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A smart phone-based system for post-earthquake investigations of building damage

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ABSTRACT

Current post-earthquake investigations of building damage are mainly conducted manually, making the collection and management of the investigation data inefficient. To overcome this shortcoming, a professional system for post-earthquake investigations of building damage is proposed herein using smart phones. This system adopts a framework which uses smart phones for distributed data collection and a web browser for centralized data management. A building-oriented database is designed to satisfy the requirements of data organization in the investigations. In addition, a data exchange mechanism between smart phones and the web server is created, demonstrating a satisfactory level of fault-tolerance for various use cases of the system. Further, an algorithm of reverse address retrieval of photos based on multi-threads is designed to conveniently index photos by their addresses. The proposed system is used in a virtual investigation of Tsinghua University campus and a practical investigation of the Tibet area during the 2015 Nepal earthquake. These case studies demonstrate that the proposed system offers an intelligentized, efficient and networked tool for post-earthquake investigations of building damage.

1. Introduction

Professional teams (e.g., academics and engineers specialized in building structures) are always sent to the earthquake-hit areas to investigate the seismic damage of buildings after an earthquake [1,2], such as the Wenchuan, Ya'an and Ludian earthquakes in China [3–5], the Canterbury earthquake in New Zealand [6], and the Tohoku earthquake in Japan [7]. Such post-earthquake investigations of building damage can collect disaster information and assess the damage of building structures timely, which is very important for earthquake engineering research and post-disaster recovery and reconstruction activities.

Current post-earthquake investigations of building damage are conducted manually involving a combined effort of completing required forms and taking relevant photos [1–7]. For example, the United States published the ATC-20 placard system which provides the investigation forms for assessing post-earthquake safety of buildings [8]. Similar investigation forms and working procedure have also been adopted in Greece [9]. In addition, plenty of photos are required to be taken for each building to record the details of seismic damage. In view of the current practices [1–8], Xu et al. [10] has summarized their drawbacks as follows: (1) the investigation forms have no direct link to the damage photos. Details of building damage are recorded in a large number of photos, which requires extensive additional work to be matched with the investigation forms. It is usual that many photos cannot be identified and are therefore wasted. (2) It is inconvenient to search a photo that is taken at a specific place or on a specific target due to the lack of addresses in the collected photos. (3) The investigation data cannot be timely shared. Effective planning of post-disaster recovery activities reply heavily on the investigation results; however paper-based forms are difficult to be shared as fast as the digital forms, which may delay the decision-making process. As described above, an intelligentized, efficient and networked investigation method is urgently needed.

Smart phones can be a great alternative to solve the above-mentioned problems for post-earthquake investigations of building damage. Firstly, smart phones can be used to complete the investigation forms and collect multi-media data of seismic damage of buildings (e.g., photos, audios and videos). In addition, these forms and the collected multi-media data can be easily linked by using smart phones, thereby reducing the time-consuming matching work. Secondly, the collected photos can be indexed by their locations because the global positioning

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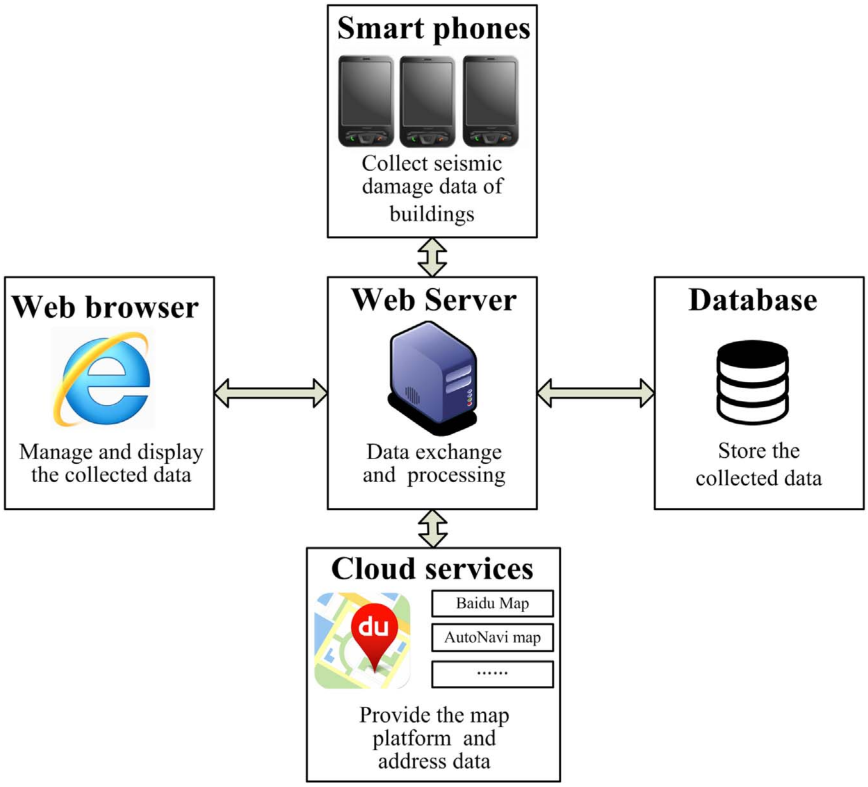

Fig. 1. The framework of the proposed post-earthquake investigation system.

system (GPS) coordinates of the photos can be stored by smart phones [11]. According to the latest analysis report of GPS performance which is published by the University of Texas at Austin in 2017 [12], the position service of GPS is available in more than 99% of the earth's surface. Therefore, the seismic zones can be mostly covered by GPS. Finally, post-earthquake investigation data can be quickly uploaded to the servers through the network of smart phones, so that seismic damage data can be timely shared to support decision making for post-disaster recovery. It is worth noting that post-earthquake investigations of building damage are normally performed after the completions of emergency rescues, so the mobile networks of the disaster area can generally be recovered during the investigations. For instance, in the Wenchuan earthquake with a magnitude of M8.0, it only took four days to recover the mobile network [13]. In the recent Jiuzhaigou earthquake (M7.0) occurring on Aug 8th, 2017, the mobile network was recovered within 24 h [14]. Therefore, post-earthquake investigations of building damage for the abovementioned earthquakes can be performed using mobile networks. In addition, the mobile network to date is fast enough to meet the transfer requirements of multi-media data in the investigation. For instance, the theoretical downlink and uplink rates of TD-LTE (Time Division-Long Term Evolution), a widely-used 4G network for smart phones, can be up to 100 Mbps and 50 Mbps [15], respectively.

The applications of smart phones for collecting disaster data in earthquakes have been reported in the literatures [16–26]. For example, in the United States, Federal Emergency Management Agency (FEMA) also released an application (i.e., FEMA App) with a function of “submit disaster photos” [27], through which the post-earthquake photos can be collected from different app users. The UC Berkeley iShake project designed a mobile client-backend server architecture that uses sensor-equipped mobile devices to measure earthquake ground shaking [28]. In Japan, Lwin and Murayama developed a smart phone application based on web geographic information systems (GIS) [29], which can timely display photos from the disaster area. In China, Peng et al. [30] developed a smart phone software called "E-Explorer" to discover the positions of survivors for rescue workers. More recently, Zhao et al. [31] developed a mobile application for earthquake intensity survey, through which the form of intensity survey can be filled in online.

However, the abovementioned researches [16–31] do not provide necessary connections between the collected data and the corresponding buildings, which will makes post-earthquake investigations very inefficient. Moreover, the existing researches only focused on collecting the disaster data, with seldom consideration of the subsequent management of the collected data (e.g., indexing and visualization), making it difficult for the collected data to be used directly for post-earthquake decision-making. In summary, the issues with data collection and management in post-earthquake investigations have not been fully addressed yet.

In this study, a professional system for post-earthquake investigations of building damage is proposed using smart phones. This system adopts a framework which uses smart phones for distributed data collection and a web browser for centralized data management. A building-oriented database is designed in this system to establish the link between the collected data and the corresponding buildings, thereby avoiding the time-consuming data identification work. A data exchange mechanism between smart phones and the web server is also created, with a satisfactory level of fault-tolerance for various use cases of the system. Furthermore, an algorithm of reverse address retrieval of photos based on multi-threads is designed to conveniently index photos by their addresses. This system is used in a virtual investigation of Tsinghua University campus and a practical investigation of the Tibet area in the 2015 Nepal earthquake. These case studies demonstrate that the proposed system offers an intelligentized, efficient and networked tool for the post-earthquake investigations of building damage.

2. Framework

The framework of the proposed system includes five components: smart phones, a web browser, a web server, a database, and cloud services, as shown in Fig. 1. Among them, smart phones and the database are used to collect and store the seismic damage data of buildings