A review of Information Communication Technology (ICT) methods for road infrastructure monitoring

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Abstract

Road infrastructure is critical to a country's economic growth because it supports other infrastructural developments. The high cost associated with building new roads has caused a shift in focus to the effective maintenance of road assets in many developed countries. This has not been the situation in many underdeveloped countries, where roads have been allowed to deteriorate and road infrastructure monitoring is still carried out manually. Due to the cost, time, subjective nature, and other biases of human inspectors, the manual approach to road infrastructure monitoring has proved insufficient. Information communication technology (ICT) monitoring methods make use of the facilities provided by ICT and its tools to provide monitoring in chosen domains. The mobility and penetration of mobile-based information and communication technology (ICT) devices make them ideal for monitoring infrastructure. In this paper, we review ICT-based road monitoring methods and provide an overview of the current community-based infrastructure monitoring approach using mobile phones.

KEYWORDS: Infrastructure monitoring**,** Community-based monitoring, Mobile crowdsourcing, Human sensing.

I. Introduction

A road network is the heart of any country's development and the major factor for its successful planning towards the achievement of sustainable development (Adebayo, 2015). Road transport's role in the economic development of any country cannot be overemphasized, which is buttressed by Adepoju (2021), who described roads as the glue for bringing together a nation's developmental elements. He went further to say that roads are needed for tapping resources, connecting people and places, and linking organizations. Somuyiwa et al. (2020) further asserted that roads are critical infrastructure for sustainable development as their efficiency is related to consumption, distribution, and production. Road infrastructure cuts across different sectors that are crucial to the growth of developing countries, including health, education, agriculture, power, transportation, and land use management.

The Nigerian road system consists of three trunks: trunk A for the Federal Government, trunk B for the States, and trunk C for the local governments. It is estimated to span approximately 200,000 kilometers, with ownership divided as follows: Federal roads account for 36,000 kilometers (18%), state roads account for 32,000 kilometers (16%), and local government roads account for 132,000 kilometers (66%) (Muhammad and Sebastian-Dauda, 2017). The high number of local roads necessitates the periodic monitoring and evaluation of local road conditions to demonstrate the necessity and value of their maintenance (Li et al., 2021). The World Road Federation (WFRF), on the other hand, says that local road maintenance in many countries is often put off in favor of a country's high-traffic, strategic road network, which is usually in cities.

In developed countries, the need for automated road management systems began in the 1960s when the focus shifted from the building of new road infrastructures to maintaining existing infrastructures due to increasing costs. Currently, methods for monitoring and reporting road problems in Nigeria are inadequate across federal, state and local governments. Available information shows that the methods employed by governments include manual routine checks by government staff, reports by paid political appointees and paper-based petitions by local residents. There is no visible promotion of the reporting apparatus to the public, and where it is available, it is not easy to use by citizens due to its manual nature. Also, there are no proper feedback mechanisms to alert the public on the status of their reports, which has led to apathy and a lack communy ownership of the roads infrastructure.

Manual road monitoring is commonly defined as visual assessments of field conditions carried out by one or more people looking at the pavement via the windshield of a vehicle or while walking on it. A manual survey's results can be written down on a piece of paper, entered into a mobile device, or entered into a computer. Several researchers have noted that manual road monitoring and reporting is time-consuming and makes repair decisions slow and costly, which can lead to neglect over long periods of time, causing repairs to be expensive and the roads more accident-prone. Also, monitoring and reporting on road infrastructure by hand is hard, subjective, and doesn't happen very often (Radopoulou et al., 2016; Li et al., 2020; Li et al., 2021). Another major disadvantage of manual road inspections is the safety issues that is associated with it.

A major gap noted in Nigeria is that the method for road infrastructure monitoring has not taken full advantage of the potential of ICT and mobile technology. Reports indicate that 170 million Nigerians use mobile phones, with about 40 million using smartphones, and smartphone users are projected to reach more than 140 million by 2025. Because of this, it is important that infrastructure monitoring use the latest ICT-based methods for road monitoring so that agencies in Nigeria in charge of road maintenance can get quick, accurate, and location-based reports.

In this paper, we first carried out a review of ICT use in monitoring and reporting and the advantages it has brought to the domains in which it has been applied. Then, we classified and discussed ICT-based road monitoring systems in the literature looking at their advantages and disadvantages. Finally, we considered mobile crowdsourcing as a current community-based method for road monitoring and the challenges the system may pose to members of the community who use the system for reporting road issues. We then talk about future work in mobile crowdsourcing for road monitoring in developing countries, taking into account development and evaluation frameworks.

2. ICT in monitoring and reporting

Current developments have made ICT affordable, and this has led to an increased interest in using ICT tools for data collection, monitoring, and reporting in many developing countries. The advantages provided by using ICTs for monitoring and reporting include more efficient data collection capability, quick data analysis, varied report presentation formats, and ease of dissemination of information. ICTs offer many promising solutions for monitoring and reporting because they make it easy to quickly collect and centralize data at the facility level and send data to the right governments agencies so they can provide the solutions that are needed (Callen et al., 2020).

ICT-based approaches for monitoring and reporting are more cost-effective for data collection, analysis, monitoring, and reporting for assessment, and can therefore play an important role in affordable and efficient decision-making by policymakers. These developments have led to reforms in many developed countries' agencies, causing them to become smart in their approach to carrying out public engagements. ICT has been applied in many domains and has improved the potential of the monitoring and reporting activities carried out within these domains. For example, the use of ICTs to monitor and report on the management of water resources has made people more aware of the need to conserve water and do other things related to water management (Fathy, 2014; Otuke, 2016; Yasin et al., 2021).

Another area where ICT monitoring has found increased use is in disaster management, where ICT-based monitoring and reporting have been used to provide timely and effective information both for citizens and government agencies responsible for disaster management (Sakurai & Murayama, 2019; de Meira & Bello, 2020; Amosun et al., 2021). The agricultural sector of developing countries has been improved by using ICT-based tools for monitoring, reporting, and evaluation. Recently, the Nigerian government launched the Nigeria Digital Agriculture Strategy (NDAS) to provide a framework for carrying out operations in the agricultural sector using ICT. Proper monitoring using ICT tools has been shown to improve farming methods and increase crop yields (Mbagwu et al., 2018; Oluwatayo & Ojo, 2019).

Furthermore, the use of ICT in the health sector has improved both individual health management and the activities of personnel in the medical industry. Developments such as reminder apps for hospital appointments and drug usage (Medisafe, MyTherapy, DoseCast, etc.), systems for monitoring healthcare providers, patients' remote monitoring, and monitoring of vital signs are ensuring healthy habits by individuals (Thakkar et al., 2016; Kalid et al., 2018; Baridam & Govender, 2019; Babar & Carine, 2020; Sobreiro & Oliveira, 2020). The use of ICT for monitoring and reporting during epidemics and pandemics has made a difference in the way diseases are managed today, unlike in the past when a lack of information for disease control led to the deaths of millions of people. Most of the control of the COVID-19 pandemic was due to the use of ICT tools to teach people how to avoid getting sick and to help scientists work together to find possible cures (Wirth et al., 2020; Radanliev et al., 2020; Ienca & Vayena, 2020; Ye, 2020; Mao et al., 2021).

3. ICT-based monitoring and reporting for road infrastructure

The growth, availability, and ubiquity of ICT-based devices have caused a great change in the way infrastructural projects are monitored and reported. Many developed and some developing countries have adopted, and are encouraging the active use of ICT tools for the monitoring and reporting of road infrastructural development. One of the advantages of ICT-based systems for monitoring and reporting road infrastructure is that such systems can use GIS, remote sensing (RS), and GPS to provide location-specific data to agencies responsible for road maintenance operations. ICT methods are also useful because they can be used for different kinds of data collection and communication. This means that different groups can collect data about roads in the ways that work best for them, whether they do it remotely or in person. Research has shown that ICT-based road monitoring and reporting systems have been implemented as call-based, web-based, GIS-based, sensor-based, and image-based, and with current trends for citizen participation in governance as smartphone photo-based crowdsourcing monitoring and reporting. In the following section, we will provide a discussion of the various identified reporting methods in figure 1.

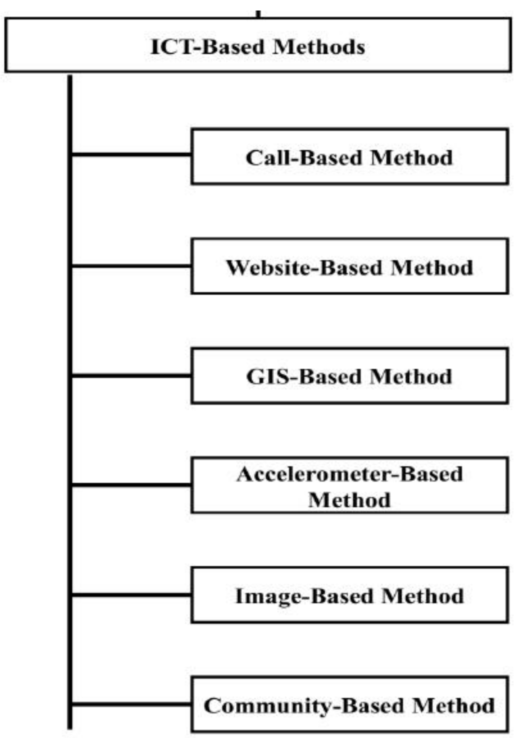

Figure 1: ICT-based road monitoring methods. The categorization is from the authors review and observations.

3.1 Call-based road monitoring

The call-based approach to road monitoring involves citizens reporting road issues by making calls to the agencies responsible for road construction and maintenance. In this method, citizens who identify road faults make a call to report them to the agency and are required to provide detailed information about the location, nature of the fault, and other information. This method places stress on the caller since most phone calls are not audible, making explanation difficult. The caller bears the burden of calls, especially in developing countries like Nigeria with no public 311 lines for reporting non-emergency issues. Most of the time, citizens who want to report may not know the number of the necessary agencies. Other issues with this method include difficulty identifying locations; it is not picture-based; hence agency workers can doubt report it; location information is dependent on the caller’s descriptive ability; etc.

3.2 Geographical Information System (GIS)-based road monitoring

A GIS is a computer-based information system that collects geographic data about an object or area, represents the data in digital form, and analyses it to produce outputs from queries to solve identified problems. Today, geographic information systems (GIS) have become a critical tool for urban and resource planning and management. Their ability to store, retrieve, analyze, model, and map broad areas with massive amounts of geographical data has resulted in an explosion of applications. Progress in GIS research has brought digital geographic information within reach of almost everyone using tools like Google Maps and Microsoft Visual Earth (Goodchild, 2007), which is being used by researchers for creating GIS monitoring and reporting designs for road monitoring and reporting (France-Mensah et al., 2017; Ahmadi et al., 2017).

GIS road fault identification systems use static or dynamic road image data obtained from satellites. The obtained data is referenced to a traditional map of the study area and then a geodatabase is created in a GIS software environment like Arc GIS and ESRI's ArcView (Ibochi et al., 2013; Adebayo, 2015) or in a normal database environment like MS Access and then linked to GIS software (Kiema and Mwangi, 2009). Spatial analysis is carried out with a spatial query tool created for the identification and extraction of road information from the database, and results are presented in digitized map forms.

GIS-based software implementation is very expensive. This cost comes from data collection using satellites, their hardware, and software, and the cost of training personnel for many governments who want to cut costs is prohibitive. There is dependence in most instances on the government for data, which may provide data that is consistent with the government's purpose. Difficulty in the integration with traditional maps is another problem due to the complexity of GIS map structures. Finally, using GIS for road data information collection and analysis is time-consuming, which can lead to delays in decision making.

3.3 Web-based road monitoring

Web-based Road monitoring makes use of the websites of road maintenance agencies for monitoring and reporting road issues. In this method, a citizen who notices a road problem can go to the agency's website and fill out a form describing themselves and the road problem. The federal road maintenance agency (FERMA) of Nigeria, for example, makes use of its website to collect road fault information from citizens. They are required to enter their details and emails, plus road location information. They can also upload pictures or videos of the road they are reportingThis method is not automated, users have to take pictures and then go to the websites to fill out forms and upload data at a cost borne by them. Sometimes people will take a picture and then forget they took the picture. The process wastes ````````````time, the data costs are high, and very few people know about these websites.

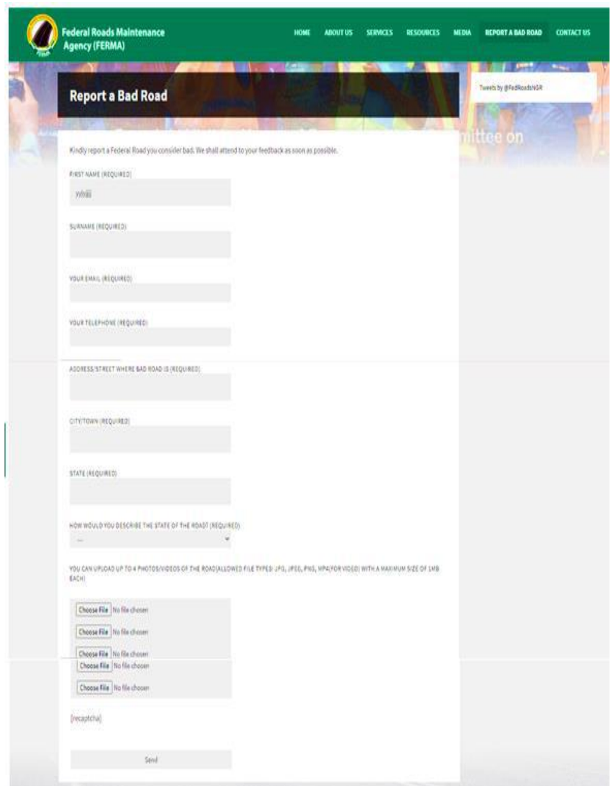

Figure 2: FERMA report a bad road page. This page was obtained from the Nigerian Federal Roads Maintenance Agency (FERMA). https://ferma.gov.ng/report-a-bad-road/

3.4 Accelerometer-based road monitoring

In recent years, research into the use of accelerometer-based methods for monitoring and reporting on different phenomena has been carried out by many authors. An accelerometer is an electromechanical device that measures acceleration or g-force. It can be used as a stand-alone or embedded in a device and has a 3-axis that measures static or dynamic acceleration forces. They sense movement or vibration in 3 directions, x, y, and z-direction. Accelerometers have been used in many engineering fields and in products such as digital cameras and computers. They are also used in cars for crash detection and airbag deployment, and more recently for road fault detection (Bello-Salau et al., 2015).

Accelerometer road fault measurements are also called vibration-based methods. This approach is based on the measurement or collection of vibration data from a 3-axis accelerometer attached to the vehicle or that of a smartphone as a vehicle moves along a paved road. The process involves several filtering steps to extract these features that define road damage (Lee et al., 2021). Two approaches have been identified in the literature for extracting and identifying vibration data using the accelerometer. They are the statistical approach and the machine learning approach.

The statistical approach makes use of the mean, standard deviation, Z-difference, variance, and energy of the Z-axis acceleration signals computed using MATLAB, LABVIEW, or other statistical software. The obtained signals or vibrations are then compared against a set threshold signal to identify portions of higher energy content, which usually indicate the presence of road anomalies (Mednis et al., 2011; Strutu and Popescu, 2014). But in the machine learning approach, acquired data is first preprocessed and then filtered to extract the time, frequency, or wavelet domain frequencies of the signals. Consequently, machine learning algorithms like Support Vector Machine (SVM), rain forest (RF), k-nearest neighbors (kNN), decision trees, etc. are used to analyze the signals and carry out the classification and detection of faults (Eriksson et al., 2008; Akanksh, 2018; Du et al., 2020; Lim et al., 2020).

The accelerometer-based road monitoring systems can only be used by vehicles on which they are installed, and driving speeds must not exceed a certain threshold to obtain useable data. They are restricted in the type of road issues they can monitor and can measure faults mainly on paved road systems, such as potholes and bumps. It also cannot measure road-surface damage in areas other than the vehicle's wheel paths and cannot identify the size of the road-surface damage outside the wheel path of the vehicle (Li et al., 2016).

3.5 Image-based road monitoring

Image-based monitoring and reporting on road status involves the use of cameras to acquire road data, which is then processed. The camera can be a simple digital camera mounted either inside the vehicle or outside the vehicle, or the camera of a smartphone fixed to a stand on the windshield of the vehicle. Methods for implementing image-based monitoring and reporting are classified as traditional methods or machine learning. Image processing with machine learning involves the use of an acquired dataset for training a machine learning algorithm in the identification of road problems (Yan & Yuan, 2018). The traditional method consists of filters, morphological analysis, statistical methods, and percolation techniques. Analysis of captured image data and results is carried out by dedicated software and then sent via wireless networks to agencies responsible for road monitoring (Siriborvornratanakul, 2018).

Image processing is a complex computing problem, and this can cause the cost of implementing this type of system to be high. The development of machine learning has improved image processing and has caused it to be readily available in developed countries. The system is driver dependent and difficult to install. Image-based reporting systems are prone to lightning issues and instability of cameras due to movement, which causes poor video images. It is not community-oriented, and can only be used to measure problems on paved roads. Also, efforts must be made to improve recognition rates by getting rid of things that get in the way of analysis, like changes in the color and brightness of the road surface in different weather conditions, shadows on the road, other cars driving by, and road signs (Lee et al., 2021).

4. Community-based monitoring and reporting

Mbile technologies offer the benefits of direct communication, empowerment, and crowdsourcing for collective problem solving (Kavanaugh, Sandoval-Almazan, and Ubacht, 2020). The growth of social media also means that citizens have become more technology-sensitive and therefore more capable of using social media technology, so expect their governments to be abreast with new technologies. This has caused governments and their agencies to adopt new technologies to satisfy citizens' expectations and devote resources to social media adoption so that they can meet citizens' needs and achieve legitimate engagement with citizens within a democratic sphere (Fashoro and Barnard, 2021).

Today, the built-in camera of smartphones has become the most prevalent method for visual information capture in our lives and the environment. This and other developments have created the potential for civic-oriented systems in which residents can support community betterment through acts of citizenship in the community, allowing local governments to conserve human and financial resources (Santos et al., 2013). Crowdsourcing is an example of an ICT-based method for community monitoring and civic-problem solving.

Jeff Howe coined the term crowdsourcing in a 2006 article in the wired magazine (Pedersen et al., 2013; Stol and Fitzgerald, 2014; Wazny 2017; Stanley, 2020; Yu et al. 2021). And he went on to define crowdsourcing as "the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in an open call" (Howe, 2006). For Brabham (2013), crowdsourcing consists of a voluntary, collaborative relationship between a crowdsourcer (an organization or an individual) and a crowd (a large group of people) that uses the internet to provide solutions to problems for mutual benefit.

Due to its appeal as a civic engagement tool, crowdsourcing has emerged as a viable option for ICT-based community monitoring and reporting. Crowdsourcing for community monitoring has been described as citizen-sourcing, a description of crowdsourcing activities by governments to tap into the collective intelligence of citizens (Van Ransbeeck, 2015). Studies (Prpic, Taeihagh, and Melton, 2015; Dutil, 2015; Clark et al., 2019) have shown that good crowdsourcing projects can reduce administrative costs, improve service efficiency, and improve the relationship between the government and the people.

Crowdsourcing can be mobile or web-based. Web-based crowdsourcing refers to crowdsourcing activities that take place on the internet, typically on the task presenters' websites, while mobile crowdsourcing (MCS) refers to crowdsourcing activities that are carried out on smartphones or other mobile devices. Mobile crowdsourcing has become the most popular way for the community to monitor infrastructure. This is because mobile devices have features like portability, location- based reporting, the ability to get multimedia data, and the ability to present information to a user in their desired format.

4.1 Mobile crowdsourcing (MCS) for road monitoring and reporting

Today, the predominant method for location-based crowdsourcing is MCS. MCS is crowdsourcing activities that are carried out on smartphones or other mobile devices. They are based on location and use GPS. This makes it possible to collect data in real time and gives the crowdsourcing project a wider reach and more visibility. Today, smartphones are ubiquitous and widely used around the world, with rich sensors (e.g., GPS, accelerometer, and camera) built into them, and multiple radios (e.g., Bluetooth, Wi-Fi, and cellular) provided (Wang et al., 2017). This lets people with smartphones sense, gather, process, and share data anywhere and at any time.

In MCS road monitoring, the facilities provided by mobile devices, especially smartphones, are used in monitoring road faults via installed MCS road monitoring apps. The camera of the smartphone is a means of providing picture evidence for the identified road segments in the report. The GPS of the device is used to provide location information that further ties the photos to the location using geotagging features. Also, in many instances, a smartphone's local mobile network is used to connect to the crowdsourcer database or agency systems where these reports are then sent. When local governments use mobile crowdsourcing to find out about the status of infrastructure, they can act quickly and effectively because the information comes from many different people in the community.

The MCS used in road infrastructure monitoring are not only for drivers or vehicles like in the case of image-based and accelometer based reporting. Rather the apps can be used by any member of the community who needs to report a road issue. This makes the MCS method community-oriented, allowing all willing members of a community to actively take part in reporting issues and thereby provide ample information for decision-makers. The MCS is also location-based. This helps to automate the identification of locations to agency staff, removing the problem of manual location identification present in the call-based systems. MCS systems can be used to report road problems of various dimensions. For instance, the GIS, accelerometer, and image-based systems can only identify certain road conditions, but the MCS systems can provide a lot more information about road issues, making them more flexible in application and broader in road information acquisition.

Many authors have researched and developed MCS systems for road monitoring. Santos et al. (2013) developed a web-based and MCS solution seeking to promote citizens' participation in reporting issues such as potholes, illegal waste dumps, etc. in their environments in Portugal using the Open 311 specification. It was integrated into an existing GIS portal in Portugal and allowed citizens to report observed problems using a web browser or mobile device in a location-based environment. Tests in Porto, Portugal, showed that the system was able to help people report environmental problems to local authorities.

In CommuniSense, Santani et al. (2015) created a model for documenting and reporting on Nairobi's road infrastructure conditions using an Android-based MCS platform that uses a smartphone's GPS to automatically determine the position of registered users when they take photos of road hazards. The user adds a description of the hazards and then uploads or saves the image to his device for later submission, depending on the condition of his mobile connection. Additionally, a user might use a map system to detect road problems; if a user selects a hazard term, the app automatically adds a marker near the user's location to identify it. The system was tested for two weeks with 30 randomly selected users from various districts of Nairobi. After verification by Amazon's Mechanical Turk (MTurk), a 92 percent accuracy ratio was obtained.

An android-based MCS system was developed by Bamne and Shinde (2016) for the Municipal City Government of Mumbai, India, to monitor and report on road surface conditions. A citizen can snap photographs of bad roads that are then geotagged using their mobile phones' GPS and submitted to a server. The server gives the user a confirmation SMS and a complaint ID upon receipt of the report information and possible resolution date. The report is then sent to a contractor or resident city engineer at the government end who is responsible for road maintenance. The MCS also has a feature called "On the Go" that lets users use images from other users to find and follow potholes in their immediate area. This helps them plan their routes around the city.

In another Android-based MCS, Deshmukh and Rajput (2016) provided a system that includes other city problems. Their system categorizes complaint categories into five groups, including litter and waste; health and safety; road damage and illumination; and a category to cater to complaints that do not fit into any group. Their system is divided into two parts: a mobile crowdsourcing platform and a web-based admin platform. A user submits complaints in the form of geotagged photographs and a description of the issue. The system transmits filed complaints to the server, where an administrator can read them and forward them to the appropriate authority, who then sends the system a report to the citizen indicating whether the issue has been handled or not. Users could also check on the status of complaints they had already made and complaints made by other users in their area.

5. Challenges of Mobile Crowdsourcing

Human users contribute data to the majority of MCS applications voluntarily through mobile sensing or human intelligent task activities via their smartphones. This engagement exposes them to potential privacy breaches and other security concerns associated with contributory mobile platforms. Additionally, the MCS's objective is to collect meaningful, high-quality data from crowd workers who may be dishonest, provide inaccurate data, or engage in malicious behavior. This section will discuss a variety of MCS-related issues, as well as potential solutions gleaned from research and studies.

5.1 Mobile device power and data limitations

Mobile devices frequently have limited power capacity, which affects the MCS's performance. The majority of smartphones use communication methods that consume an enormous amount of power due to the disparate energy requirements of download and upload links (Chatzimilioudis et al., 2012). To overcome this obstacle, tasks must be scheduled efficiently and intelligently distributed among task workers to minimize network load (Kong et al., 2019). This ensures that the task execution process does not put a strain on task workers' device batteries and prevents them from accessing their usual functions, such as making a call, texting, or using the internet.

Primary applications in MCS, such as sensing via GPS, image geo-positioning, and data transmission, all consume a significant amount of energy on the smartphone. To address this issue, Conti et al. (2015) propose an adaptation scheme for determining the location of a phone that switches between precise but energy-inefficient GPS probing and energy-efficient but less precise Wi-Fi/cellular localization. The cost of data is another factor that affects MCS, especially in so-called public-oriented MCS. One way to encourage user participation is to offer an initial free data disbursement to users of the platform who take part in reporting. Another way to overcome the data issue is for the platform to use delayed transmission (Santani et al., 2015). This gives users the ability to save the photo of the location with its geolocation information and then send the report when they have data or there is free Wi-Fi available.

5.2 Privacy and security

The major characteristics that make MCS privacy- and security-critical and challenging are human involvement in data collection activities, crowdsourced task characteristics, and the dynamic topology of the users' circumstances (Yang et al., 2015). Furthermore, Wang et al. (2013) summarized the threats and vulnerabilities in MCS to include disclosure of user identity, disclosure of user location and activity, combining crowdsourced data with user data, lack of user privacy awareness, the vulnerability of mobile devices, reliance on information that may be inaccurate, and retaliation for reporting sensitive information. While MCS platforms prefer to use location and environmental information provided by task workers to make appropriate task recommendations, Gong et al. (2016) observed that this can result in privacy disclosure if the platform is attacked by threat actors.

Certain privacy protection mechanisms can be used in MCS to ensure its privacy and security. They include allowing users to choose which personal information to share, preserving user anonymity, and utilizing cryptography to protect both the crowdsourcer and the worker from eavesdropping. increasing platform users' privacy awareness, informing them of the full risks of a privacy breach, detailed methods of protection, and providing them with the ability to freely opt in or opt-out. Also, there should be punishment for those who violate platform rules, which can serve as a deterrent to users engaging in security-lax behaviors.

5.3 Incentives

Incentives are a form of payment used to encourage user participation in mobile crowdsourcing applications. Jaimes, Vergara-Laurens, and Raij (2015) identify incentives as a critical component of the recruitment process because they influence user participation in MCS data collection activities. This is because tasks in an MCS are performed at the user's expense. These costs may include time spent performing tasks; data costs; transportation costs associated with data collection during crowdsourcing activities; and the risk associated with the disclosure of sensitive data on MCS platforms. The factors that motivate users or contributors to participate in crowdsourcing activities and communities have been extensively studied (Yang et al., 2015; Phuttharak and Loke 2019; Phuttharak and Loke 2020).

Incentives can be monetary, entertainment-related, service-related, or based on social responsibility. Monetary incentives are financial compensation for a crowd worker (Wang et al., 2017; Kong et al., 2019), while entertainment-based incentives involve gamification of the MCS process for a crowd worker using score points, leader boards, etc. (Morschheuser et al., 2016) to encourage workers. Additionally, service-based incentives provide personal benefits to crowd workers, such as knowledge gained from participating in MCS activities, the development of a new skill, etc. The social incentives are referred to as intrinsic incentives that provide a user with satisfaction from seeing how the activities benefit the larger society.

In summary, because each type of incentive has distinct benefits and drawbacks, MCS systems should seek to combine them to develop effective and practical ways of motivating individuals to participate in and provide high-quality solutions for MCS systems. For example, in MCS for public infrastructure monitoring, users can be motivated by an initial data subscription to contribute to the service. Then they can be awarded badges of participation that they can share with their social media friends. This will encourage public-spirited people to want to take part in the MCS activities and also serve as a digital word of mouth (WOM) means of making the MCS app known to more users.

5.4 Task Design

Task design is another critical factor in MCS because it provides a description of the MCS task and, if not implemented properly, can result in low-quality input and, consequently, poor output. Three important components of task design are task definition, user interface (UI), and task granularity (Yufeng Wang et al., 2017). A task definition consists of a primary section that provides a concise description of the task, its nature, and time requirements, among other things. And a second section details the qualification requirements for the task worker. This also specifies the criteria for evaluating the contribution of a crowd worker. For example, if an MCS task asks for location-based data from a certain region, the MCS should tell users that their submissions will be rejected if they come from a different place.

The MCS user interface (UI) is the interaction point through which workers access and contribute to the task. A friendly user interface can increase the number of workers and the likelihood of high-quality outcomes, while a complicated user interface may discourage honest workers, resulting in low system utilization, low-quality results, and delays. The granularity of a task is a measure of its difficulty. According to research, the complexity of the task has a significant effect on the crowd's motivation to participate in crowdsourcing activities (Ghezzi et al. 2018; Lee et al. 2015; Zhao and Zhu 2014). In MCS, tasks are classified as simple or complex. Simple tasks are those that require little sophistication, for example, tagging or describing. These tasks are easy and quick to do, and you don't need any special knowledge or skills to do them. Complex tasks, on the other hand, are harder to do and may need special knowledge.

Complex tasks require additional time, resources, and expertise, so fewer people will be interested or qualified to perform them. One way to address this issue is to introduce modularity into MCS tasks. Modularity enables complex tasks to be broken down into smaller sub-tasks that are resolved by crowd workers and then combined to obtain the final solution. Generally, it is important that task designers properly evaluate the task's difficulty and the effort required to complete it during the task design phase (Liu et al., 2016) and use the information to provide adequate motivation (Phuttharak and Loke, 2019).

5.5 Trust

The lack of trust between crowdsourcers and crowd workers, particularly in MCS for monitoring public infrastructure, is a critical issue. Citizens, who are typically the expected crowd workers, believe that civic engagement will not be productive because they perceive authorities as untrustworthy entities (Yfantis, Ntalianis, and Mastorakis, 2019). Additionally, some (mostly in developing countries) (may have participated in manual reporting in the past and received no feedback or follow-up actions indicating their report was considered. To address this and increase citizen trust in the MCS system, some authors have proposed a feedback system in which reported issues are logged and a message ID and acknowledgment are emailed to the citizens (Bamne & Shinde, 2016).

Additionally, several well-established public-oriented MCS, such as SeeClickFix, FixMyStreet, and Citizens Connect, offer discussion groups in which citizens who submit reports can discuss these issues and also view other members' posts (Santani et al., 2015). Another way to foster trust in an MCS for public infrastructure is to enable visible escalation to higher authorities other than local agencies while informing users via message or app updates. They can also provide a mechanism for broadcasting such reports to news outlets' news feeds when responsible local and state authorities are unavailable.

5.6 Quality control

This assists in establishing the MCS system's output standard. Quality control is a concern throughout the crowdsourcing process and has received the most attention thus far due to the critical role that quality control plays in obtaining high-quality output (Niu et al., 2019). The output quality is determined by a variety of factors, including the behavior of crowd workers, the design of the MCS user interface, the incentive mechanism, the task design, and security and privacy concerns (Wang et al., 2017). Additionally, device resource availability and trust can affect quality. For instance, if users take photos and do not have data to immediately send the report, they may lose the report if procedures to ensure the report can be stored and sent at a later time when data is available are not built into the MCS. The design of tasks with an intuitive user interface, proper task decomposition, and task assignment (in task-oriented MCS) to qualified task workers all contribute to the output's quality. Another potential means of ensuring quality is to adhere to the rules of contribution management in the MCS.

6. Conclusion and future research

The growth of ICT has brought a great change in many aspects of human existence. One such area observed has been in reporting on infrastructure developments and maintenance using mobile devices. In this paper, a review of ICT methods for road infrastructure reporting has been carried out, and a look at the disadvantages of the identified methods was also provided. The desire to have a system that can be used by members of the local community to report road issues, with the possibility of reducing the many unattended road faults in our communities, necessitated this review. It was also observed that the capabilities of the smartphone make them good candidates for use as a means to provide such reports to agencies.

The use of mobile crowdsourcing (MCS) in reporting road issues will allow the community to be involved in providing information about their environment to agencies responsible for taking care of these problems. However, further research is needed to understand how such systems can be effective in environments with no established open 311 platforms, and where control of activities is centered under the control of an individual, such as is the case of many local governments in Nigeria. Also, further research into MCS frameworks is needed as most observed MCS road reporting systems were implemented in developed countries with established routes for community-based reporting and feedback. It is therefore worth studying the many MCS frameworks to propose one that suits the environment of a developing country.

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