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Review

Quick Response Code Technology-based Contact Tracing Solutions to Mitigate Epidemic Outbreaks: A Review

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Abstract: Several epidemics and pandemics have plagued humanity over the years; however, the coronavirus disease 2019 (COVID-19) pandemic revealed humanity's lack of preparedness for epidemics and pandemic outbreaks. Although several approaches have been proposed, designed, and implemented during and post-COVID-19 by researchers to deal with future epidemic outbreaks, there is a need for lightweight technology solutions to develop technology-based contact tracing (TCT) solutions. Quick response (QR) codes can be considered a lightweight technology as they provide environmentally friendly solutions with flexible applications across industries. They also enable contactless interactions and transactions, which is essential for the health and safety of users in the event of an epidemic. To the best of our knowledge, there exists a few pieces of literature that solely discuss and review the QR code-based TCT solutions adopted during the COVID-19 pandemic. As such, this work explores the QR code for its potential and use as a TCT approach. On this premise, this review discusses factors influencing QR code-based CT and further discusses existing QR code-based techniques for mitigating epidemic outbreaks. Additionally, the hybridization of QR code-based techniques with other TCT solutions has limited discussions that solely focus on QR code-based techniques; as such, QR code-based techniques are compared against other technologies adopted for TCT. The review recommends possible solutions to address the challenges in utilizing QR code-based solutions as it concludes the review.

Keywords: Contact Tracing, Epidemics, Pandemics, Quick Response, Technology-based Contact Tracing

1. Introduction

1.1. Background and Motivation

The increased data demands of users to access more information while expecting an exponential decrease in the physical technology (whether the technology is novel or existing) has led researchers and organizations to adopt higher frequencies such as fifth-generation and beyond (B5G) wireless communications [1]. As such, existing technologies that use industrial, scientific, and medical (ISM) bands such as Bluetooth [2], wireless fidelity (WiFi) [3], radio frequency identification (RFID) [2], near field communications (NFC) [4], among others [2], [3] have been consistently undergoing modifications to meet the data demands of users. The quick response (QR) code is no exception. Although, the QR code is not part of the ISM band, since it uses optical patterns to encode information, rather than using radio frequency (RF) to transmit or receive signals. Its application as a lightweight technology solution to curb the spread of epidemics is vital.

1.2. Literature Review

QR codes were created in 1994 [5], and since its creation, the applications of this technology have seen exponential growth in its functions and applications [6-8] beyond its initial application to label automotive parts [5]. Modifications that have been implemented over the years to QR code technology have found applications in industries such as education [9], construction [6], shipping [10], aviation [11], and healthcare [2], among others. Thus, the affinity of the QR code technology with several sectors, most of which are key sectors connected to the daily livelihoods of several users of the technology, has made it one of the leading technology-based contact tracing (TCT) applications that were implemented to flatten the curve of coronavirus disease 2019 (COVID-19) [12]. On 5th May 2023, the director general of the World Health Organization (WHO) declared an end to COVID-19 as a global health threat, while delineating that it does not mean the absence of the disease nor its existing threat as a pandemic [13]. Although, there are several scars left by the recent pandemic, most of which resulted from humanity's lack of management, fairness, and harmony [14]. The poor usage of existing tools and technologies to combat the spread of the pandemic largely contributed to the challenge humanity faced in flattening the curve of the pandemic. To learn from our mistakes, it is crucial to improve our level of preparedness in designing and implementing more efficient tools from existing as well as novel technologies to combat future epidemics or pandemics. As such, this work focuses on QR codes as a TCT solution. As a lightweight technology, QR code requires less hardware and technology, which minimizes its manufacturing cost. In addition, it improves the performance and durability of products by improving their strength-to-weight ratio and flexibility [15], it increases the durability and reduces environmental impact, and it can adapt to change and promote the sharing of knowledge by being people-oriented rather than process-oriented, which increases adoption by people who have fears and doubts about TCT solutions [16].

As delineated in the work of [17], there have been many epidemics and pandemics that have plagued mankind, however, COVID-19 was a global threat, which at the time of writing was one in which the volume of infection was the highest humanity had experienced. To curb the spread of the pandemic and flatten the infection curve, contact tracing (CT) was adopted as one of the essential strategies to mitigate the spread of the disease [18]. To address the challenges faced with manual CT methods, TCT solutions were developed to address the shortcomings of the manual CT approach as described in [2], [3]. TCT techniques can help identify and alert contacts at scale and in a semi-automated approach, alleviating human capacity limitations resulting from the manual CT approach and improving speed and accuracy. However, TCT techniques are not a silver bullet to deal with pandemics as they also pose various challenges, such as privacy and security issues, ethical dilemmas, technical limitations, user equipment (UE) heterogeneity, and social acceptance, among others [2], [12], [18], [19]. Nonetheless, this review explores the attractiveness of QR codes as a lightweight TCT solution to mitigate the spread of epidemics.

1.3. Contribution

QR code. At the time of writing this review, several works discussed QR code as a TCT solution, however, there were few available literature that primarily reviewed QR code as an adopted TCT solution to mitigate outbreaks. As such, this review discusses QR codes as a TCT solution. It excludes literature that primarily discusses its applications as Electronic Vaccination Certificates (EVC).

1.4. Paper Organization

Regarding the rest of this article, Section 2 discusses the QR code technology and explores its functions and usage. Section 3 focuses on the adoption of a QR code as a TCT solution. The benefits of QR code-based CT are discussed in Section 4. The following section, that is, Section 5, discusses factors affecting QR code-based CT. Section 6 discussed general classifications of QR code-based techniques adopted to mitigate outbreaks. The effectiveness of QR code-based CT is compared to other TCT solutions in Section 7. Section 8 discusses the recommendations developed to address the challenges described in Section 5. Finally, Section 9 concludes this review.

2. Quick Response Code

QR code technology is a type of matrix barcode that can store and encode data in a two-dimensional pattern of black and white squares. QR code stands for quick response code because it can be read quickly and easily by a camera or scanner [20], [22]. Due to its ability to offer eco-friendly solutions while generating revenue for various types of businesses, QR codes can be considered a lightweight technology. In addition, they enable contactless interactions and transactions, crucial for consumer health and safety in the current situation [25]. The QR code system includes an encoder and a decoder. In addition to the function of the encoder mentioned above, it is also responsible for generating the QR code, while the decoder decodes the data originally encoded on the QR code [20], [22].

2.1. Structure of the QR Code

The main elements that form the structure of the QR code are concisely discussed hereunder.

2.1.1. Finder Pattern

The QR code has large squares in its upper right, left, and lower left corners that help the scanner locate and orient the code. A complete central black square with 3 × 3 modules, an outer black square with 7 × 7 modules, and an inner clear square with 5 × 5 modules make up the QR code structure [22]. Fig. 1 shows that the modulus widths of each position sensing pattern are distributed in a ratio of 1:1:3:1:1.

2.1.2. Alignment Pattern

Alignment patterns are small black and white squares that can appear in more complex QR codes. They are usually located in the lower right corner, but they can also be present several times depending on the version of the QR code [22], [23] as in Fig. 1. They help the QR reader to correct the distortion when the code is twisted or curved. They are also used to decode image module mapping.

2.1.3. Timing Patterns

These are the modules that alternate between black and white on both sides of the QR code, which aid the scanner in determining the size and placement of each module. They always begin and end with a black module, which also serves as a measure of the size of the data matrix. On the 6th line of the QR code, between the separators, is where the horizontal synchronization pattern is located. On the 6th column of the QR code, between the separators, is where the vertical timing pattern is located. Timing patterns aid in the detection and orientation of the QR code by QR code scanners [24].

2.1.4. Separators

Separators are rows of white modules that are one module wide and positioned adjacent to the search patterns to separate them from the other parts of the QR code. Only the edges of search patterns that contact the interior of the QR code are given separators. They aid in preventing confusion between search patterns and data modules [20].

2.1.5. Quiet Zone

The quiet zone is a blank space or margin located at each end of a linear QR code that should not contain any text, graphics, or other printing [20]. Another name for it is white space [25]. The quiet zone aids the QR reader in differentiating the QR code from its surroundings and preventing confusion. There should be at least four elements on each side of the QR code, but more room is preferable. The quiet zone should have the same reflectance value as the light modules.

2.1.6. Encoding Region

The area of the QR code that houses the encrypted data is known as the encoding region. It is made up of modules that are black and white and represent bits of data. The coding region stores data effectively using four defined coding modes (numeric, alphanumeric, byte/binary, and kanji); modifications are also possible. The coding region is located inside the search patterns and separators. It may also include error correction modules and format information [24].

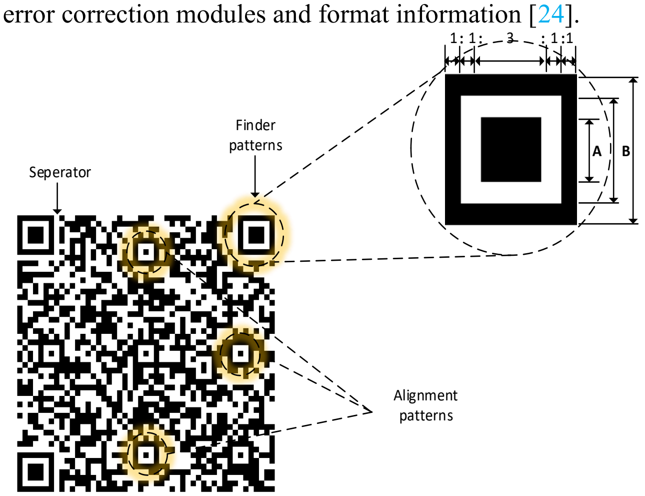

Figure 1. QR code to a paper on Wi-Fi TCT solution.

2.1.7. QR Code Error Correction

Two crucial elements of QR codes are data and error correction. Data is the information included in a QR code and is encoded in one of four defined encoding modes: numeric, alphanumeric, byte/binary, and kanji [24]. Error correction is a feature that makes QR codes visible even when they are damaged or dirty [20]. The Reed-Solomon error correction algorithm is used to mathematically add backup data to the QR code as a measure of redundancy [23]. There are four levels of error correction: L (up to 7%), M (up to 15%), Q (up to 25%), and H (up to 30%) [20]. The minimum print size changes as the level increases since the QR code image becomes denser. Additionally, error correction also allows adding logos or images to QR codes by removing certain data modules [26].

3. QR Code Based Contact Tracing

QR code-based CT is a type of location-based TCT approach that uses barcodes that can be scanned by smartphones to help individuals understand the risk of an epidemic and limit the spread of an outbreak [2]. Some research findings suggest that QR codes can be effective with sufficient population adoption and usage and/or when used in combination with other strategies [27], [28]. As identified in several literature [2], [3], [12], QR code-based CT solutions are easy to deploy and have high location accuracy. As identified in [12], the QR code-based CT solution in China did not retrieve user location data; instead, two different colors were displayed to differentiate the health status of individuals [12]. These were officially considered electronic certificates of the health status of individuals and can be used for CT, self-triage of exposure risks, self-updating of status contactless medical appointments, and psychiatric consultations [28].

Delineated in Table 1 below were jurisdictions identified in the literature to actively deploy QR code-based CT solutions during the COVID-19 pandemic.

Table 1. Selected jurisdictions that adopted quick response-based CT.

Jurisdictions	App	Hardware	Centralized/ Decentralized
China	The Aplipay Health Code	Smartphones	Uncertain
New Zealand	NZ COVID Tracer	Smartphones	Decentralized
Singapore	SafeEntry	Smartphones/ Wearable tokens	Centralized
Hong Kong	LeaveHomeSafe	Smartphones	Decentralized

This table does not include the QR code-based solutions that were solely proposed in the literature. In Table I, New Zealand had originally deployed a QR code-based CT solution in May 2020, but in December 2020, they updated the CT application (app) to include a Bluetooth-based CT solution [29]. As discussed in the work of [2], there were several arguments on whether the deployed TCT solution should be centralized or not, but within the QR code-based solutions, the decentralized solution had the largest adoption rate.

4. Benefit of QR Code-based CT

There exist several TCT solutions (as discussed in Section 1 and differentiated in Section 7), nonetheless, the key benefits of QR code CT over other digital CT [2], and [3] solutions are:

4.1. Easy to Deploy

Since it doesn't need any specialized hardware or software, QR code contact tracking is simple to implement [2]. All that is needed is a bare minimum of equipment and resources, such as smartphones with cameras and internet access and QR code stickers or posters at entry/exit points [29]. As a result, it is adaptable to various situations and scenarios, including public spaces, workplaces, schools, transportation, enterprises, etc. [2], [30]. Users can verify their health status and/or keep track of the locations they have been to by scanning QR codes with their smartphones. Once the information scanned by the users is uploaded, health authorities can safely retain and access the data gathered by the QR codes when necessary [29], [30].

4.2. High Locational Accuracy

High location accuracy means that the location of an object or person can be determined with a high degree of precision and accuracy. For example, GPS can provide location accuracy down to about 10 meters [31], but high-end users can improve GPS accuracy with dual-frequency receivers and/or augmentation systems that can allow real-time positioning to within a few centimeters [17], [31]. QR code-based CT can have high location accuracy because it relies on scanning QR codes that are placed at specific locations, such as restaurants, shops, or transit stations. By scanning the QR code, the user can log their visit to that location and receive a notification if they were exposed to someone who tested positive for COVID-19 at the same location [31]. This can help identify the exact locations where virus transmission has occurred and inform users of their risk of exposure.

4.3. Location Privacy of Users

User location privacy refers to the right or ability of individuals to control how, when, and to whom their location information is revealed or accessed [3], [31], [34]. Various devices and systems, such as cell phones, towers, or databases that can track or record the geographic position of individuals in real-time or retrospectively [34], can collect location information. Loss of location privacy can expose individuals to various risks, such as unsolicited advertising, physical attacks, harassment, user profiling, or inference of sensitive information [35]. However, QR code-based solutions do not retrieve user location data but only store the health status of individuals based on their symptoms and risk of exposure. This can reduce privacy concerns for users who do not wish to share their personal or location data with third parties [2], [35].

4.4. Reduce Viral Transmission

The use of paper flyers, which can carry viruses and disseminate them to those who touch them, can be reduced by using QR code-based CT solutions [28]. Additionally, it reduces the necessity for physical contact, which exposes people to virus-carrying droplets or aerosols when distributing flyers, filling out forms, or sharing personal information [27]. Additionally, it reduces the need for manual data entry, which can result in erroneous contact identification and notification or a delay and lengthen the window of opportunity for the spread of infection [36]. Additionally, it works in conjunction with other CT techniques like manual tracing or Bluetooth-based apps that can broaden CT's range and effectiveness and, as a result, cut down on transmission by swiftly isolating infected connections [37], [38].

4.5. Provides Additional Services

To estimate their risk of exposure and symptoms and to get recommendations for testing and isolation, contacts can self-triage using extra services offered by QR code CT [12]. Additionally, it informs contacts about their health condition and gives them access to pertinent materials and information on the prevention and treatment of an epidemic [3], [39]. It also makes it easier for contacts who require testing or treatment to schedule medical appointments, and it decreases the wait time and paperwork at testing facilities or clinics [39]. Additionally, it facilitates psychiatric consultations with contacts who may be going through anxiety, stress, or depression as a result of exposure to an epidemic or isolation as a result of an epidemic [29].

4.6. Ethical and Legal Issues

By gathering and storing personally identifiable information—which may be delicate, identifiable, and valuable—such as location, time, name, phone number, and health condition, the QR code CT presents moral and legal questions [40–42]. Additionally, it necessitates the users' consent and openness to notify them of the goal, extent, duration, and security of data collection and usage and provide them with the option to accept or reject the system [40], [41]. Additionally, it provides assurances for the security and protection of data against unauthorized access, abuse, disclosures, or breaches that could endanger users' privacy, security, or reputation [41], [42]. It also prevents stigmatization and discrimination against users based on their exposure to an epidemic, which may limit their access to social, professional, or career possibilities [42].

5. Factors Impacting Quick Response Code-based Contact Tracing

Delineated hereunder are factors that influence QR-based TCT solutions to mitigate epidemics:

5.1. Privacy and Trust

Users may be concerned about how their personal information is gathered, saved, and shared by applications and about their ability to rely on app developers and authorities to keep their information secure and private. As such, they may be more eager to utilize a system that safeguards their data and respects their consent since privacy and trust influence user adoption and usage [12]. Additionally, it influences user behavior and compliance since engaged users are more likely to scan QR codes, report symptoms, and heed public health recommendations [29]. Users can also anticipate that their data would only be used for CT objectives and not for other goals, such as law enforcement or commercial interests, by ethical and legal duties [12], [29].

5.2. App Utility

The ability of the application to recognize and alert users who have been exposed to an infectious disease like COVID-19 after scanning a QR code at a specific area or with a specific individual is referred to as application utility in QR code CT. The amount and speed with which contacts are tracked down and quarantined are just two of the variables that affect how useful an app is in QR code CT, which improves the efficiency of quarantines in stopping further transmission. It also considers how many people use the app and how frequently they scan QR codes. Additionally, when processing personal data, it considers the application's level of security and confidentiality.

Some studies suggest that the use of apps in QR code CT scans may improve the control of an epidemic, particularly when combined with additional interventions like testing and isolation [27]. However, context, design, and user behavior can all affect how effectively an application works [43]. Low adoption rates or inconsistent app use by the general public, technical problems with battery life, network compatibility, ethics-related problems with consent or trust, and social factors like stigma, discrimination, or compliance are some difficulties that could limit the app's usefulness in QR code CT.

The application utility in QR code CT is not a panacea to stop an epidemic, but rather a possible instrument that needs to be carefully considered and used to maximize its advantages and reduce its risks.

5.3. Facilitating Conditions

Factors such as availability, accessibility, usability, compatibility, and perceived utility are all examples of facilitating conditions that support the usage of a technology [28]. Facilitating conditions can have an impact on the uptake and effectiveness of QR code CT by influencing the users' behavior and attitude towards the technology.

Testing the QR code to guarantee that it functions easily and dependably is one potential enabling condition for CT QR code [12], [44]. To make the QR code simple to read and scan, pay attention to the appropriate size. The QR code may be made to look more appealing and recognizable by using unique logos and colors. Placing the QR code where it is visible and reachable will ensure that it can be read as easily as possible. Explain how to use the QR code and why it is vital, and offer clear directions. Using encryption, anonymization, and permission methods, ensures data security and confidentiality. Encourage understanding of and trust in QR code technology and its advantages for public health.

5.4. Social-Cognitive Factors

Users may be encouraged to use apps by their social norms, attitudes, beliefs, values, and emotions, such as a sense of duty, camaraderie, compassion, or fear. Psychological and social aspects known as socio-cognitive factors affect how people perceive, comprehend, and respond to a situation or technology [44]. By influencing user's desire, intent, and behavior toward technology, socio-cognitive factors can have an impact on QR code CT. Some possible social-cognitive factors for QR code CT are:

5.4.1. Perceived Usefulness

It refers to how strongly a user feels that using technology will enhance their output or performance. Users may be more inclined to use the CT QR code if they believe it will help them protect their health and stop the spread of an epidemic [45].

5.4.2. Perceived Ease of Use

It reflects how much a user thinks utilizing the technology will be simple. Users may be more inclined to utilize the CT QR code if they believe it to be simple, practical, and reliable [12].

5.4.3. Perceived Risk

The degree to which a user anticipates experiencing losses or unfavorable effects as a result of employing technology. Users who believe that using the CT QR code poses a risk to their security, reputation, or privacy may be less likely to do so [45].

5.4.4. Social Influence

It refers to the extent to which a user's conduct is influenced by the thoughts, hopes, or deeds of others. Users may be more inclined to utilize the CT QR code if they believe it to be socially acceptable, normative, or helpful to others [45].

5.4.5. Self-efficacy

It refers to the extent to which a user believes they possess the abilities, information, and resources necessary to use technology effectively. Users may be more inclined to use the CT QR code if they believe it to be within their capabilities and consistent with their lifestyle [12], [45].

5.5. Ethical Concerns

Users might have moral concerns with applications, such as if they violate their human rights, autonomy, or dignity, or if they incite stigma or social prejudice. Moral or ethical questions raised by technology use, such as how it affects human rights, values, and dignity, are known as ethical considerations. User trust, permission, and accountability to the technology are all impacted by ethical considerations when it comes to QR code CT. Some possible ethical concerns for QR code CT are:

5.5.1. Privacy and Data Protection

Users' rights to privacy and data protection may be violated by the use of QR code CT, which entails the capture and storage of location and personal data. Users can be concerned about who will have access to their data, how it will be used, stored, or shared, and whether it will be anonymous and safe [46], [47].

5.5.2. Equality and Fairness

Different user groups may experience injustices and inequalities as a result of the QR code CT. Some users might not have access to smartphones, the internet, or QR code scanners, for instance, or they might experience difficulties with language, literacy, or a physical impairment. If they are discovered to be contacts or infected, some users may also experience stigma or discrimination [47], [48].

5.5.3. Autonomy and Consent

QR code CT may impact the user's autonomy and willingness to use technology. Users might not have a say in whether to use the technology, how to utilize it, or what to do if they are made aware of a potential exposure. Additionally, authorities, employers, or peers may exert pressure or coercion on users to use the technology or follow its recommendations [46], [48].

5.5.4. Accountability and Responsibility

Concerns about accountability and responsibility for the technology's outcomes may be raised by QR code CT. Users might not be aware of the parties accountable for the technology's precision, dependability, and efficacy or any possible damages or faults. When utilizing the technology or responding to its messages, users might not be aware of their rights and obligations [46], [47].

5.6. Perceived Technology Threats

Applications like data breaches, cyberattacks, identity theft, or spying may be perceived by users as potential dangers or harms. Users' negative attitudes or perceptions toward technology, such as its possible hazards, dangers, or downsides, are examples of perceived technological threats. QR code CT can be affected by perceived technological dangers through affecting user trust in, acceptance of, and satisfaction with the technology. Some possible perceived technology threats for QR code CT are:

5.6.1. Data Misuse or Abuse

Users could worry that the location and personal information obtained by QR code CT would be abused or misused by uninvited parties like hackers, marketers, or governments. Users can worry that their information would be used for other than CT, including profiling, spying, or prejudice [44], [47].

5.6.2. Technical Errors or Failures

Users could question the QR code CT's legitimacy, accuracy, and dependability. While scanning QR codes, users may suffer technical issues or crashes due to a bad network connection, a low battery, or an unsuitable device. As such, false positive or negative notifications may also be given to users, which can cause confusion, anxiety, or complacency [12], [44].

5.6.3. Social Pressure or Stigma

The use of QR code CT by users may subject them to societal pressure or stigma. Authorities, employers, or peers may exert pressure or coercion on users to utilize the technology or abide by its suggestions. If users are discovered to be contacts or to have the QR code CT on them, they may additionally experience stigma or discrimination [44, 47].

5.6.4. Loss of Autonomy or Freedom

Users can view the QR code CT tool as a danger to their freedom or liberty. The technology may make users feel as though they have no control over whether to use it, how to use it, or what to do if they are informed about it. Additionally, the CT QR code may also make users feel confined or watched over [44], [47].

5.7. Perceived Health Threats

Users can observe the severity of an epidemic and if they are susceptible to it, additionally, users can check if applications might lower their risk of developing health problems. Perceived health threats are negative beliefs or attitudes users have about a health problem, such as its severity, susceptibility, or consequences. Perceived health threats can impact QR code CT by affecting user awareness, motivation, and compliance with the technology. Some possible perceived health threats for QR code CT are:

5.7.1. Low Perceived Severity

Users might underestimate how seriously or adversely an epidemic will affect them or other people. Users may underestimate the threat of an ongoing epidemic by assuming that they are not vulnerable to complications or infections, or that they will be able to recover quickly if they become unwell [12], [47].

5.7.2. Low Perceived Susceptibility

The likelihood or susceptibility of users to exposure or infection to an ongoing epidemic may be underestimated. Users may believe that they are immune to or protected from the virus, that the epidemic is not common in their area, that they have not been in contact with infected people, or any combination of these [12], [47].

5.7.3. Low Perceived Benefits

Users could undervalue the advantages or outcomes of employing QR code CT. Users can think that the QR code CT is ineffective, unnecessary, or not useful for halting the spread of an epidemic or safeguarding their health [24], [44].

5.7.4. High Perceived Barriers

Users could exaggerate the expenses or difficulty of employing QR code CT. Users may believe the QR code CT to be untrustworthy, impractical, or both. Users may also encounter obstacles such as a lack of resources, expertise, or access to the technology [12], [27].

5.8. Technology Familiarity

Users' prior knowledge of and expertise with related technology, such as QR codes, Bluetooth, or GPS, may have an impact. The level of a user's technology familiarity refers to their prior knowledge or experience with the technology, including their understanding of its features, functions, and advantages. Technology familiarity can have an impact on QR code CT by influencing user comfort, trust, and pleasure with the technology. Some possible impacts of technology familiarity for QR code CT are:

5.8.1. High Technology Familiarity

Users can feel more at ease and confident utilizing the technology if they are familiar with the QR code CT. Users can simply read notifications, scan QR codes, and take advice. Additionally, users might feel more satisfied and confident in the technology's outcomes.

5.8.2. Low Technology Familiarity

Users who are not familiar with the QR code CT could feel less at ease and confident when utilizing it. Users can have trouble seeing messages, scanning QR codes, or heeding advice. Additionally, users might feel less happy and less confident in the technology and its outcomes.

5.9. Persuasive Design

Users may be motivated by an app's design characteristics, such as its usability, aesthetics, feedback systems, or gamification components. Users who have negative views or attitudes about technology, such as its manipulation, coercion, or deception, are said to be subject to persuasive design threats.

Threats from persuasive design can have an impact on QR code CT by altering users' confidence in, independence from, and accountability to the technology. Some possible persuasive design threats for QR code CT are:

5.9.1. Manipulation

By deploying persuasive strategies like prizes, comments, or social proof, users may believe that QR code CT is influencing their thoughts or feelings. Users can think that the CT QR code is attempting to sway their judgment or behavior without their knowledge or agreement [44], [49].

5.9.2. Coercion

Users may perceive that the CT QR code uses coercive tactics, including threats, penalties, or nudges, to influence their behavior or emotions. The QR code CT may cause users to believe that they are being forced into making decisions or taking acts against their will or freedom [44], [50].

5.9.3. Deception

Users could feel that the QR Code CT is manipulating their behavior or emotions by employing dubious information, ulterior motives, or troubling patterns. Users may believe that the QR code CT is attempting to influence their choices or activities truly and accurately without their consent [12], [44].

5.10. Social-Demographic Factors

Depending on a user's age, gender, education level, financial level, or cultural background, they may adopt apps differently. Users' sociodemographic attributes, such as age, gender, education, income, or ethnicity, describe their social and demographic background. Socio-demographic variables can have an impact on QR code CT by changing how users access the technology and how aware they are of it. Some possible socio-demographic factors for QR code CT are:

5.10.1. Age

Users of various ages may have varying degrees of awareness and access to QR code CT. Older users may have less access to smartphones, the internet, or QR code scanners. They might also know less about how to use technology. Younger users might have greater access to, awareness of, and knowledge of technology, but they might also lack confidence or a favorable attitude toward it [44], [51].

5.10.2. Gender

The access, awareness, and attitude toward the QR code CT may vary among users of different genders. Due to discrimination or gender disparity, female users may not have as much access to smartphones, the internet, or QR code scanners. Male users may have greater access to technology, but they may also see it with less optimism or trust due to privacy or security worries [12], [44].

5.10.3. Education

Users with varying levels of education may have varying degrees of access to, awareness of, and attitudes regarding the QR code CT. Due to societal or economic constraints, users with low levels of knowledge may have less access to smartphones, the Internet, or QR code scanners. Higher-educated users may have more access to technology, but they may also see it with less optimism or trust due to ethical or political considerations [27], [51].

5.10.4. Income

Users with varying levels of affluence may have varying degrees of access to, awareness of, and attitudes toward the QR Code CT. Due to cost or affordability difficulties, low-income customers may have less access to smartphones [2], the internet, or QR code scanners. Due to privacy or security concerns, users with higher income levels may have more access to technology but also less confidence in it [2], [12], [51].

5.10.5. Ethnicity

Different ethnic groups' users may have varying degrees of access to, levels of awareness of, and attitudes regarding the QR code CT. Due to discrimination or cultural or linguistic obstacles, users from minority ethnic groups may have reduced access to smartphones, the internet, or QR code readers. Although users from majority ethnic groups might have easier access to technology, they might also see it with less optimism or trust due to ethical or political considerations [12], [44].

6. Quick Response Code-based Techniques to Mitigate Epidemic Outbreaks

There have been several QR code-based CT techniques developed to mitigate the spread of epidemics. Nonetheless, most of the existing techniques are generally classified as follows:

6.1. Symptom-based QR Health Codes

These TCT methods employ health QR codes that are generated by public health agencies based on the self-reported symptoms, test outcomes, and travel history of users. The codes do not retrieve user location information; instead, two distinct colors are shown to indicate a person's level of health. For CT scans, exposure risk self-triage, health status self-updating, medical appointments, and contactless psychiatric consultations, QR codes can be utilized. Officially, they are considered electronic certificates of people's health status [51].

6.2. Venue-based QR Check-in Codes

These are presented by companies and locations in open spaces like restaurants, shops, workplaces, or schools. Users enter and exit sites by scanning QR codes with their smartphones, and the information about their visits is kept either locally on the users' devices or a central server. The server notifies other users who visited the same locations at the same time if a user tests positive for an ongoing epidemic after uploading their visit records [2], [12].

6.3. Test Result-based QR Verification Codes

When people take a test to check their health during an epidemic, they are produced by test providers or labs. The user's name, the test date, the test type, and the test outcome are all contained in QR codes. Users can examine their test findings and, if necessary, share them with others, using QR codes on their smartphones. Travel across borders or between areas with varied epidemic limitations can also be made easier with the help of QR codes [2], [12], [51].

7. Effectiveness of QR Code-based CT to Other TCT Methods

The effectiveness of QR code CT compared to other methods is not well established by rigorous research evidence. However, according to certain studies, QR code CT scanning can be successful if it is widely adopted, used, and/or combined with additional tactics like Bluetooth-based apps, tracing manuals, and tests [29], [51].

Following a data issue that disrupted CT scans in England for 6 weeks, observational research indicated that computed tomography (including QR code scanning) was associated with a 63% reduction in subsequent new infections and a 66% reduction in COVID-19-related mortality [52]. This study, however, did not separate the impact of QR code reading from other CT techniques.

A modeling study estimated that QR code reading could reduce infections by 24–71% with a mobile tracing app, depending on the proportion of users and reading delay [53]. However, this study assumed that scanning the QR code would capture all contacts and locations, which may not be realistic in practice.

Another modeling study suggested that reading the QR code could reduce the reproduction number of COVID-19 from 2.2 to 0.57 if used by 80% of the population and there were no more transmissions by cases and contacts [53]. However, this study also assumed perfect QR code scanning compliance and efficiency, which may not reflect real-world scenarios.

7.1. Comparison of TCT Solutions

In contrast to other CT technologies like Bluetooth-based apps, hand tracing, and testing, QR code CT is not a stand-alone solution but rather an additional tool [27], [54]. Depending on their settings and requirements, various nations have embraced various combinations of these technologies. For instance, Singapore employs QR codes to register entry and exit points to public spaces and China uses them as electronic certifications of health status and exposure risk [27], [54], [55]. Summarized in Table 2 is a comparison of existing TCT solutions built atop several wireless communication technologies.

Table 2. Comparison of technologies used for TCT [2, 3].

Factors	QR Code	BLE	RFID	NFC	Wi-Fi	GPS
Location sensing	Yes	Yes	Yes	Yes	Yes	No
Data collection	Manual	Automatic	Automatic	Manual or automatic	Automatic	Automatic
Architecture	Centralized	Decentralized	Centralized or decentralized	Centralized or decentralized	Centralized or decentralized	Centralized or decentralized
Scalability	High	High	Low	Low	Medium	High
Proximity sensing	No	Yes	Yes	Yes	Yes	No
Application cost	Low	Low	High	Medium	Medium	Low
Real-time application	Low	Low	High	Medium	Medium	Low
Location/Proximity accuracy	High	Medium	High	High	Low	Medium
Security and privacy	Low	High	Medium	High	Medium	-
Availability and compatibility	High	Medium	Low	Low	High	High
User acceptance	Medium	High	Low	Medium	High	Low

8. Recommendations

Section 5 delineates certain factors that impact the use of QR code-based CT solutions. As such, this section discusses and summarizes some possible ways to overcome the challenges of QR code-based CT. Discussed hereunder are some approaches adopted to handle some of these factors:

8.1. Population Uptake and Usage

Public health authorities can inform the public about the advantages and safety of QR codes, provide incentives and prizes to users, and impose strict requirements for scanning in high-risk areas to encourage adoption and use among the general population. risk [12], [44].

8.2. Availability and Accessibility

To ensure the availability and accessibility of QR code posters, public health authorities can provide guidance and support to businesses and places to adopt QR codes, standardize the format and design of QR codes, and suggest methods alternatives to users who do not have smartphones or the internet access [28], [44].

8.3. Privacy and Security

To protect user privacy and security, public health authorities can adopt decentralized and anonymized data storage systems, implement encryption and authentication mechanisms, and comply with data protection regulations and ethical principles [28], [44].

8.4. Usability

Public health authorities should provide user-friendly, intuitive interfaces, offer audio prompts and feedback to visually impaired users, and test the performance and operation of QR codes in various environments to increase the usability and accessibility of QR codes [28], [56].

8.5. Contacts and Exposures

Public health authorities can combine QR codes with other digital CT tools, including Bluetooth apps or wearable devices, and add manual CT techniques to them to record all encounters and exposures [44].

9. Conclusion

The main focus of this review is on the potential of lightweight technology, such as QR codes, as a TCT approach to reduce epidemic outbreaks. As such, it outlines the variables that affect QR code CT as a TCT solution. Based on this concept, it discusses the TCT techniques used in the literature to lessen an epidemic's impact. The impact of QR code-based CT on other TCT technologies is also examined. QR code-based CT is a promising technique that can complement manual CT methods and other TCT techniques to contain the spread of epidemics. However, it also requires careful design, implementation, evaluation, and governance to ensure its effectiveness, efficiency, acceptability, and sustainability.

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