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A geolocation-aware mobile crowdsourcing solution for the emergency supply of oxygen cylinders

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Abstract

Emergency medical oxygen cylinders are commonly used as first aid kits to prevent strokes during chronic obstructive pulmonary disease (COPD) / asthma attacks. In this paper, we propose a geolocation-aware mobile crowdsourcing solution for the emergency supply of oxygen cylinders to patients suffering from sudden breathing difficulties. The proposed crowdsourcing solution leverages the proliferation of mobile devices to connect requestors of emergency oxygen cylinders with potential suppliers from the crowd during crises. We describe the design process of the system, its technical implementation details, and key features. We also discuss some of the encountered challenges and summarize the actions taken to address them.

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Keywords: Smart healthcare; crowdsourcing; collaborative systems; mobile health information systems; crisis management

1. Introduction

Respiratory diseases are the leading causes of death worldwide with chronic obstructive pulmonary disease (COPD) / asthma being the fourth most common cause of mortality [1]. During an asthma attack, patients suffer

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from shortness of breath, chest tightness, and a drop of oxygen-level in the blood, which can be fatal if the situation persists for long periods.

Various environmental factors act as powerful respiratory irritants that can contribute to worsening the shortness of breath among COPD patients. For instance, on September 30, 2019, very hot and dry conditions in Huntsville, Ala, made it very hard for people to breathe, causing many to seek emergency hospitalization for respiratory complications [2]. The Associate Press [3] reported that on November 5, 2018, many women in New Delhi, India, received emergency oxygen cylinder treatment for respiratory complications due to severe smog as pollution jumped to an alarming level.

The aforementioned transient conditions can trigger a temporary crisis whereby the demand for oxygen therapy exceeds the regular supply availed from hospitals and emergency medical services. Even in developed countries, the increase in the number of people with chronic respiratory problems has put tight budgetary constraints on the number of patients who are eligible for home oxygen delivery services from National Health Service (NHS) authorities [4]. As a result, for better crisis response and management, the need to identify new sources of oxygen delivery to cover the shortage in supply becomes even more accentuated.

In this paper, we propose crowdsourcing as a potential alternative for the emergency supply of oxygen cylinders during emergencies. Our geolocation-aware participatory application connects COPD/asthma patients (consumers) with nearby providers of Oxygen cylinders during emergencies. The providers can consist of registered health service providers, private clinics, or individuals (e.g., other asthma patients) who are volunteering to offer oxygen cylinders.

The remaining of this paper is organized as follows: In Section 2, we present a literature review of major related studies and highlight the contribution of this research. In section 3, we present the system analysis and design aspects of the proposed solution, followed, in section 4, by a description of its implementation aspects. Section 5 describes the main user interfaces, while section 6 presents our testing and validation activities, followed, in section 7, by discussions of the main challenges that emerged from this study. Finally, in Section 8, we provide a summary of the main findings of the paper.

2. Literature review and research contribution

Many healthcare crowdsourcing applications have been proposed in the literature. Bigham et al. [5] proposed VizWiz, a crowdsourcing platform to recruit human workers to help blind people answer questions related to visual problems. With VizWiz, blind people send pictures from their mobile devices, speak a question, and then receive multiple spoken answers from the crowd.

McComb and Bond [6] developed a web-based crowdsourcing solution, with an element of gamification using reward points, which enables junior doctors to upload cases and receive advice from expert physicians.

Merchant et al. [7] developed a crowdsourcing application for mapping Automated External Defibrillators (AEDs) in Philadelphia. Registered participants used the app to photograph AED locations (along with AED information) in return for a chance to win US\$ 10 000 prize. One thousand four hundred twenty-nine submissions were received.

Freifeld et al. [8] proposed an application that collects information from patients using Asthmapolis, a GPS-enabled inhaler that is linked to a user's mobile device to tracks asthma attacks. The application generates a risk map for environmental triggers.

This contribution aims to design interactive technologies to support COPD/asthma patients during emergencies by initiating the concept of crowdsourcing the supply of oxygen cylinders as a potential basis for emergency response. To the best of our knowledge, this is the first contribution that aims to explore the concept of crowdsourcing the supply of oxygen cylinders during emergencies.

3. System analysis and design

We have adopted the Design Thinking technique which is a popular Human Centered Design (HCD) design methodology and a problem-solving approach that allowed the development team to create prototypes quickly, test them, gather feedback, and then create an improved version. The Design Thinking process is an iterative process

that aims to think out of the box and challenge assumptions to discover new ways to meet users' needs [9]. The method consists of five iterative stages: Empathize (learn about the user groups for whom we are designing), Define (construct a point of view that is based on user requirements and intuitions), Ideate (brainstorm and generate creative ideas and solutions), Prototype (build a mockup to show to others), and Test (return to the original user groups and test ideas for further feedback).

3.1 System analysis

Several focus group meetings, and brainstorming sessions guided the analysis activities, followed by three main collaborative prototype evaluations workshops. UML use case modeling has been adopted to capture the functional requirements of the system as use cases (1) focus on the interactions of the actors with the system, (2) are effective techniques for communicating system behavior in the user's terms, and (3) help in identifying exceptions to successful scenarios, which can further improve system robustness.

3.2. System design

3.2.1. Application architecture and description

Smartphones are ideal candidates to support mobile crowdsourcing solutions because these internet-enabled and geolocation-aware mobile devices are gaining increasing computational power and ubiquity. The general architecture of the proposed solution is shown in Fig.1, and it consists of three main entities: The asthma patients (consumers/end users), the crowdsourcing platform, and the oxygen cylinder providers (supplying crowd).

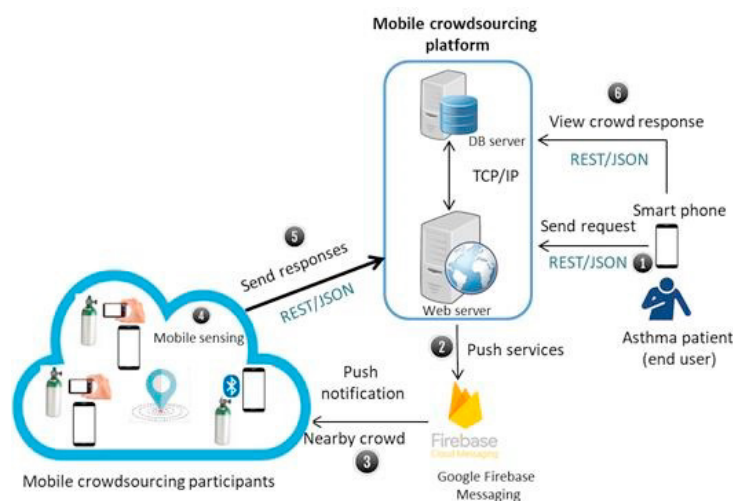


Fig.1. General system architecture

3.2.1.1. The Crowdsourcing platform

The platform provides crowdsourcing services to both COPD/asthma patients and oxygen cylinder providers who must be registered, using a mobile application, as consumers (end users), oxygen cylinder suppliers, or both (in case an asthma patient has spare oxygen cylinders to supply). The platform plays the role of mediator between these two entities. Typically, the platform is owned by a trusted entity such as a regional or National Health Service authority. The crowdsourcing platform accepts geo-tagged emergency requests and pushes notifications to registered oxygen cylinder providers, using Google Firebase Cloud Messaging (FCM).

The crowdsourcing platform integrates and validates the received responses and publishes the results for consumption by the requestors. The crowdsourcing platform supports several services, including registration, reputation, end-user service request, dispatching, data integration, and data storage.

3.2.1.2. The COPD/asthma patients (end users)

The end users are the asthma patients who, under emergencies due to respiratory difficulties, are seeking donors of oxygen cylinders among those registered crowd members who happen to be located within a specified radius from their current location.

End-users interact with the mobile application to send emergency service requests to the platform and can then access geo-tagged responses that are displayed graphically on a map. By clicking on a given icon, the end user can access the metadata associated with the corresponding supplier. The user can call the oxygen cylinder provider automatically by a simple click on the displayed phone icon. The end-user can subsequently connect to the platform to report his rating of the contacted crowd supplier.

3.2.1.3. The oxygen cylinder providers (supplying crowd)

The supplying crowd consists of mobile users who (1) are registered to the platform, (2) happen to be in the neighborhood of the end-user at the time the request was sent to the platform, and (3) accept to respond to the request. To avoid unpleasant surprises, the application requires the provider to read the remaining oxygen supply (p.s.i pressure) from the designated cylinder via the smart-phone’s Bluetooth interface and to append the information into a geo-tagged response to be delivered to the platform. In case the oxygen cylinder is not equipped with a Bluetooth-enabled pressure monitoring system, the provider uses the smartphone camera to take a picture of the analog gauge display, select the residual oxygen level among three categories (Low [$p < 600$ p.s.i], Medium $600 \leq p < 1500$ p.s.i] and High [$p \geq 1500$ p.s.i]), and append the response into a time-stamped and geo-tagged message to the platform. In this particular case, the platform cross-checks the reported oxygen level against the true level displayed in the uploaded gauge picture. For this purpose, we have implemented a computer vision algorithm that extracts the needle orientation and classify the reading into one of one of the abovementioned three categories. Discussions of this algorithm are omitted due to lack of space.

3.2.2. Physical architecture

Our solution is 3-tier architecture that consists of (1) the user interface (stored on the client smartphone), (2) the business application logic (stored on one or more servers), and (3) the data (stored in a database server).

3.2.3. Logical and software architecture

The logical architecture consists of four layers, namely the presentation layer, the service layer, the business layer, and the data access layer. The software architecture of the proposed system is illustrated in Fig.2, and it illustrates in more detail the software elements associated with each layer of the logical architecture, as well as the relations among them.

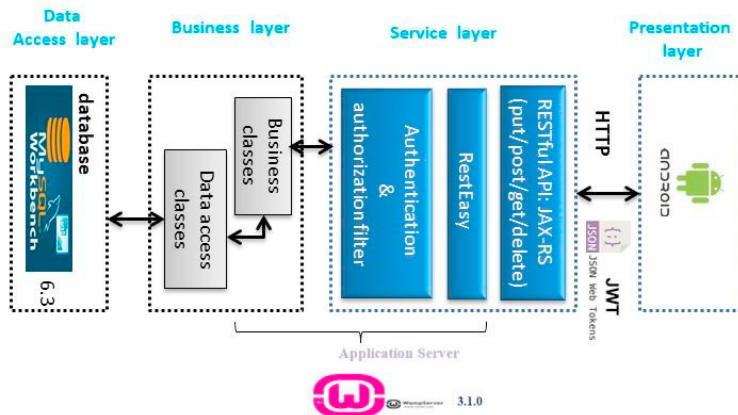


Fig. 2. Software architecture

4. Implementation

We have opted for various technologies and development tools to implement our proposed solution:

First, we opted for RESTful Web Services because of their inherent advantages in terms of simplicity, performance, scalability, and maintainability. Under the REST architecture, data and functionalities are treated as resources that are accessed through their Uniform Resource Identifiers (URIs). These resources are represented in JSON format and are manipulated using basic HTTP methods. We have opted for JSON as a data-interchange format because it is simple, flexible, lightweight, language-independent, and fast to parse into JavaScript objects.

Second, we used the Android SDK platform, which includes several packages such as the Android SDK platform package, the system image packages and the source files.

Third, we made use of the *Gradle* toolkit, which is used by Android Studio to automate and manage the build process, while allowing the development team to define flexible custom-build configurations. In our case, we used Gradle version *com.android.tools.build:gradle:2.3.3*, in conjunction with Android Platform 9 API 28 and Android Studio 3.2.1 IDE.

Fourth, we have implemented the Volley HTTP library, developed on GitHub, to make the app's networking requests faster and more efficient.

5. User interfaces and interactions

As shown in Fig.3.a, when the user logs in to the app and clicks on the “Ring Bell” icon to issue a request to the platform for an oxygen cylinder, he is prompted to confirm his action. A confirmation message (Fig. 3.b) will be returned once the server forwards the message to the registered participating crowd members.

Upon receiving the message request, the platform broadcasts an alert to all subscribed suppliers. However, only those who are located within a specified (5 Km by default) radius from the requester are notified. Fig 3.c shows the alert screen which is accompanied by an audible alarm sound.

If the notified crowd supplier opts to respond to the request, he/she is prompted to choose between 2 options to report the residual oxygen level (Bluetooth reading or image capture of the analog gauge reading) before being forwarded to the next screen (Fig.4.a). In the first case, the provider is prompted to directly read the amount of oxygen via the smartphone Bluetooth interface and send the result to the platform. In the latter case, the camera is activated and the provider is prompted to capture a snapshot of the analog gauge display inside a circular bounding box (Fig 4.b). The user is then taken to another screen, where he is requested to select the residual oxygen level among three categories (Fig.4.c).

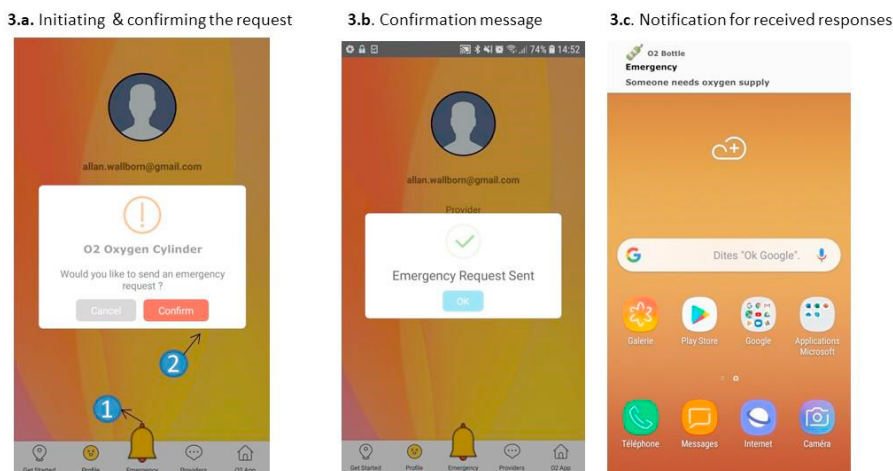


Fig. 3. Sample of UI dialog screens

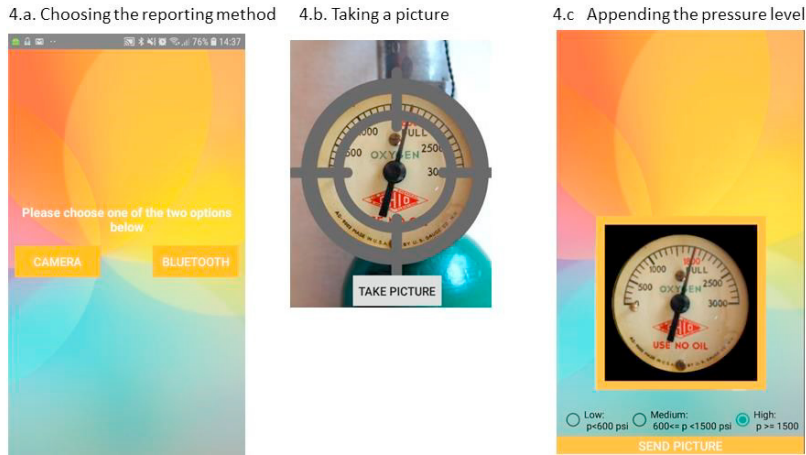


Fig.4. UI for crowd responses

The crowdsourcing platform integrates and validates the crowd responses. Any response, based on an image capture of the oxygen cylinder’s gauge, and whose user-reported level does not match the one reported by the platform’s computer vision algorithm, is tagged with an uncertainty caution alert.

The platform polls the received responses ten times, once every 2 minutes, and, as soon as one or more responses are received, it pushes the results to the end-user for consumption. By a simple click, the user can access geo-tagged responses displayed on a map as shown in Fig.5. By clicking on a given bottle icon, the requestor can access the metadata associated with the crowd supplier, which includes the supplier name, credibility score, residual oxygen level (as a p.s.i pressure value or as one of three levels: Low, Medium, or High), and a reliability caution alert if applicable. The user can click on the displayed phone icon to make a call to the provider.

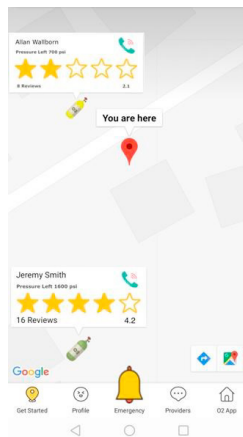


Fig.5. Reported response from the crowdsourcing platform

6. Testing and validation

Testing and validation of the proposed system against its requirements proceeded following an iterative process that involved the research team as well as three volunteering research assistants as test participants.

Among the key priorities of our testing activities was the need to ensure a high degree of usability by adhering to proven human-centered design principles for interactive systems as recommended by ISO 9241-210:2010 specifications [10] We adopted the three usability metrics (efficiency, effectiveness, and user satisfaction), as

defined by the ISO/IEC 25022:2016 standard [11]. Accordingly, seven prototypes associated with five iterations have been developed, tested, and modified repeatedly to meet better our usability goals better.

We have performed several functional testing experiments and successfully evaluated the system against their requirements. Additional testing involving COPD/asthma patients, are envisaged in the future as part of a pilot study.

7. Discussions

As with most crowdsourcing solutions, our proposed approach is subjected to several design challenges that are briefly discussed below.

7.1. Security and privacy

The main privacy concern is the potential leak of personally sensitive information when initiating or responding to a request. The data sent from the asthma patients to the platform contains sensitive information related to the patient's ID, an implicit indication of personal asthmatic health condition and location. Similarly, the spatio-temporal data exchanged between the crowd suppliers and the platform contains identity information along with location information whose disclosure can threaten the privacy of the supplying crowd. In all cases, it is a challenge to guarantee the privacy of the participating crowd as anonymity [12] is not a practical solution for our special application. Instead, we will rely on the trustworthiness of the server provider and the mechanisms that will be put in place to prevent the leakage of private information. To this effect, several measures have been put in place to address potential security and privacy concerns:

First, our solution integrates the core principles of privacy notices and informed consent that are exposed to the users when they engage with the application for the first time.

Second, to secure the transmission between end-users, the crowdsourcing participants, and the platform, we made use of signed (HMAC/SHA-5) JSON Web Tokens (JWT), an open standard based on RFC 7519 that defines a self-contained way for securely transmitting information between parties.

Third, the Transport Layer Security (TLS) is used for establishing secured encrypted communication channels between the platform and the clients.

Fourth, the records stored in the platform's database are automatically encrypted and password-protected.

7.2. Trust and Reliability

Reliability can be impaired because of the lack of attention in completing the assigned task when responding to a request or because of intent to deceive. For instance, it is challenging to confirm the correctness of the reported residual oxygen level. In our case, we tried to partially address this issue by using computer vision techniques to cross-check the pressure-level computed from the analog gauge picture against the reported level. This assumes that the gauge picture is authentic, which is not always the case.

Reputation and trust of the crowd are important considerations in most crowdsourcing apps like the one described here [13]. Trust is an inherent challenge in most mobile crowdsourcing solutions that are often based on the premise that the crowd is expected to behave honestly and provide valid data, which is not always the case [14]. In our case, it is difficult for the platform to guarantee that end users are sending genuine emergency requests or that the providers are responding with reliable data. However, since the identity of all participants is not anonymous from the platform's perspective, such a threat is minimized. In fact, in our case, the platform requests that each user who wishes to register must go through an authentication mechanism. The platform verifies the phone number of users by sending a verification code (One Time Passcode: OTP) during registration, which removes the possibility of a user registering with a fake mobile number. The rating scores of crowd members can also be used as proxy indicators of their reputation and trustworthiness. Members with poor ratings can have their subscriptions suspended by the platform.

7.3. Mobile device Battery life

Since the usability and reliability of the app depend heavily on the battery life of the mobile device, care has been exercised to ensure that the processing and memory requirements of the proposed app are kept to the minimum. To minimize battery drain, we followed some best practices in mobile app development, taking advantage of the inherent features of Android in reducing power consumption. Among these we can cite the following:

- Batching inbound and outbound data transfers to optimize network access scheduling
- Exploiting the cache tools of the Android Volley networking library by caching user's data to reduce making unnecessary requests to the platform.
- Using Geofencing so that only users within the perimeters of the Geofence will receive notifications
- Using Google Firebase Cloud Messaging (FCM) services to push notifications from the platform towards the supplying crowd participants. FCM provides a lightweight mechanism that alleviates the need for the crowd's mobile apps to poll the platform for updates when there is no data to transfer.

8. Conclusion

In this contribution, we introduced the concept of crowdsourcing the supply of oxygen cylinders for COPD/asthma patients during emergencies and implemented an advanced proof of concept prototype system. It is hoped that this contribution will trigger new innovative applications of crowdsourcing to healthcare in general and life-saving during emergencies, in particular.

Among the promising areas for future research is the potential application of anonymization and other privacy-preserving techniques to the crowd responses without impeding the platform's capability of delivering reliable services.

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