

A Comprehensive Crowd-Sourcing Approach to Urban Flood Management

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Abstract. Urban flooding is a common occurrence these days due to many reasons. Providing timely and adequate help to the victims is challenging. Enlisting the citizens to help themselves using their smartphones to provide real-time status updates and ensure timely delivery of needed help is a winning proposition. This paper describes a novel crowd-sourcing approach to urban flood management addressing the inherent challenges using smartphone applications and services that can be deployed by a variety of entities – government agencies, NGOs, social networks, etc. It enables sharing of real time information on the status of flooding, rescue and relief requests and responses, etc. It also collects data from various smartphone sensors in the background which is analyzed and synthesized to track the location and movement of people and to assess the integrity of structures such as bridges. It can also be a valuable resource for future city planning.

Keywords: Urban flood relief · Crowd-sourcing · Smartphone sensors
Sensor fusion · People movement detection · Structural integrity detection

1 Introduction

Urban flooding is a common occurrence across the world. It is estimated that the overall annual cost of floods in Asia alone runs upwards of USD 16 billion [13]. As a result of continuous heavy rains, the city streets get flooded, especially when the planned drainage capacity is insufficient or it has been damaged. The drainage capacity could have been damaged or blocked due to some vegetation growth or due to some construction work leading to improper dumping of debris, etc. Storms, mudslides, etc. could also cause damage to the drainage system. In some cities adjacent to rivers, flooding could also be due to the swollen river. Coastal cities could also experience flooding due to storm surges.

In all these cases, when the flooding occurs, the authorities may not have timely and accurate information and updates on the nature and extent of flooding at various locations, the amount of damage to life and property, the rescue and relief needs of the

people, volunteer help available, etc. They will have to rely on the feedback from the rescue personnel who reach the location or on the calls for help received from the victims. This results in substantial delays in the estimation of damages and the allocation and dispatch of relevant relief and rescue efforts to the affected citizens. This could in turn cause added suffering and result in additional losses to life, health and property. In this paper we propose a solution to gather accurate and timely information through the crowd-sourcing method powered by internet-enabled smartphones and computers. With the help of this real-time information, we believe the people's suffering can be greatly reduced.

Smartphones are ubiquitous in today's world especially in the urban areas. Many people possess more than one smartphone. Use of smartphone apps for various tasks has become a way of life. This behavior presents a unique opportunity to unleash the power of these smartphones and their usage patterns towards solving the problems associated with the way urban flood management is done today. If the citizens of a metro can be motivated to get involved in crowd-sourcing initiatives to help the authorities or other relief agencies in flood management, it has the potential to revolutionize the approach to flood management. The citizens need to realize that they are actually helping themselves by participating in crowd-sourcing. When this realization dawns, they will want to help spontaneously without the need for any incentives. The participation of citizens in crowd-sourcing will enable real-time status updates on flooding and will ensure timely delivery of appropriate rescue and relief supplies to the victims. It will also encourage citizens to participate in the relief efforts by donating their time and money towards it.

This paper presents a novel crowd-sourcing approach to urban flood management. This solution will address the inherent problems in conventional urban flood management with the help of citizens. A suite of smartphone applications and services that can be deployed by a variety of entities – government agencies, NGOs, social networks, etc., is developed. This suite enables sharing of real time information on the status of flooding, rescue and relief requests and responses, etc., among the citizens, rescue personnel and government authorities. This information is also made available to the citizens in real time thereby benefitting them directly. This suite also collects data from various smartphone sensors in the background. This data is analyzed and synthesized to track the location and movement of people during a flooding event and also to assess the integrity and load carrying capacity of bridges. This is done by collecting data from the smartphones of people walking and driving on the bridges. The safety information of the bridges is used to calculate various safe evacuation routes and these routes are presented through a map interface. In addition to the citizens as end users, the app-suite provides detailed, relevant and up-to-date information to the relief and rescue providers. The administrative authorities can also use the data collected from this suite for matching demand and supply, to generate custom reports and as a valuable resource for future city planning. By conducting root cause analysis of issues based on the data collected, they can identify suitable remedies towards improving drainage systems and other infrastructure to mitigate future floods.

2 Related Work

Crowd-sourcing has been attempted in the past fairly successfully towards solving specific problems related to flood management. In the framework of the FP7 SPACE Project GEO-PICTURES, AnsuR and United Nations (UNOSAT) collaborated on using a smartphone App for crowd-sourcing geo-referenced insitu images for the purpose of improving flood assessment from Radar EO Images. This was successfully deployed during the 2001 monsoon season in Thailand when severe flooding occurred (The European Association of Remote Sensing Companies 2012) [1].

During the 2012 floods in Philippines [2] and Beijing, China [3], successful crowd-sourcing initiatives were launched. In Philippines, the initiative was to track the places and people in need of help the most using a spreadsheet in Google docs. Google Person Finder app was also used. The participation from the public was robust and enthusiastic both for using the spreadsheet for tracking as well as for updating the spreadsheet based on their knowledge. In Beijing, China, users of the Guokr.com social network launched a campaign to create a live crisis map of the flood's impact using Google Maps. Up-to-date real time status information was generated by crowd-sourcing hours before similar information was released by the government agencies. The success of the above initiatives bears clear testimony to the power and feasibility of crowd-sourcing as an urban flood management tool.

Our goal is to take this to the next level by providing an integrated and comprehensive suite of flood management applications and services based on the smartphone. This suite will enable the end users to share their knowledge about the flood and the victims. The suite will also provide useful and current information about the flood situation, rescue and relief service needs and availability information to the public. The suite will also provide detailed and relevant information to the rescue personnel on the ground to help in their rescue and relief operations. Additionally, it will empower the administrative officials to quickly and efficiently match the demand and supply for rescue and relief, and provide searching and filtering options to generate custom reports and tables. It will also help in the city planning exercise for the future by helping the officials conduct root cause analysis of various problems encountered based on the data collected.

Jha et al. [4] provide operational guidance to government policy makers, NGOs and technical specialists on how to manage the risk of floods in a rapidly transforming urban environment and changeable climate. Reference [5] is an article in the Intellectap publication, Searchlight discusses the issues posed by urban flooding in India. The technique of data fusion from smartphone sensors has been used in several applications [6, 8, 10].

3 Research Challenges

There are several challenges in urban flood management and the application of crowd-sourcing for urban flood monitoring. The families living in cities tend to be nuclear and isolated with very little social interaction with the neighbors. They also tend to live in multi-storied multi-tenant buildings consisting of hundreds of housing units. Identifying the location of trapped victims who need help and identifying the type and quantum of

help needed becomes a big challenge in such situations. In addition, there may be buildings in the city that are poorly planned and constructed in the low-lying areas which were water bodies at one time. The slums and the other underprivileged populations in the city tend to live in such areas. The roads leading to such areas may also be narrow and very poorly maintained. However, the price points at which smartphones are available today have made them affordable to practically all strata of society. Therefore, introduction of smartphone based crowd-sourcing of flood management and relief will mitigate the challenges mentioned above to a great extent.

In addition, there are certain challenges that arise when crowd-sourcing is applied. The veracity and reliability of the data obtained needs to be ascertained. Spurious and malformed data may be supplied simply due to callousness on the part of participants or with specific malicious intent by some rogue elements in the society. Such bad data needs to be identified and weeded out. The application can dynamically build and maintain the trust profiles of end users. The users can be rated based on their trust profiles and those below a threshold can be discarded. There is also the chance of inadvertent duplication of rescue or relief requests coming in either from the same source or from multiple sources. We need to have suitable mechanisms to identify and eliminate such duplicates.

Motivating the end users to participate actively in crowd-sourcing is also a challenge. General display of apathy by the citizens towards the call for participation is a likely scenario. This needs to be handled by raising the awareness about the benefits that will accrue to the society which will directly improve their own quality of life. The younger generation in schools and colleges is the ideal target audience for creating this awareness by running campaigns. In addition, incentivizing the end users by providing free data or SMS service or discount coupons at shopping malls, etc., are potential ways to improve participation.

There is also the likelihood of the flooding affecting the functioning and stability of the communication network in the city. This is more likely in a rural scenario than in an urban scenario. When this happens, ad hoc networks may be provisioned to provide alternate channels of communication to the residents. Flooding may also affect the availability of power and the users may not be able to charge their phones. Vending or providing battery packs or other sources of power will alleviate this situation.

4 Our Approach

We are developing mobile and web applications targeted to citizens, rescuers and administrators. These applications are supported by a high performance, scalable, fault tolerant server architecture. The mobile and web applications feature light-weight, high performance, and simple-to-use interactive graphical user interfaces in multiple languages. The registration process for the citizens is kept simple and quick with only email verification. Whereas for the rescuers it will require some more background checking. For the administrators, the system allows more flexible/configurable registration process which suits the respective authorities who use the system.

The mobile application allows citizens & rescuers to upload information, request for and respond with rescue and relief. In addition the mobile application also captures the

various sensor data automatically and sends to the server. All the information and requests are geo-tagged and time-stamped for accurate analysis and representation. The web application, in-addition to above features, also has reporting interfaces for summary and data visualization and analysis. A sample screenshot of requests from a locality overlaid on a map is shown in Fig. 1.

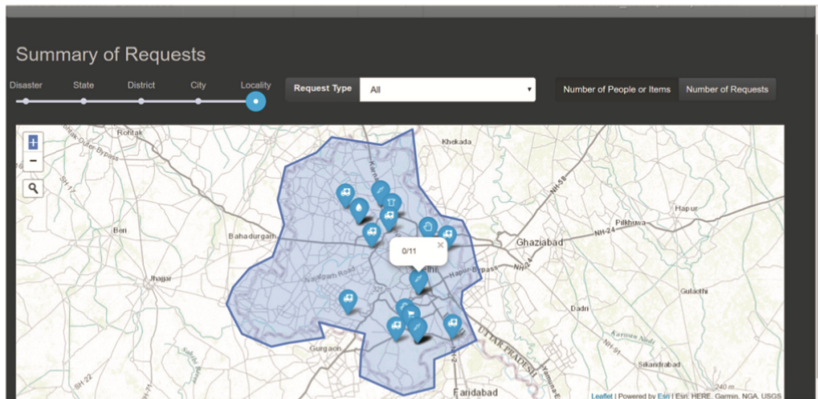


Fig. 1. A sample screenshot from the web app

The users can upload images and videos of any flood and hazard situation. These images and videos are automatically analyzed using machine learning techniques and computer vision algorithms to determine the extent of flooding, damages to property and lives, and various hazard situations like fallen trees, washed out roads, collapsed electric poles, etc. Users also can fill some simple and intuitive forms explaining the situation. Users are also allowed to enter free-form text. The free-form text is analyzed using natural language processing techniques to extract relevant information. All such information about the extent and depth of flooding, damages to property and lives is stored with geo-tag and time stamp information. The information is further summarized and presented in various reports.

The mobile application also automatically captures and sends various sensor data such as data from GPS, accelerometer, light sensor, etc., to the server. This data is analyzed to infer location of people and their movement characteristics which is in turn used to estimate the count of stranded people.

During the flooding situation, people might use various bridges in the city to evacuate to safe places. But because of the flooding, the bridge's structural integrity might be affected. There is a critical need to ensure that the bridges are safe to use during the evacuation process. Our approach is to extend the mobile application such that the built-in movement sensors of a smartphone can capture vibrations of the bridge which naturally emerge during its usage. The acceleration sensors in most off-the-shelf smartphones have been proven to be sensitive enough to capture vibrations caused by moving vehicles or even by pedestrians. These vibration patterns can be used to draw conclusions about the remaining integrity of the construction. Eventually this data can be used to suggest to which degree the bridge can still be used.

Safe evacuation routes are automatically determined based on the integrity of bridges thus calculated, along with various hazard situations on the roads. This information will be continuously revised based on the latest available information. This work is being done by one of the partners in the consortium.

Apart from sharing the information related to flooding and damages, users can request or offer help through these applications. Users can request for rescue of stranded people and animals, request for relief such as food, clothing, water, blankets and other essentials, and services like medical help, power supply, water supply, cleanup of damaged property, fallen trees, fallen electric poles, dead bodies of animals and people. Citizens can request for or offer shelters. The status of each shelter such as free capacity, timings, restrictions, etc., will be available on the summary page. These requests for help are also geo-tagged and time-stamped. This allows for aggregation of the amount of help needed by various regions, so that the authorities can properly allocate and dispatch efforts and resources promptly and accurately. This ensures that citizens receive adequate help in a timely manner.

The application also allows citizens to pledge and respond with help or supplies. All the responses for help by either authorities or citizens will be entered into the application, allowing the requesters to see that help is on its way. This can lead to rapid and efficient micro-level matching of demand and supply in real time which will in turn result in a highly responsive and effective system of mitigation and relief for the victims of flooding. Figure 2 shows some sample screens from the mobile app.



Fig. 2. Sample screenshots from the mobile app

The citizens can view the latest flooding information such as extent of flooding, help required, help being provided, hazards, integrity of bridges, suggested evacuation routes, along with the pictures sent by people. This information page will be automatically updated in real-time. All the information will be presented both on a map and as spreadsheets. The authorities have more interactive data visualization tools to slice and dice the information along the spatial and temporal grains for better relief planning. These data tools are also quite useful long after the flooding has abated, in future planning of city infrastructure.

All the collected data related to flooding, help requests and responses are geo-tagged and time-stamped. The images and text are analyzed using machine learning techniques and natural language processing techniques to extract information about flooding, damages and hazards. All the information is correlated with multiple sources when possible to ensure accuracy. The duplicate information is removed using geo-location and by correlating with multiple sources. Where possible, the call-center process can be used to confirm the exact rescue and relief requirements. The data is then, on a periodic basis, aggregated into multiple levels of summaries along the spatial and temporal granularities. This data also can be used to automatically match available resources to the help requests in an optimal manner. This data can be used to plan for and provide required help, targeting it to the areas where it is needed the most. This allows for historical and geographical analysis of flooding, damages to infrastructure, help and shelters required and provided, etc. This data can be a valuable resource for planning future infrastructure work in the cities to avoid further flooding scenarios.

The system provides both mobile and web interfaces, supported by scalable, high performance, event-driven, and robust server architecture (Fig. 3). The entire system is based on open source packages, which will reduce the deployment costs considerably. The data is exchanged with server in the light-weight and universal JSON format. All the server commands are exposed in the form of APIs, which can be accessed by these mobile and web interfaces. The same APIs can also be accessed by third party systems as well. All the interfaces are designed to be intuitive, light weight, highly interactive and responsive to suit the screen size and would let users achieve what they want with minimum clicks.

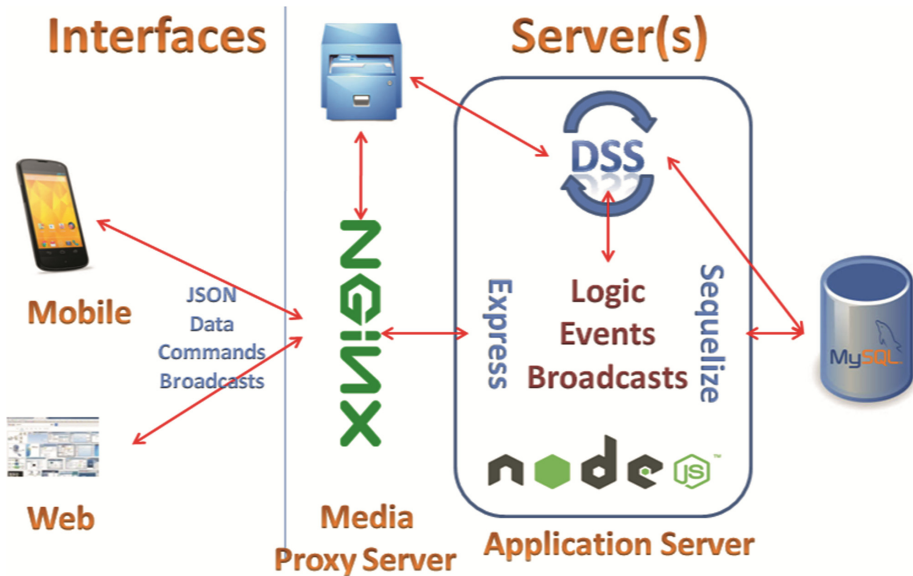


Fig. 3. System architecture

On the server side we use a high performance web server called NGINX, which handles all the media such as images, audio and video. The web server is backed by the Application server powered by high performance, highly flexible, extensible, robust, and heavily adopted NodeJS server. We use Express package as command router inside NodeJS, and Sequelize as the ORM (Object Relational Mapping) package to interact with MySQL database.

The code which comprises the application logic is written in a re-usable modular fashion. The logic consists of periodic event code to run any scheduled tasks and broadcasting code to push any relevant updates to user interfaces based on what's being viewed by a given user at that time. That way, the user would get updates on only what he/she is currently viewing, thereby reducing bandwidth and resource consumption.

The DSS module is the brains of the system, which employs several machine learning and natural language processing algorithms to analyze image and text data. It also ensures data accuracy by correlating data from multiple sources. It employs data mining techniques to predict the extent and duration of floods and finally aggregates data into multiple spatial and temporal granularities so that it can power the data visualization interfaces.

The data flow diagram (Fig. 4) shows how and what data is exchanged between various users, processes and data stores. All the users like citizens, rescuers and administrators can upload images, audio and video files, which are handled by NGINX server and these media files are stored in the file system. The users can also query for latest summary of the flooding event which has information about extent of flooding, damages to life and property, hazards, status of rescue and relief efforts etc. All the queries are handled by NodeJS application server and the application logic hosted on NodeJS, which in turn queries the data from MySQL database. The users can submit requests for rescue and relief and they can also respond with offer of efforts and resources towards rescue and relief. All these requests and responses are handled by NodeJS application server and the data is stored in MySQL database. In addition, the smartphone users automatically transmit various sensor data. All this data is also stored in MySQL database through NodeJS application logic. Apart from these data exchanges, the administrators can manage the rescue and relief efforts and can also query for various statistical data based on dates, geo locations, etc., to analyze the various aspects of flooding. All these data requests are handled by NodeJS and MySQL database. All the users would get automatic broadcasts whenever any data related to what they are currently viewing in their applications or data related to requests and responses they submitted is updated. All these broadcasts are determined and triggered by NodeJS application server.

The Decision support system triggers various sub processes either periodically or based on any data events. The media analyzer process would analyze images, audio, video and free-form text to extract information related to extent of flooding, hazards, rescue and relief requests and responses, whenever such information is submitted by users. The data aggregation process summarizes all the statistical data related to flooding and rescue and relief operations into various spatial and temporal granularities, and these summaries are provided to users through summary pages and data visualization tools. The data cleanup process removes duplicate and inaccurate data by confirming with multiple data sources and/or by confirming with the users through call-center process.

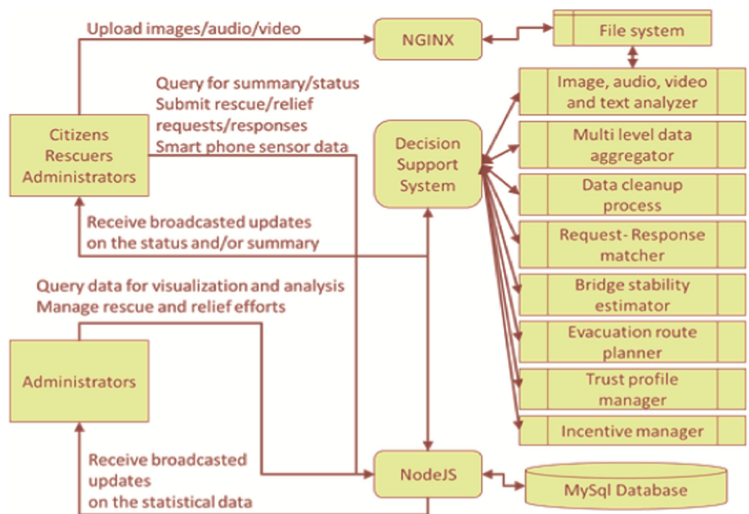


Fig. 4. Data flow diagram

The matching process optimally matches the offers for rescue and relief with requests for rescue and relief on the basis of location, urgency, and any other factors which are configured in the system. The Bridge stability estimator estimates the structural integrity of the bridges based on the data collected by user’s smartphone sensors and a few other factors not discussed here. The Evacuation route planner uses the bridge stability estimations and hazard conditions analyzed by other modules to suggest several safe evacuation routes out of the flood zones to various shelters. The trust profile manager updates the trust score of the user based on authenticity of information provided by user. The incentive manager updates incentive score of the users based on the number of authentic and unique information provided and based on the rescue and relief offerings. Except the media analyzer process, all the other sub processes are triggered on a periodic basis. All these sub processes query data from and update the processed data to the MySQL database through NodeJS application logic. Whenever any sub process updates the data in the database, the NodeJS application logic determines the relevance of this data to the currently logged in users and broadcasts these updates automatically to their interfaces so users can view these updates in real-time.

4.1 Deployment Models

We envisage the following deployment models which allow for faster deployment and also provide flexibility if the users choose so. We offer it to the world as Software as a Service (SaaS) deployed in the cloud; all that the users need to do is to register and start using it. When a disaster occurs, the relevant authorities would create a disaster event in the system and assign relevant geographical regions to the disaster and all the users who live in those areas can start sharing information related to the disaster. Since it is a SaaS implementation, many people in different regions would be using the same system

simultaneously for different flood scenarios if needed. All the information across many such events is stored in the same logical location, which becomes a valuable resource for intense data analysis and planning. Apart from SaaS, we also provide enterprise deployment options for required Governments or NGOs. Both types of deployment come with detailed APIs, which allow for any other systems to interact and extract data and present or use it in multiple ways.

A third model would consist of two parallel deployments, one as SaaS and one as an enterprise deployment. While the enterprise version will get updated based on authentic information by an administrative body such as a Government agency or an NGO, the SaaS version can be updated by the general public. In this model, the SaaS version will have faster updates in near real time. The administrative agency can use this information to verify the authenticity and update the enterprise version with authentic information based on their finding in addition to initiating the necessary action. This model was suggested by an officer of the Indian National Disaster Management Agency (NDMA) when we got our prototype reviewed by him.

4.2 Current Status and Adoption Strategy

We are in the process of releasing a beta version of this system. Our beta users will consist of Government agencies such as NDMA as well as NGOs. We also plan to run a mock drill within our University campus to stress test the system under heavy load. Stress testing using canned test cases has already been done successfully.

The computer vision algorithms are being tested and verified using some flooded pictures obtained from Kulmbach, a town in Germany chosen by our German partners for prototyping their work. These pictures have the water level marked along with the dimensions of bridges which are used as reference objects. The water level arrived at using computer vision are compared to the measured values.

Usually crowd-sourcing models could suffer from lack of adoption from users as there is no tangible incentive to users. However, once it is shown to work well in a couple of instances, adoption for subsequent deployments becomes that much easier. We plan to use the following approach to help in the adoption. Amrita University's parent NGO, M.A. Math has done relief work during flooding events in many cities in the past through its voluntary organization, "Embracing the World" [12]. We plan to choose a couple of such cities for our initial deployment as we can leverage the connections M.A. Math has with the local authorities and people in those cities. We will then run advertising campaigns in the local schools and colleges about this application and how they can benefit and serve their community at the same time by using it. We will work with the local data providers to provide some form of credit for data usage by this application so that users won't incur data charges for sharing images, videos etc. We will also introduce some incentive points for every unique piece of information shared by the users. These incentive points could be exchanged for shopping vouchers or free mobile talk time.

5 Conclusion

The widespread adoption of smartphones and their common usage patterns among the urban population can be very effectively leveraged to improve the efficiency of urban flood management and provide relief in near real time to the victims. We take a comprehensive approach with applications that target multiple user types – citizens, relief providers and administrative authorities. It allows them all to provide relevant and useful information towards flood management while at the same time getting the latest status information from the system. The system is used to both request and volunteer for relief and rescue operations thereby providing micro-level matching of supply and demand in real time. In addition, sensor data from smartphones is collected automatically and synthesized to estimate locations and mobility patterns of victims and also to estimate the stability of bridges. Safe evacuation routes are calculated based on all the available information and displayed on a map.

By providing both a mobile app and a web app, we also cater to operations that require more real estate on the screen, especially various types of maps and reports that may need to be generated by the administrative authorities. A scalable and cost-effective architecture based on open source software packages, light-weight communication protocols to make the application highly responsive and a simple and intuitive graphical user interface to ensure ease of use are some of the salient features of the solution. We will support both SaaS and enterprise deployment models. We have also outlined our adoption strategy that addresses the inherent challenges in crowd-sourcing. Overall, our proposed comprehensive approach to crowd-sourcing of urban flood management has tremendous potential to revolutionize the conventional methods of flood management.

This is presented as an urban flood management system as the smartphones are widely used and internet is ubiquitous in urban areas. This system is equally effective in rural areas as long as smartphones or computers with internet access are available.

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