A QR (quick response)-based Telemedicine Framework for Sustainable Containment of COVID-19: Evaluation of an Approach Assisting Returning to Normal Rhythms

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Abstract

We discuss a framework of Telemedicine using symptom-based quick response (QR) codes to contain the spread of coronavirus disease (COVID-19). The approach can be effectively deployed as a uniform platform interconnecting a variety of responders (e.g., individuals, institutions, and public authorities) affected by the pandemic, which minimizes the errors of manual operations and costs of fragmented coordination. In the meantime, it enhances the promptness, interoperability, credibility, and traceability of telemedicine. The proposed approach provides a supplemental mechanism not only to manual control measures but also to extant digital telemedicine partially failing in these facets. The deployment of the approach in a setting with nearly 40 million population has gained sizeable effects of containment and played remarkable roles in shifting the negative Gross Domestic Product (GDP) 6.8% to be positive by July 2020. The cumulative cases there were 363, of which 361 recovered (recovery rate 99.4%) as of July 12, 2020. The simulation shows that when only partial measures of the framework were followed less rigidly, the cumulative cases of COVID-19 would potentially increase ten-folds in magnitude. The approach can serve: (1) as a reliable solution to counteract the emergency of public health crisis; (2) as a routine tool to enhance the level of public health; (3) to accelerate the recovery of social activities; (4) to assist better decision making for policymakers; and (5) as a sustainable measure allowing for scalability.

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Viewpoint

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Abstract

We discuss a framework of Telemedicine using symptom-based quick response (QR) codes to contain the spread of coronavirus disease (COVID-19). The approach can be effectively deployed as a uniform platform interconnecting a variety of responders (e.g., individuals, institutions, and public authorities) affected by the pandemic, which minimizes the errors of manual operations and costs of fragmented coordination. In the meantime, it enhances the promptness, interoperability, credibility, and traceability of telemedicine. The proposed approach provides a supplemental mechanism not only to manual control measures but also to extant digital telemedicine partially failing in these facets. The deployment of the approach in a setting with nearly 40 million population has gained sizeable effects of containment and played remarkable roles in shifting the negative Gross Domestic Product (GDP) 6.8% to be positive by July 2020. The cumulative cases there were 363, of which 361 recovered (recovery rate 99.4%) as of July 12, 2020. The simulation shows that when only partial measures of the framework were followed less rigidly, the cumulative cases of COVID-19 would potentially increase ten-folds in magnitude. The approach can serve: (1) as a reliable solution to counteract the emergency of public health crisis; (2) as a routine tool to enhance the level of public health; (3) to accelerate the recovery of social activities; (4) to assist better decision making for policymakers; and (5) as a sustainable measure allowing for scalability.

KEYWORDS

COVID-19; coronavirus; symptom-based; quick response; eHealth; digital health; telemedicine; pandemic; epidemic; interoperability

Introduction

The coronavirus disease (COVID-19) caused by Severe Acute Respiratory Syndrome Coronavirus 2(SARS-COV-2) has identified millions of confirmed cases and hundreds of thousands of deaths worldwide since the first cases were officially reported in December 2019 and thereafter it was declared as a global pandemic by WHO (World Health Organization) [1]. The negative impacts of COVID-19 are unprecedented and pervasive at a variety of levels, extensively spreading from individuals, institutions to public authorities. For individuals, in addition to being a crisis in physical health, COVID-19 has also substantially affected mental health as evidenced by the growing amount of consultations regarding psychological stress, anxiety, and depression [2]. Prior research shows that the ratio of the population concerned about symptoms, prevention and therapy, and psychological problems during COVID-19 epidemic consists of 65%, 15% and 11% respectively, which claims at a commensurate level compared with the past outbreak of Severe Acute Respiratory Syndrome (SARS) pandemic [3,7]. Further, the pandemic has caused remarkable fells in GDP for many economies, and thus firms need to employ measures to resume production and survive unexpected disasters in the future [4]. Absent credible and traceable information, it would be of dilemmas for governments to make coherent and accurate decision making [5]. Lifting the lockdown of COVID-19 is an enormous challenge as in the absence of effective screening and isolation aided by digital health, the second-wave outbreak of COVID-19 cannot be precisely predicted contingent on present scientific understanding [4,6]. Subclinical infection through asymptomatic and pre-symptomatic transmission unnoticeable to individuals in close contact and delays in sharing of knowledge complicates the trajectory of the outbreak, causing the pandemic a longer time to settle down [7,8]. The curve of the first-wave outbreak would flatten followed by the sizeable reduction in new infection, which promotes the opportunity to reopen the economy [8,24]. However, even workplaces renew the interrupted production, doubts cast over whether it is feasible to sustain the same pace as it was prior to the outbreak. Given the infectiousness of COVID-19 and the dynamics of high subclinical transmissions, controlling the epidemic by mere manual contact tracing is less effective and infeasible. WHO forecast that the pandemic was still at its early stage, which necessitated the long-term efforts in combating with COVID-19. Hence, solutions to these challenges are of concern to individuals, firms, and public authorities struggling to return to normal rhythms [9].

A range of measures has been employed to contain the spread of disease during the current COVID-19 and past pandemic by exploiting the digital health approach [10-19]. These control measures have proved the efficacy for plenty of countries in productively depleting the first-wave outbreak of COVID-19, of which contact tracing is considered as the centerpiece of containment and attracts a great deal of attention. It involves identifying, quarantining, and alerting contacts of infected individuals [12]. Some countries that ceased contact tracing due to high prevalence are currently reinstituting this strategy to curtail the potential impact of the second-wave outbreak [10]. However, contentious issues facing contact tracing apps are characterized by the debate on which deployment framework (i.e., centralized versus decentralized) and sensor technology (i.e., Bluetooth, GPS (Global Positioning System), and QR) can better address critical challenges such as effectiveness and sustainability of containment. Centralized architecture mostly complies with the Pan-European Privacy-Preserving Proximity Tracing (PEPP-PT) and personal data is collected for public control. In contrast, decentralized approach mainly follows the Decentralized Privacy-Preserving Proximity Tracing (DP-3T), consequently, private information is not collected and inference of exposure is constrained only to local devices [15]. Nevertheless, even in the decentralized framework, a centralized database accommodating at least the infected is of necessity for reliability guarantee. Hence, essentially the concept of decentralization is only partially tenable [13-15]. Decentralized systems mostly do not fetch sensitive data of users such as locations and permission of sharing is requested for the sake of privacy-preserving. They hinge substantially on peer-to-peer self-report of a trustworthy status to the peer network, thus high participation of the population is of essence to meaningful containment. This mechanism may not completely address all likely routes of transmission between individuals even with full participation accounting for potential delay in knowledge sharing [15]. The decentralized Bluetooth framework recently co-provided by Apple and Google supports privacy-preserving and provides users with anonymized contact exposure and guidance of response if the risk is identified. However, as the non-identifiable data is either changed or deleted periodically, traceability of the outbreak is jeopardized. Second, the definition of close contact is rather flexible, therefore the detection precision of exposure might differ in different settings. Third, globally only around one-quarter of smartphones are compatible with the Bluetooth standard required by Google and Apple, which inevitably inhibits the effectiveness [13-15]. The latest rebounding of confirmed cases in Japan has witnessed the fragility of the Bluetooth framework [1]. On the other hand, extant contact tracing apps collecting GPS to identify exposure improve the credibility of data. It supports evidence-based decision making but raises other concerns. The first is that location is a mere close proxy for but not equal to contact, therefore the contact inference based on GPS data could generate confusion for the public due to bias in technical precision. The second is how to curb misuse and unauthorized access to sensitive information [15,18].

Beginning with contact tracing, telemedicine has become more sophisticated, covering the technologies from tele-surveillance, telecare to triage (e.g., sorting of patients). Although the aforementioned tools and technique may remarkably enhance the current capabilities of containment and reduce the spread of COVID-19, a broader framework is needed to increase its effectiveness through the integration of existing digital health [11,12,15,16]. Negative impacts of COVID-19 on physical health, mental health and social rhythms are dramatic and far-reaching, hence individuals, institutions and public authorities urgently need integrated guidance and delay-free information that can safeguard the well-being of the public and assist them with a smooth transition back to work and normal activities [17]. The lack of an inclusive repository with a uniform structure causes repeated failures for extant telemedicine. Compared with the GPS-based approach, symptom-based QR telemedicine does not identify the location details of users and thus the vulnerability inherent to the former can be waved. Further, credibility and traceability can be enhanced relative to the self-report mechanism used in the Bluetooth approach [15,17,18].

Different from location-coupled QR telemedicine, here we evaluate a symptom-based QR framework addressing the disadvantage of GPS and Bluetooth. The major aim is to appraise how the approach can serve as an urgent countermeasure against the COVID-19 crisis, as well as a routine tool used to guide daily activities in workplaces, travel spots, and communities back to normal rhythms.

Core Concept and Framework of the Tool

Features for Individuals

The first crucial concept used in the approach is symptom-based QR health codes issued by public health authorities. The codes do not pick up location data of users, instead, two colors are supported to differentiate the health status of individuals. The images of the QR codes are illustrated in Figure 1. Green denotes not being infected with COVID-19 according to polymerase chain reaction (PCR) test record and thus the individual passes the health verification. In contrast, orange signals one is either being infected or the likelihood of being infected is high, which can be stratified into the scenarios listed below:

(1) COVID-19 infected.
(2) Close contact of the individual in (1).
(3) Come from regions where the infection rate of COVID-19 is high.
(4) Resident of a community under strict public surveillance due to severe infection there.
(5) Presence of record with high fever within the past 14 days.
(6) Presence of record indicating the purchase of anti-fever medicine within 14 days.

Figure 1. Color schema of QR code.

(A) green QR code (B) orange QR code

The QR codes are officially regarded as the e-certificates of individuals' health status. The information of codes is automatically read and analyzed by QR scanners. The core notion of the design is to enhance the credibility of data, speediness of processing, and to reduce errors of manual operations.

The second is the synthesis of critical features including contact tracing, exposure risk self-triage, self-update of health status, healthcare reservation, non-contact psychiatric consultation, and QR codes for other family members. The platform also coherently merges health insurance and prescription service, which reduces the costs and delays of operations for users.

Features for Institutions

The approach consolidates features that can assist firms with early and automatic case screening and flexible social distancing based on QR information. This avoids cross-transmissions between workers and guarantees smooth resumption of production at the normal rhythms. Each worker can double-check the health colors (no other private information is shared) of other colleagues in concern, which lowers systematic mistakes of mis-surveillance. The accounts of QR scanning sites are configurable and scalable. Firms can choose to report local statistics to public authorities for subsequent analysis. Coupled with proximity detection techniques, it can offer to alarm the scenarios of potential close contacts. Managers can thus set up a flexible and corrected threshold to implement automatic reminders of social distancing when science gains updated knowledge on the disease.

Features for Public Authorities

The approach can help policymakers perform more effective decision making and public surveillance. The accounts of QR scanning sites at travel spots are administered by public authorities. Any individual needs to present the QR code to use public transportation systems such as buses, railways, or airports. The summary at each site is synchronized with public authorities for general analysis.

The QR-based uniform design increases the seamless synergy amongst individuals, institutions, and public authorities and reduces the delays in information processing and transmission. In Table 1, we illustrate the core concept and potential scenarios of implementation. Figures 2-3 present the brief diagram and screenshots of the approach respectively.

Table 1. Concept of the QR-based framework.

Concept	Subject	Descriptions
Products		
	Individuals	Mobile-based app (iOS and Android)
	Institutions, public authorities	Web-based platform (Windows)
Scenarios		

	Individuals	Fetch E-certificate of health status
		Update health status dynamically
		Self-triage of exposure risk and self-isolation
		Contact tracing of past potential exposure
		Non-contact healthcare reservation when infected or suspected of being infected
		Apply QR for other family members
		Consult remotely on psychiatric care
	Institutions	Surveillance on the health status of employees and close contacts
		Set up automatic alerts of social distancing
		Mutual surveillance between employees
	Public authorities	Issuance and administration of QRs
		QR-based travel control
		QR scanning accounts management
		Statistics and outbreak inference
Strengths		
	Participation	Equity of access and high participation
	Costs	Reduce costs of manual operations and cross-platform synergy
	Errors	Reduce errors of manual operations
	Others	Sustainability and scalability

Figure 2. Diagram for the QR-based approach integrating features critical to individuals, institutions, and public authorities.

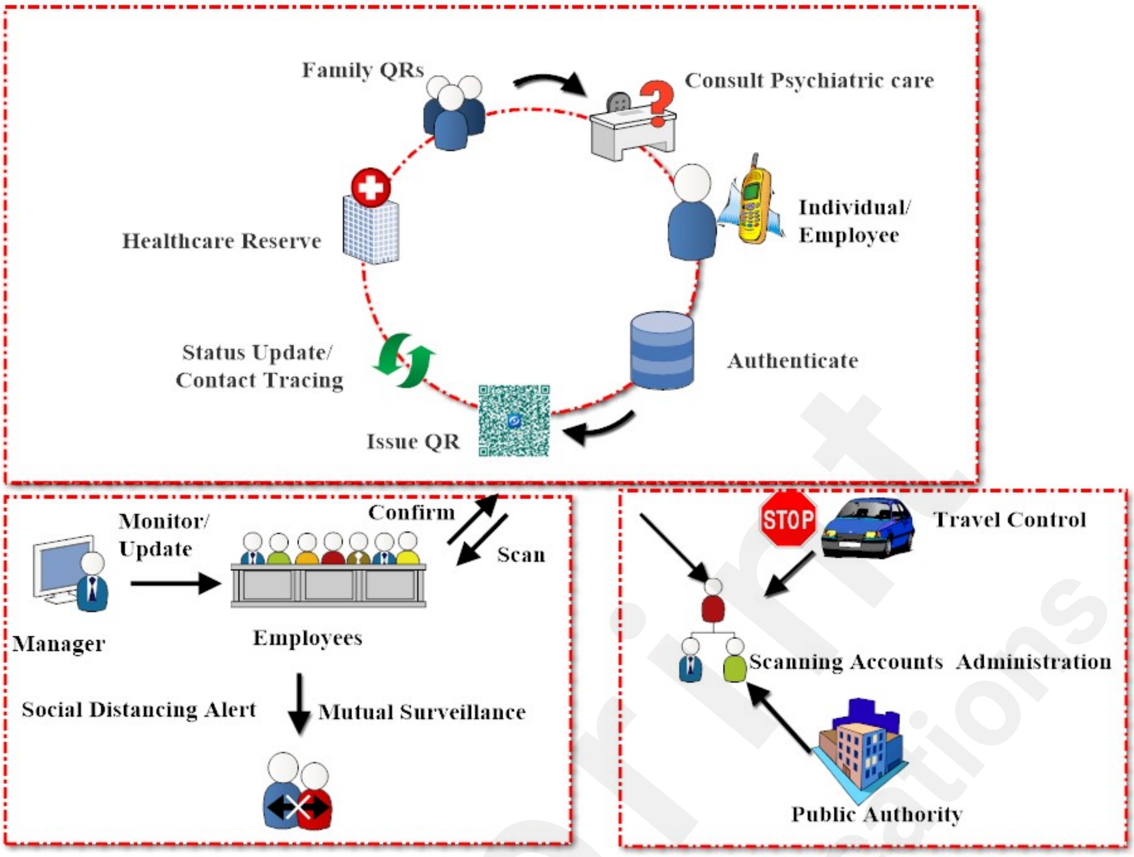


Figure 3. Mobile screenshots of QR-based approach for individuals.

(A) QR code Tracing (B) Health Status Update (C) Risk Self-triage (D) Contact

(E) Healthcare Reserve (F) Apply QR of family members (G) Psychiatric Consultation

Quantitative Analysis of the Effectiveness

The decision to apply a cross-platform approach of surveillance and how best to integrate discrete components into a uniform health system requires evidence of its effectiveness in practice, with particular scrutiny on the context where it is to be deployed [3].

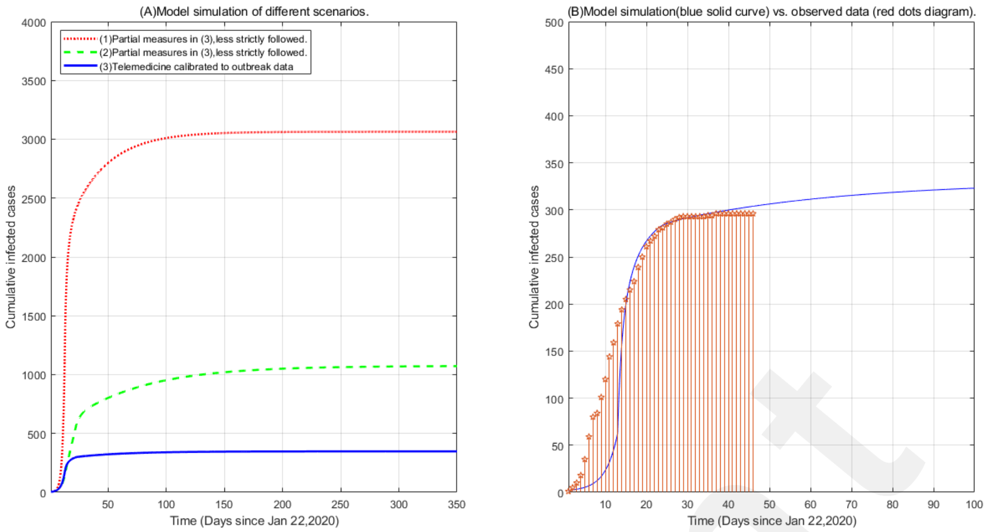
Since the spread of COVID-19 established, the tool has been formally deployed in Fujian, a province located in South-East of China with a population of nearly 40 million by late June 2020. All individuals aged three or older were officially requested to present the QR codes in daily public activities such as the use of public transportation systems, working at institutions, and entering/exiting schools. Almost 5 million individuals left Wuhan, the epicenter of the COVID-19 pandemic in China when the outbreak established. About one-third of those individuals traveled to other regions like Fujian province [20]. With the app in use, by July 12, 2020, the cumulative cases of COVID-19 positive were confined to 363 individuals, of which 361 individuals in total recovered from the disease. Only one patient died and one patient remained COVID-19 positive at that point. It has gained meaningful effectiveness of containment through a strict strategy of centralized control and extensive deployment of the tool. The latest data shows that since the outbreak started, the provinces' GDP in China including Fujian fell to negative 6.8% in the first quarter of 2020 due to nationwide lockdown. However, contributable to the gradual lifting of lockdown and reopening of production, the GDP bounces back to be positive by July [4].

In Figure 4, we deployed the model introduced in [21] to simulate the heterogeneous epidemic evolution of the COVID-19 outbreak in Fujian using the data published by Johns Hopkins University [22]. The epidemiological mean-field framework sketched in [21] captures the average effect involving the whole population, which extends the classical Susceptible-Infected- Recovered (SIR) model and evaluates more complicated disease transmission scenarios partitioned into eight stages of infection including susceptible, infected, diagnosed, ailing, recognized, threatened, healed and extinct. The status of each stage is determined by the interactions among different adjacent stages. The core concept hinges on the deliberation that subdivided models enhance the accuracy in portraying the dynamic spread of COVID-19. It estimates how progressive countermeasures would affect the spread of the pandemic. The system is manifested to correctly delineate the dynamics of the epidemic and is suitable in the prediction of containment measures with varying strength and nature. The simulation denotes that restrictive social-distancing measures need to be effectively combined with contact tracing and other countermeasures to deplete the spread of COVID-19. Assumptions of the model are depicted as follows:

(1) The presence of mutually exclusive stages of infection.
(2) The likelihood of being susceptible again after recovering from the infection is negligible.
(3) The distinction between non-diagnosed and diagnosed individuals.
(4) A delay in the emergence of symptoms.

We calibrated the model to the Fujian outbreak data starting from January 22, 2020, when the first case was identified there (see Figure 4(A) blue solid curve, and Figure 4(B)). The curves in Figure 4(A) denote the cases where the features of digital health in our framework are adopted in chronological order to counteract the spread of disease up to a one-year horizon. The imposed countermeasures include: (1) social distancing including workplaces and mutual surveillance between workers is followed since day 2; (2) thereafter contact tracing of the individuals in close contact with the infected is appended starting day 12; (3) further, contact tracing of individuals with a record of high fever and record of the purchase of anti-fever medicine is added on day 22; (4) finally, non-contact psychiatric consultations and travel control are followed. Comparatively, these measures might be employed simultaneously in practice. The blue solid curve (Figure 4(A)) corresponds to the approach utilizing all the above four measures. The simulated cumulative cases amount to nearly 350 cases by July 2020, which is close to the observed outbreak data in practice. The red dotted curve indicates the case where (1) and (2) are followed but in a less strict way, of which the cumulative cases would increase almost ten-folds to 3100 half a year later. In contrast, the green dashed curve implies the case where more looser measures of (2), (3), and (4) are followed. This scenario causes about three-folds growth in the cumulative cases to 1100 cases by July. Hence, the strict deployment of the merged measures has remarkably contained the spread of COVID-19.

Figure 4. Simulation of heterogeneous countermeasures during COVID-19 outbreak.



Strengths and Limitations of the Approach

The centralized approach is distinct from other decentralized models in three paramount ways. The first is attributable to the integration of features that are of importance to the concerned population in one identical platform, which is pivotal when combating with high contagious diseases as delays of data sharing can deteriorate the spread of COVID-19. Tools used at the individual or public authority level might not respond timely and accurately to the needs at the institutional level. The collective provision of features oriented for a wider range of users promotes broader applicability of the platform. In lieu of spontaneous self-report mostly used in decentralized frameworks where the agreement of individuals is requested, this approach affirms waiting-free high participation. As delays and misinformation are still of public concern, this responds to the urgent need of a uniform framework internalizing various sources of corroboration and efforts. Second, the tool facilitates the self-triage for individuals and self-scheduling for institutions. Hence, the load balancing of the pressure on the overburdening healthcare system is plausible. It also prevents unnecessary and risky in-person visits. Third, attributable to the performance in interoperability, credibility, and traceability, it can play valuable roles both as the emergent and routine tool to counteract COVID-19.

Several concerns need to be addressed to ensure successful implementation. First, it is of importance that no malicious or unauthorized utilization of the QR data emerges. Second, for economic settings where the general population is highly sensitive to privacy-preserving, the acceptance of this approach will be compromised and thus the effect of containment needs to be closely observed.

Illegal or unauthorized use of healthcare information is detrimental at a variety of levels [23]. Reports forecast that this can cause an average financial loss of nearly 7.13 million U.S. dollars globally in 2020 [24]. Unlawful use of data can damage the reputation of service providers and negatively impact the confidence and health of patients. The Harris study targeting 1527 individuals finds that 8% (i.e., 123 out of 1527) of the respondents refrained from participating in health programs due to reduced confidence in the quality of data protection [25]. Another research conducted in 3959 individuals suggests that unauthorized use of patients' information will increase the likelihood of negative perceptions and responses. It finds that almost two-thirds (i.e., 69.8%, or equivalently 2764 out of 3959) of the participants expressed security-relative concerns that impeded the subsequent healthcare interventions and interactions [26]. The simulation performed at Oxford University implies that digital contact tracing interventions would forfeit the potential to substantially contain the spread of COVID-19 when the population uptake rate reduces to lower than around 60% (600,000/1,000,000) even if deliberately implemented alongside other countermeasures [27].

Conclusions

The framework in this study has substantially controlled the spread of COVID-19 in Fujian since the first case was officially reported in Jan 2020, where almost 40 million of population reside. Out of the reported 363 cumulative cases, 361 recovered (recovery rate 99.4%), one patient deceased (mortality rate 0.3%) and one patient remained COVID-19 positive as of July 12, 2020. Attributable to the early deployment and rigid implementation of the approach, it has successfully helped transit the GDP from negative 6.8% to be positive by July. Firms have succeeded in resuming to normal production gradually without sacrificing the effective containment. The tool has assisted the public authorities with effective containment and travel control. The model simulation shows that if the partial measures were followed less rigorously, the likelihood of confirmed cases would increase, leading to multiple times of growth in cumulative cases of COVID-19. The credibility, interoperability, and sustainability empowered by the design would make the long-term containment of COVID-19 feasible. Digital health is one of the principal factors contributing to the success of containment, however, it cannot solve all the challenges the world is facing presently [3]. The convergence of COVID-19 diagnostics and treatment provides opportunities to deliver potentially disruptive technologies to drive the development of integrated health systems. These should increase accessibility to contain the pandemic while improving the promptness, interoperability, and credibility of outbreak detection, surveillance, and guiding more precise and sustainable public health responses [28].

The deployment of telemedicine to specific settings has to account for both technical and other non-technical factors. The effectiveness of telemedicine may differentiate due to cultural conflicts, users' moral and religious backgrounds in different countries and regions [29]. The collaboration of stratified participants should be guided by the law enforcement for better protection of individuals' data, preventing the malicious breach of privacy information as well as any abuse beyond the scope of legal screening, contact tracing and surveillance [30]. This symptom-based QR approach facilitates the optimized allocation of limited healthcare resources [28,31]. It clearly helps identify and isolate cases at an earlier stage and generate seamless non-delay cooperation for individuals, institutions, public authorities, and other responders both in the short run and in the long run. It can be utilized to effectively counteract the emergency of a public health crisis, and simultaneously as a routine surveillance gadget in the post-pandemic era to facilitate rapid recovery from the shock. The integration of features that are critical for the containment of COVID-19 in a uniform platform will be the trend of research to achieve more effective control. The capability of rapid response, traceability, and credibility given by this approach supports the society to fulfill the balance between sustainable containment and smooth recovery of the economy. This tool is scalable for extension of functionality with the advancement in artificial intelligence, big data, and other technologies. It will enable coordinated data-sharing mechanisms ahead of, during, and after an epidemic, improving the quality and sustainability of data in an unprecedented era of high-impact and cyclical pandemics. Information obtained from the app can also increase scientific understanding of the dynamics of COVID-19 and deliver positive insight for other infected communities.

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Authors' Contributions

IN designed the research and drafted the manuscript. SW analyzed the content. IN, SW and WQZ contributed to the modification of the manuscript drafting. SW, WQZ, and YG provided framework analyses of the content. All authors read and approved all sections of the final manuscript for submission.

Conflicts of Interest

None declared.

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Abbreviations:

COVID-19: coronavirus disease
DP-3T: Privacy-Preserving Proximity Tracing
GDP: Gross Domestic Product

GPS: Global Positioning System
PCR: polymerase chain reaction
PEPP-PT: Pan-European Privacy-Preserving Proximity Tracing
QR: quick response
SARS: Severe Acute Respiratory Syndrome
SARS-COV-2: severe acute respiratory syndrome coronavirus 2
SIR: Susceptible-Infected-Recovered model
WHO: World Health Organization

Supplementary Files

Figures