A situational awareness framework for improving earthquake response, recovery and resilience

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Published version

GIBSON, Helen, AKHGAR, Babak, HAJIRASOULIHA, Iman, GARCIA, Reyes, OZDEMIR, Zuhal and PILAKOUTAS, Kypros (2016). A situational awareness framework for improving earthquake response, recovery and resilience. In: 16th World Conference on Earthquake Engineering, Santiago, Chile, 9-13 January 2017. (In Press)

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A Situational Awareness Framework for Improving Earthquake Response, Recovery and Resilience

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Abstract

When we think of understanding the impact on the buildings of a city from an earthquake we imagine structural engineers assessing structures and the local area through measurements and readings. However, the access to such areas is not always straightforward and nor is it necessarily possible to have enough manpower to complete these analyses. Instead, crowdsourcing and smart sensors can be utilized in both the pre and post disaster phases using information witnesses to give enhanced situational awareness to those coordinating the earthquake response effort. Even in remote areas many people have access to smartphones, wearable technology and mobile internet access. Furthermore, with the advent of smart cities, further sensors can be placed strategically on infrastructure and transmit information about its structural health. Dedicated mobile applications can be used to capture reports, photographs and videos of vulnerable infrastructure before and after an earthquake. These photos and reports can then be mapped to identify areas where structures or critical infrastructure are most at risk or where other secondary effects may occur. This can be done before sending in expensive manpower to areas that may not yet be safe. Moreover, those who are submitting information do so in the knowledge that they are contributing to a faster and more efficient response, providing vital information about where resource can be most effectively used, and, in return, closing the intelligence loop, receive situational awareness information about their immediate environment. We present an initial situational awareness framework for earthquake management that encompasses the preparedness, response and recovery phases. It is envisaged that this framework will help develop more effective risk assessment and management frameworks for structures and critical infrastructure (e.g. industrial facilities).

Keywords: crisis management; situational awareness; earthquake response; crowdsourcing; social media

1. Introduction

Situational awareness is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [1]. It is important for multiple stakeholders to have accurate, up-to-date situational awareness of their immediate surroundings in the aftermath of an earthquake. These stakeholders include the victims of the earthquake itself whose homes, communities and workplaces may have been destroyed, who may have loved ones and friends missing, and whose access to food, appropriate water and sanitation may be compromised; and the first and emergency responders, the earthquake relief effort, and the structural and other assessors who also need to understand the current overall situation, especially in places that may be difficult or dangerous to access.

Even in these difficult moments, many ordinary people can prove to be extraordinarily resourceful, helpful and determined to resolve the current predicament through assisting in the post-earthquake response effort to restore things back to normal as soon as possible. It is conceivable that those officially responding after the earthquake may have access to information that those in the disaster zone do not; conversely, the victims may be able to see critical information that those in the control rooms do not. Therefore, it is mutually beneficial to both parties to be able to quickly and securely share information with each other that enhances the situational awareness of all stakeholders contributing to a more effective post-earthquake response.

This paper presents a framework for a situational awareness system that facilitates the rapid sharing of information between those directly experiencing the earthquake's aftermath with those in the control rooms; and vice versa. This system aims to augment and improve the post-earthquake response by utilizing social media, mobile phones and smart technologies to provide enhanced situational awareness to all those affected by or involved in the earthquake. The paper proceeds as follows: Section 2 will discuss the background on crowdsourcing, social media, smart sensors, and situational awareness considerations for earthquakes and other crisis events. Section 3 will present our framework for a situational awareness system that is customized to an earthquake scenario, whereas Section 4 presents the main conclusion of the study. This paper presents the work done within two Newton Fund research projects on "Post-earthquake Disaster and Risk Management through a Rapid Response Framework for Industrial Zones in Turkey", and "Rapid Earthquake Risk Assessment and Post-Earthquake Disaster Management Framework for Substandard Buildings in Turkey". The projects amalgamate complementary expertise of leading institutions from the UK (Sheffield Hallam University, The University of Sheffield) and Turkey (Gebze Technical University, Istanbul Technical University). It is expected that these frameworks will help develop more cost-effective risk assessment and management frameworks for structures and critical infrastructure such as industrial facilities.

2. Background and Related Work

Earthquakes are a commonly occurring natural disaster that have a devastating effect on the communities that lay in their wake. Earthquakes are just one type of natural disaster that can make use of situational awareness platforms for improving emergency management and disaster response. Emergency management and disasters can be divided up into a number of phases: (1) prevention, preparedness, and mitigation; (2) warning; (3) impact; (4) response; (5) recovery [2, 3]. Existing research into the use of social media, crisis response and situational awareness has focused specifically on the response and immediate recovery phases; however, it is believed that these tools can be applied across the whole earthquake management cycle, especially since earthquakes often occur in known vulnerable regions. This section discusses work on the use of crowdsourcing, social media, sensors and situational awareness for crisis response.

2.1 Crowdsourcing

Crowdsourcing is the act of "obtaining information or input into a particular task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet" [4]. Crowdsourcing has become a popular method of acquiring and verifying massive amounts of information about a particular crisis or disaster situation. Crowdsourcing for crisis response first became popular with the advent of the Ushahidi Platform [5] that was developed due to the violence that occurred in Kenya post the 2008 elections. Ushahidi provided an online map based interface to which users could send reports via an online form or via SMS messages. Reports were manually verified before being placed on the map. A key outcome of this initial deployment of Ushahidi was that the creators needed to "close the information loop", that is, ensure that information sharing goes two directions: both to the 'owners' of the map but also back out to those reporting the information too [6]. Ushahidi went on to be a platform in its own right which could be deployed for any scenario. It has become a mainstay of crisis management tools having been deployed during the earthquakes in Haiti [7], Chile and Christchurch as well as the winter storms in Washington D.C. and the Queensland Floods.

Crowdsourcing is not only useful for the collecting of information it is also incredibly helpful when trying to validate information too. This can occur in a number of ways. Firstly, the 'wisdom of the crowd' approach gives rise to the idea that any false information collected during the crowdsourcing effort will be very quickly drowned out or refuted due to the amount of correct information that is collected. Secondly, this kind of validation can be done more explicitly by actually asking volunteers via a mobile application or otherwise to specifically verify information. This may be to verify social media posts – it is common during the crisis for people to post images of previous crises and claim that they are actually part of the current one [8]. Platforms such as Verily [9, 10] have been developed to perform this kind of fact checking. One step beyond fact checking, and particularly relevant to the classification of infrastructure pre and post-earthquake, is the idea of using crowdsourcing to classify disaster related information in the form of micro-tasking. The MicroMappers platform [11], in conjunction with the StandbyTaskForce [12], have a team of 'clickers' who view text, images and videos related to a crisis situation and classify the images based on a specific question. The question may ask about the relevancy of the information, the location of the image/video, or the extent of damage shown in the image, for example [13]. This verification helps to counter an accusation leveled at crowdsourced and social media data: that it is difficult to assess the credibility of the original source [14].

It is believed that the application of crowdsourced data through the use of both specific mobile and online platforms, as well as social media (see next section), have demonstrable functions in the earthquake management and response phases for collecting information that will inform situational awareness for all stakeholders.

2.2 Social Media and Crises

Any major event now generates hundreds of thousands or even millions of posts on social media sites such as Facebook, Twitter, YouTube, and Instagram. Many of these posts are commentary on the event from distant locations but within the noise lies a goldmine of information from witnesses to the disaster. This information, when harnessed correctly, can provide a wealth of knowledge to those who are assisting with the crisis response effort. Although we have extolled the virtues of specific crowdsourcing applications for the collection of crowdsourced data above, it should be noted that, even with prominent awareness raising campaigns, many people will not download specific applications to provide information but they may happily post highly relevant information on Facebook, Twitter and other social media platforms without even realizing they can be contributing to the crisis response; others, may want to help but prefer to do it through an interface that is already familiar to them. Therefore, social media data is a key component of our situational awareness system.

Social media, and specifically Twitter – partly due to the ease of access to data on the platform, has already attracted a vast amount of research on how it can be utilized most effectively during a crisis. In fact, this information can also be considered part of a new intelligence domain SOCMINT [15] a subset of the wider domain of OSINT (Open Source Intelligence). The use of social media has been investigated in almost every conceivable type of disaster: earthquakes, shootings, terrorist events, flooding, hurricanes, wildfires; to name a few. However, collecting the data is only the very first step in process of utilizing such data for more efficient and effective crisis response. Further steps concerning the processing of such data are required before reaching the complexities of presenting this data for enhanced situational awareness.

Methods of processing social media data include the federation of data from multiple sources (such as combining it with crowdsourced data, the creation of advanced categorization taxonomies which classify data automatically, the extraction of specific entities from the data, for example, people, objects, locations and events (known as P.O.L.E) [16] to obtain further details about the information being posted, the use of image or video processing, classification of sentiment (the feelings expressed within the text), and the use of aggregation to group multiple sources which reduces information overload and increases corroboration. For each of these tasks there are then multiple methods that can be used to achieve the desired results, see [17] for a recent review.

2.3 Usage of Smart Sensors

The Internet of Things (IoT) maybe (along with drone footage) next frontier in terms of disaster and crisis management. The proliferation of IoT devices is growing exponentially as new types of sensors are developed. The usage of smart sensors for monitoring the structural integrity and health of buildings before and during and after an earthquake is not a new idea but initial sensors struggled because of small memory and low powered CPU options as well as the limited bandwidth available to transmit such data [18]. A sensor may be used to monitor light, sound, temperature, motion or atmospheric conditions. They can be used to monitor both the health of structure before an earthquake, providing real-time information about which buildings, bridges and other structures may be most vulnerable during an earthquake or they can also be used in the preparedness, response and recovery phases to identify infrastructure which is most at risk and needs urgent attention.

Newer sensors can provide an even greater opportunity for the management of earthquakes [19] as they are able to transmit greater amounts of information about different environment conditions. Furthermore, smart sensors do not just have to specifically designed for one purpose, existing sensors like those that monitor energy, gas or water usage within a home can also provide useful information about the availability of these services in different affected areas. People are also sensors: both through the smartphones that they carry but the companion connected devices such as smartwatches, fitness monitors and other wearables [20]. The possibilities of tapping into this vast repository of data for crisis response are extensive.

Here it is proposed that smart sensors can be another component of the situational awareness system providing real-time information on the environment as well as updates from other smart sensors that users' consent to provide their data from. Additionally, companion smart applications for smartwatches could also provide further data and functionality.

2.4 Situational Awareness in Crises

Data stored only in databases and not made available to those coordinating the response is barely more useful than not having access to the data at all. Based on Endsley's definition [1], given in the introduction to this paper, a situational awareness platform must enable uses to comprehend what is happening, where it is happening, when it happened and what this might mean for the future. A situational awareness platform must present this information clearly and logically to assist in decision-making support for those viewing it. Nevertheless, most existing platforms that provide situational awareness for crisis response are straightforward and often only complete the first three of those aims. That is, they present the what, where and when but do not attempt to model the 'what's next?'.

Existing situational awareness platforms for crisis response (commercial and research) include the aforementioned Ushahidi [6], Twitinfo [21], TweetTracker [22], CrisisTracker [23], Twitcident [24] (now PublicSonar [25]), Palantir [26], Athena [27], SensePlace2 [28], and others [29] . These tools all tap into a variety of social media and other source and aim to display this information in the best possible way to support situational awareness. Lanfranchi, Mazumdar and Ciravegna [30] made a series of recommendations for how best to display data visualizations for situational awareness which included filtering, highlighting interesting information, using familiar charts, present the context, make the system reflect real-time, and if possible, show clusters, correlations, and allow for exploration. These recommendations make sense no matter whether the information is displayed on multiple large monitors in a command and control room, a single monitor, a tablet, or a mobile phone. Furthermore, they are relevant whether the person viewing that information is someone assisting in the crisis response or a citizen in the midst of the disaster.

Except Athena, most of these tools do not, however, provide a dual-aspect display of information. They either present the all information to everyone or it is restricted to whoever is running the service. There is little two way communication nor the federation of data from multiple sources to provide one complete overall picture.

3. A Situational Awareness Framework for Earthquake Response and Recovery

Previous research by the authors have considered crises and crisis response in the impact and (very) short term recovery phases [27, 31, 32]; however, within this framework a wider scope is seek to consider all stages of emergency management, recovery and, in particular, look at how this can be applied to the secondary hazards and effects of an earthquake.

The framework is guided by the holistic view of situational awareness that should encompass the entirety of the emergency management lifecycle. The main components remain the same over each phase but their function is adjusted depending on the goal they are trying to achieve. The framework is comprised of five main components: social media inputs, sensor inputs, a mobile application, data processing and the situational awareness platform itself. Versions of the application and the dashboard are made available to the public and earthquake responders and management to create an earthquake ecosystem of two-way communication that is mutually beneficial to citizens and officials. Foresti et al. [19] suggest a general framework made up of similar components; however, it is purely one directional in terms of providing information for emergency responders and does not consider how this information can usefully also be relayed back to those experiencing the effects of the earthquake first hand. Indeed, getting information back out to those caught up in the earthquake to be of equal importance to the information received by the emergency management team. Fig. 1 presents the overview of the situational awareness framework and the data flows within it.

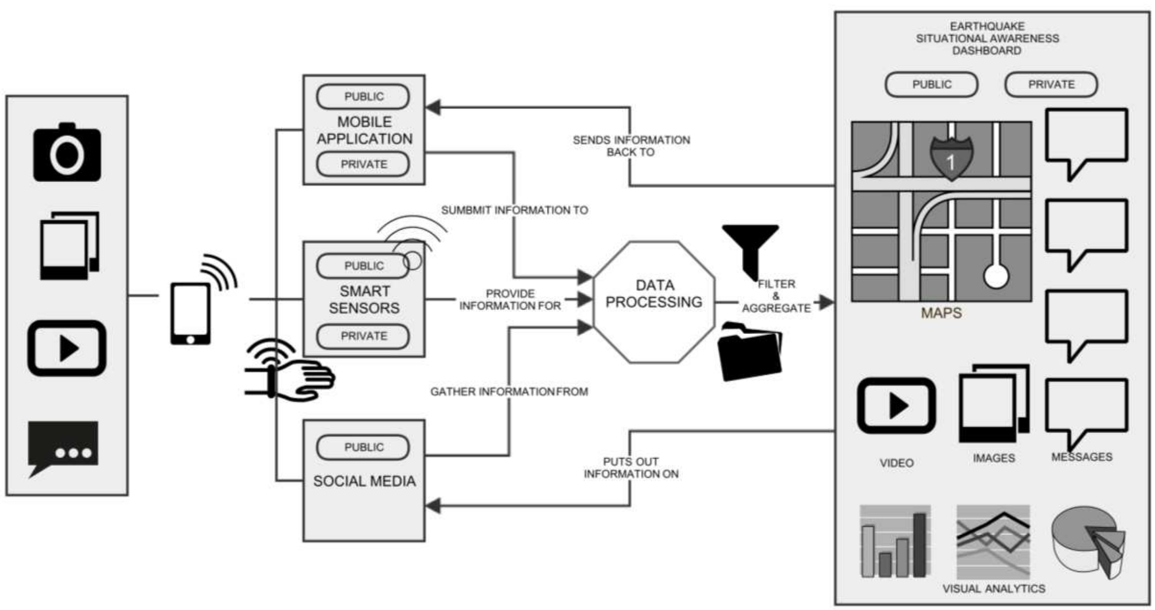

Fig 1: Situational awareness framework for earthquake management

3.1 Situational Awareness for Prevention, Preparedness and Mitigation

The framework is not limited to the times when an earthquake is happening or the aftermath of such events. To encourage people to use, download and send content via the application during an earthquake it is advantageous if they are familiar with its usage prior to such events. Thus, the platform can receive content from the mobile application such as images of structures that they think look unsafe or, in the opposite direction, those in emergency management can request images of particular areas from those in the vicinity or send out reminders of crucial safety information to enhance citizens' preparedness efforts. Even during these non-crisis periods data collected from smart sensors can provide vital information about changes in the infrastructure or provide a baseline to measure against after an earthquake has struck. Fig. 2 shows a flow chart explaining how the system would monitor on-going measurements in the pre-earthquake phase.

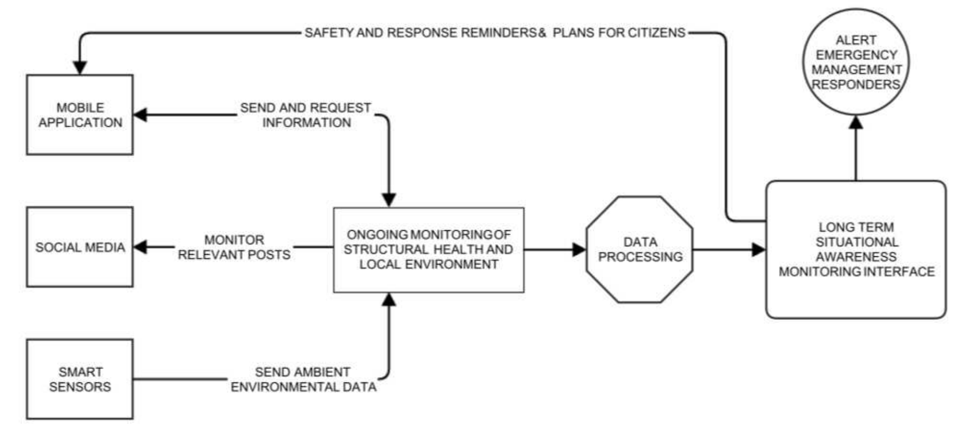

Fig 2: On-going situational awareness monitoring for earthquakes

3.2 Situational Awareness for Earthquake Response and Recovery

The framework in Fig. 1 above demonstrates the main components utilized in the earthquake response in the initial impact and recovery period. In this phase there is a large spike in the amount of data received from sensors, from social media and from the mobile application. In this phase, situational awareness is focused on immediate and emergency response to limit the initial impact of the earthquake. This will include identifying where medical help is required, where the majority of the destruction has occurred, and where people may be trapped. A situational awareness system enables responders to see where and the extent of these incidents in order to prioritize which to attend to first. Getting information out to those experiencing earthquake in this phase is also imperative. Using both social media and a mobile application enables command and control to push this information out almost immediately through the use of direct notifications as well as presentation through maps and visualizations appropriate for mobile devices. First responders on the ground can also make direct use of the mobile application as they can use it to send situational reports back to those in command and control as well receiving instructions, up-to-date information, and enhancing their own situational awareness by using the apps features. By providing situational awareness to those on the ground, the system gives advanced notification of where is and is not safe for them to go, and where they can go in order to assist in most effectively in the crisis response.

The secondary effects that occur as a result of an earthquake can be as devastating as the initial impact. These include aftershocks; tsunamis, landslides and avalanches; water, food and sanitation issues; significant damage to infrastructure in terms of buildings and bridges but also to critical infrastructure; the spread of disease and sickness; and as people become more desperate, the increase in crime and looting. In the recovery effect, a situational awareness platform that also tracks and monitors this recovery effort is as, or even more, vital to improving resilience and speeding up recovery than the initial emergency response. The same basic framework can be used to ingest and process the data and it is only the adjusting of the characteristics that are extracted by the data processing engine that need to be developed. Operators in command and control can view the data using the same maps and charts as in the impact phase, the can use the same channels (mobile application, social media, smart sensors) to monitor the extent of the recovery process and call for information to be sent to them from those carrying out the response effort (official representatives, volunteers and citizens). They can also pass out information via these channels, for example, safe places to obtain clean water, food and supplies, areas providing medical assistance, areas which are dangerous for the public to enter, and of any potential risks. Furthermore, at this stage they may also be able to make short and longer term predictions and simulations about the state of the infrastructure and effort required to truly recover. Fig.3 shows a high-level example of how this process may proceed.

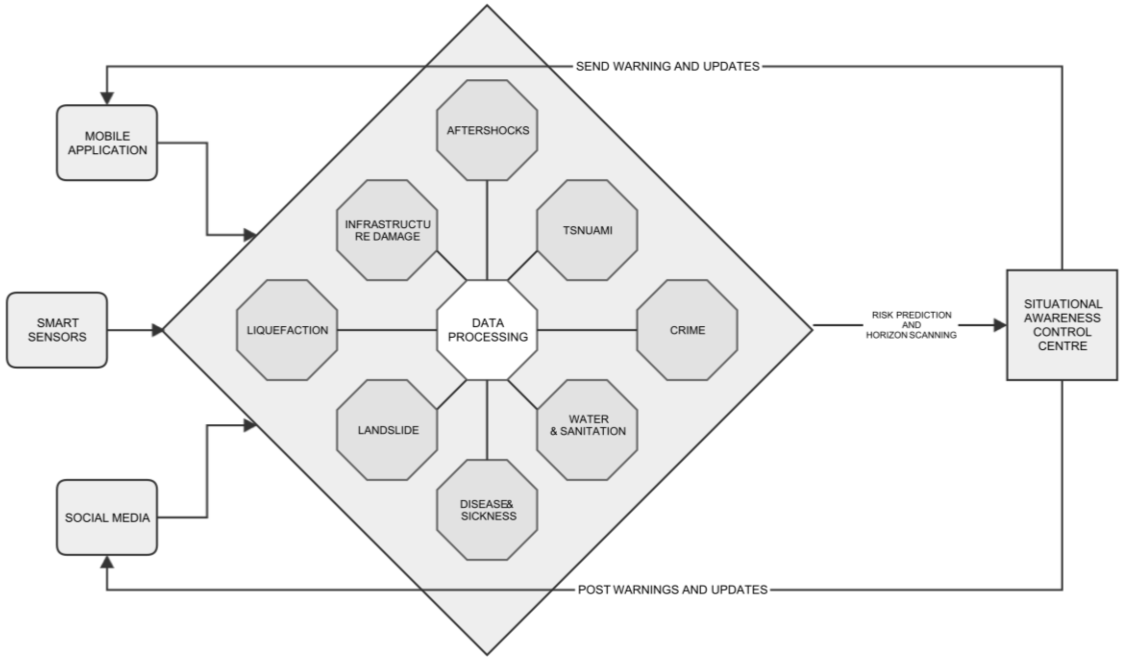

Fig 3: Impact of secondary hazards on situational awareness for the earthquake recovery phase

5. Conclusions

This paper presented a situational awareness framework for improving earthquake response across all phases of emergency management: preparation, impact, response and recovery. This framework considers the provision of situational awareness for both the public, volunteers, and those involved in the official response in command and control as being equally important for successful recovery from the effects of an earthquake. It details how this can be achieved using new and emerging technologies such as harnessing the power of social media, the development of dedicated mobile applications, and the use of a number of smart sensors (both environment and wearable). By combining this data effectively, which in turn can also be combined with 'official' data sources, an enhanced picture of the current earthquake preparedness, response and recovery can be achieved. It is expected that this framework will help develop more effective risk assessment and management frameworks for structures and critical infrastructure (e.g. industrial facilities).

6. Acknowledgements

The research leading to presented results has received funding from the British Council Newton Fund Institutional Links Grants. The financial support from RCUK-TUBITAK through their Newton Fund programme is also acknowledged.

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