study proposes the potential integration of quick response code in health information system to monitor the migration patterns, validate COVID-19 certificates and tracking people's COVID-19 health status to facilitate regional and international travel amid the COVID-19 pandemic. The study sought to address the following research objectives:

- Identify QR code-based applications deployed to tackle COVID-19.
- Identify digital technologies that could facilitate the integration of QR technology in health systems.
- Highlight compounding challenges, threats and impediments that could hinder the implementation of the QR code health system.

2 Related Work

2.1 Quick Response Code in Healthcare

Quick response codes are two-dimensional barcodes presented in black and white mosaic patterns that stores information read by smartphones or devices with in-built cameras [18]. QR Code carries data both horizontally and vertically, unlike barcodes which are in 1-D. This allows information encoded to be scanned in any direction, as well as enabling the storage of large amounts of information. Data can be restored even if the symbol is partially unreadable or damaged. QR code technology

to transmit information through its higher data storage capacity, lower implementation cost, technical simplicity, widespread use, and availability [19]. Access to the encoded information in QR code technology is through free programs and the decoding is done using camera-equipped smartphones. Authentication procedures are relatively easier to implement using QR code technology, which provides security to users against unauthorized access. Authentication can be done with the use of a password and a QR code encrypted string consisting of the International Mobile Equipment Identity (IMEI) number of a user and digital watermarking [20]. QR code technology can access information in offline print media such as posters, cards, signs among others. This allows the transmission of information from one source to another at any time, with minimal restrictions.

QR codes are not a new concept, but not yet widespread in the medical world, but it is gaining attention. Most recently, QR code has been used to develop contact tracing applications and to maintain social distancing [21]. Most recently, Australia implemented contact tracing applications based on QR codes [22]. In Myanmar, QR code technology is used to monitor its citizens' health status and be able to inform the public about accurate information concerning the coronavirus [23]. QR code technology by its nature implements social distancing as information can be encoded, and it only requires a user to have a smart camera-equipped phone to decode the message thus minimizing human interaction. In China, a quick response code system was implemented to develop an electronic survey to check individuals' symptoms and record body temperature to minimize physical contact and interaction time between healthcare professionals and patients [24]. In addition, in China, QR code serves as a COVID-19 health status certificate and travel pass, with colour-codes representing low, medium, and high risk; individuals with green codes are permitted to travel unrestricted [25], whereas individuals with red codes are required to self-isolate for 14 days. Thus, the implementation of QR codes in healthcare serves as a powerful solution in improving communication, transparency between healthcare providers, caregivers, and care recipients. Also, QR codes have been implemented in healthcare through education and training to increase participant engagement, promote just-in-time learning, simulation, and training support [26]. The increase of participants' engagement can be in the form of anatomy teaching, formative assessment, case-based learning. For instance, in the case of anatomy teaching, medical student's experience an anatomy specimen museum where QR codes are attached to a particular specimen and provide ease of access to additional contextual information.

2.2 *Application of Emerging Technologies for QR Code Apps in Healthcare Services Delivery During COVID-19*

a. Blockchain in QR Code technology

Blockchains are distributed digital ledgers of cryptographically signed transactions that are grouped into blocks, where each block is linked cryptographically to the previous one after being validated and undergoing a consensus decision [27]. This technology allows a decentralized environment or data management that has no central authority. It allows simultaneous secure transactions due to the use of cryptographic principles. Blockchain can be in the form of a record that continues to grow into a block, which is connected and secured using cryptographic techniques [28]. Blockchain technology uses both distributed ownership and distributed physical architecture involving a large set of computers. Distributed systems are used by several users, in which blockchain users can maintain their copy of a ledger (a collection of transactions in the blockchain). Its distributed design also means nodes are dispersed widely and geographically. However, a validation key is required in blockchain, to build a new block, there must be a reference to a previous block (how the actual blockchain is made), if a reference is not included in the new block, other nodes will reject it [29]. For instance, Cheng et al. [30] proposed a system that solves the problem of counterfeiting education certificates by creating digital certificate systems that were based on blockchain technology.

Blockchain and QR technologies have been used to develop applications in healthcare. For instance, blockchain technology has been applied to manage patients' medical data where each patients' data can have an audit trail of the permissions, authorization and data sharing between healthcare systems to ensure the integrity of medical data [31]. Patients' data are linked with their blockchain-based identity. Blockchain can also add security to data access for QR code-based applications to ensure security and improve remote access to medical data [32]. Blockchain can facilitate the data verification process on the data encoded on QR codes. QR code-based applications are structured almost same the way as the implementation of blockchain, and this is ideal for security in a transactional process of a decentralized and transparent network [33]. Although blockchain technology sometimes experiences some technical barriers related to data storage and distribution, data can be re-identified or compromised even though blockchain can encrypt data. The speed and scalability of a completely distributed system might be affected by blockchain [34].

b. Artificial intelligence in QR technology

This technology has the potential to improve hypothesis generation and hypothesis testing tasks within a system by revealing previously hidden trends in data. Machine learning expands on existing statistical techniques, utilizing methods that are not based on prior assumptions about the distribution of the data, and can find patterns in the data [35]. Also, Idrees et al. [36] proposed a navigation technique for the visually

impaired to efficiently move around indoors using QR codes to find both the optimal path as well as the shortest path to a destination deduced from the current location the user might be in. QR codes have also been used as artificial landmarks where it exists as a localization system for mobile robots. For example, smart wheelchairs for indoor navigation and these landmarks are detected by a webcam oriented to the ceiling, each QR code contains the coordinates of the landmark in the working environment. QR-code-based positioning is a push service rather than a pull service, thus, the user and application ask for a position whenever needed rather than being constantly tracked [37]. The QR codes are affixed to a landmark where mobile phone users can scan and access data.

c. 5G technology in QR code-based apps

5G technology is the current evolution of wireless connectivity, which uses microwave frequencies to accommodate many simultaneous users [38]. 5G is characterized by low latency, high speed, enhanced high-resolution bandwidth, superior reliability, and less energy consumption. The speed of 5G is about 10–30Gps, while 4G is 300 Mbps. 5G latency is said to be as low as 1 ms [39]. 5G allows an increasing number of remote-end applications that requires a communication network powerful enough to connect patients, healthcare professionals, medical equipment, and information sharing effectively. This can enhance the decoding and redirection of QR encoded information, this means retrieval and access to information on the internet would be fast for QR code-based systems due to the connection speed. 5G technology capability to connect devices remotely at a high speed, has enabled medical devices to become real-time connected devices used in different sectors in the health systems, such as wearable sensors to remotely monitor COVID-19 patients [40]. 5G has made it possible for virtual devices and virtual systems in health care, connected to the cloud to help patients with their treatments in real-time in things such as rehabilitation, remote operations as well as diagnosis. Immersive data traffic and system configuration, through high-speed technology, speeds up the process of decision making and location access. For instance, in China, 5G technology significantly transformed its response mechanism to the COVID-19 pandemic by providing better assistance to the frontline staff and facilitating improved virus tracking, patient monitoring, data collection, analysis and health care services [41]. Health care services delivered through 5G technology in China include online surveys, QR code prevention and control apps [42] as well as online mental health services to manage psychological health problems such as anxiety and depression, home delivery services and services for patients with chronic diseases [43].

d. Internet of Things (IoT) in QR code-based apps

The Internet of Things is defined as a scheme of interconnected computing tactics, digital, and mechanical devices possessing the capability of transmission of data over the defined network without having any human involvement at any level [44]. The IoT gateway utilizes security tokens to authenticate devices and services. Since QR technology is widely used for the authentication of users, IoT has the capability of encrypting transmitted data between the devices and IoT gateways and from

there to the cloud. These devices capture, monitor, and transmit data to a public or private cloud to facilitate a new level of convenient and efficient automation [45]. IoT supports secure authentication between the scanning device and the device being scanned through QR codes. Since QR code is used to transmit encoded information. IoT facilitates such devices to share information via a wireless connection through the QR code-based mutual authentication protocol for the Internet of Things [46]. During COVID-19, there are several QR code-based applications deployed in the IoT environment to tackle the pandemic. For instance, QR code-based system, e-Class system was developed and deployed in IoT setup to ensure that students attend classes consistently, as well as keeping track of student academic performance [47].

e. Internet of Medical Things in QR code-based apps

Internet of Medical Things (IoMT) has been utilized for collecting diversified types of emotional and physical health-related data using smart wearable devices. Such smart sensory devices have been significantly used to remotely collect patients data such as body temperature, blood pressure, motion, and blood glucose during the COVID-19 pandemic [48]. These devices use sensors such as ECG sensor and EEG sensor to perform multiple functions including tracking COVID-19 patients [39], remote health monitoring and exigency warning [49]. In Japan, Hong Kong and Singapore hospitals have adopted the QR code technology where patients' data and hospital location are encoded in a QR code printed on a wristband [50]. Test tubes, medical equipment and drug packages, prescriptions are printed with QR codes for authenticity. In China, QR code-based health system was developed and first used in Hangzhou as an electronic voucher to grant permission for an individual to enter or exit a populated public space as well as permission to move from one area to the next within the region [51]. However, the implementation of the health QR code has increased the risk of social isolation with the population of China considered as old people [52]. The system relies heavily on smartphones which probably leave out older people without access to smartphones. Another QR code system that has been prominently used in China is the symptom checker. Each QR code (for an individual) is a health status certificate that is color-coded to serve the purpose to easily identify a person that should be in quarantine or isolation facilities [25].

f. Big data in QR code-based apps

Big data are complex data sets that traditional data processing systems cannot efficiently and economically store, manage, or process. Big data technology supports variety of healthcare services such as health data collection, disease monitoring, developing clinical decision support systems, and health management [53]. In the context of COVID-19, several digital tools including contact tracing apps and smart wearable devices continuously collect a vast amount of health data that could be used for mapping purposes, visualization, and most importantly, for effective decision making. For instance, big data together with computational algorithms have been used for modelling virus transmission, aiding infection control measures and emergency response analyses required during local or international disease outbreaks

[54]. QR technology has been used to develop vaccination certificates or immunity passports as well as contact tracing applications that generate massive data for aiding infection prevention and control measures in many countries including China, Taiwan, New Zealand and South Africa [11, 55].

g. Fog computing in QR code-based apps

Fog computing is an architecture that brings closer to the end-user the distribution of computation, communication, control and storage services [56]. This technology is based on remote cloud servers that are used to store and process large data collected from sensor nodes. Fog computing acts as an intermediary between cloud computing and end-users. It provides storage and computing services closer to end devices for real-time analysis. Fog computing's latency can enhance QR code's real-time processing because of instant access of services to end-users, while cloudlets enable improved privacy and reduced latency, bandwidth, scalability, reliability, and energy efficiency [57].

3 Issues Around the Use of QR Code-Based Apps in Healthcare Service Delivery

As mobile technologies increasingly becoming ubiquitous and pervasive, the adoption of QR code technology increases rapidly. This is evident by the adoption of the QR codes which grows rapidly during past years and the number of users increases exponentially, due to its features like high data storage capacity, fast scanning, error-correction, direct marking, and ease of use. Quick response technology has been adopted in various application domains including medical education and training [26], digital payment systems, digital marketing, and healthcare applications. For instance, QR code has been used to store case histories in maxillofacial radiology [58], safer use of medications by elderly patients [59] and patient instructions following orthopaedic cast application [60]. However, QR code is not immune to security threats and other factors that influence their adoption. There are several factors influence how the public accepts or refrain from using QR code-based apps. These factors include the adhesion of the population, regulatory policies, digital inequality, and ethical issues [61]. Acceptability depends on how leaders mobilize the new knowledge acquired with the shift in technological advancements to fight COVID-19.

a. Data Regulations

Concerns such as whether COVID-19 related data collected using QR code-based apps during the pandemic will be deleted or kept for other purposes after COVID-19 raises issues pertaining to regional and international health regulations [62]. This calls for a clear, legal and regulatory policy as well as frameworks for regional and international health data sharing post-COVID-19. However, the data captured during

the pandemic can be used in future for developing robust and feasible health solutions to prepare for other pandemics in the future. Data regulations should specify data ownership, security, standards, format, and storage (centralized and decentralized) [63]. For instance, in centralized applications, data is collected, pseudonymized and send to a central database managed by an administrator or agency [64]. The decentralized application, however, makes use of users' storage to keep the collected data. Liability between the two is the access to the information, for example, the centralized approach means data is "owned" by or rather goes through the agency with which it is stored. In such circumstances, strict transparency about where the data are drawn from, public scrutiny of the process, and strong legislative protections against misuse like in South Korea [65].

b. Scalability

In the post-deployment of the QR code-based system, some parameters determine the scalability of a system. These can be summarized as; the number of users adopting the system, adding system features as well as system performance under severe workloads. These parameters summarize things like traffic, the number of computations done on both users' phones and the backend upon QR code requirement. Amid COVID-19, the system needs to be highly scalable to incorporate adding features, for example, some countries improved contact tracing apps to generate vaccination certificates or immunity passports [66]. If a system is not used or adopted, it is rendered as not scalable to the public and/or to users. Users adopt a system that has been reviewed as secure, therefore, scalability is also dependent on technical limitations such as highly skilled manpower to ensure data security and encryption while developing, deploying, configuring and maintaining a system [13]. A system should win users trust in terms of usability and privacy protection [67].

c. Security and privacy

QR codes require data encryption to ensure data protection and security. The fact that devices communicate through codes generated rather than the actual transmission of data is an upside for security reasons related to QR codes. Moreover, humans cannot read the code or decode it by simply looking at it, they can only get access to the information through QR code reader software. However, QR codes can be manipulated and compromise the security of data encoded in the code through phishing, fraud, and attacking the reader software [68]. QR code manipulation can be used to redirect users to sites or information and possibly tamper with the integrity of data encoded in the QR code leading to vulnerabilities and malicious attacks [69]. Also, the interconnectedness of digital solutions makes the systems vulnerable to passive and active attacks. Therefore, security standards, data and communication link encryption should be clearly defined to ensure data confidentiality, integrity and availability of the systems. Also, data standardization and health data protection should be clearly defined. Regulators should encourage the development of consent-based QR code-based digital solutions such as COVID-19 contact tracing apps, immunity passports and digital vaccination certificates that can be accessed in a secure, verifiable, and privacy-preserving way.

d. Policies and regulatory frameworks

The adoption of QR code-based health apps could be affected by different health policies and regulatory frameworks and policies in different countries. The absent framework, global standards and policies guiding the international and regional integration and synchronization of digital solutions for sharing of COVID-19 health data [9] such as vaccination certificates retards the adoption of QR-code systems in healthcare. There is a need for setting up global standards as a roadmap to guide the development and deployment of effective digital solutions in case of public health emergencies such as COVID-19. Regional and international regulatory authorities should be involved in public and private sector initiatives, policies, guidelines and develop a framework guiding the implementation of COVID-19 digital certificates. Regular consultation with end-users, governments, and technology solution providers through regional public–private sector initiatives.

e. Technology

There is a huge technological gap between developed and developing countries in healthcare services delivery through digital health technologies [70]. The digital gap is exacerbated by various factors including low budgetary support [71], lack uniform and regular funding for technological innovations and robust e-health policies [72]. This may affect scalability, interoperability, data management of health data at the regional and international levels. To alleviate some of these challenges, there is a need for private and public partnerships and investments to improve technological infrastructure.

4 Ethical Issues Emanating from QR Code-Based Applications

Digital applications linked with the recent combat against COVID-19 have posed ethical and legal challenges to suspected and infected individuals [13]. Tracking the population's location data has fed into insecurities that the public has in mass surveillance, which could lead to ethically unjustified measures and stigmatization [61]. However, the QR code health system is not immune to ethical issues such as security, privacy, monitoring, over-surveillance, and discrimination. Surveillance of individuals has been a major issue, since the advent of highly individual and contextualized surveillance methods during public emergency [73]. For instance, the use of contact tracing apps and issuance of COVID-19 vaccination certificates pose considerable scientific, practical, equitable, ethical and legal concerns. Among other challenges, the issuance and sharing of COVID-19 data raised ethical concerns since data will be accessed by many regulatory authorities in various jurisdictions without predefined international standards and regulations. This may violate ethical values such as honesty, truthful consent, transparency, security and privacy. Therefore, the use of QR code apps (contact tracing and vaccination information) in health systems

raises the following ethical concerns such as; will the privacy protection of people be guaranteed? and COVID-19 data collected through QR code-based contact tracing apps and vaccination certificates, or immunity passports be used for their intended purpose?

Due to the existing socio-economic disparities among different populations especially in developing countries affect the adoption and rolling out of digital technology to tackle COVID-19 due to poor internet connection and speed, infrastructure, and computing devices. Disadvantaged communities might not have access to QR code-based apps because of the digital divide. Rolling out of COVID-19 digital solutions should not assume that the whole global populations have universal access to digital technologies, yet the gap still exists between technology access and utilization among vulnerable populations [73]. Thus, socio-economic inequalities contribute to healthcare disparities.

5 Conclusion

Quick response technology has been gaining attention and adopted in many disciplines from education, banking and finance, and recently in healthcare services. Therefore, it seems that it is quite promising in health and solves many issues to do with authentication and security of patient data as well as patient data distribution amongst stakeholders. From the discussion done in this chapter, it seems very possible that the QR code technology can be applied in health information systems to monitor the migration patterns of people, validate COVID-19 test results and vaccination certificates. However, care and measures should be taken into consideration to avoid misuse and protect users' data. Future work should focus on developing feasible digital tools to cater for feature phones and most importantly, alternative ways of providing services to the populace without access to digital devices is required.

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