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RAPID DAMAGE MAPPING TO SUPPORT POST-DISASTER RECOVERY

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SUMMARY

In an event of a natural disaster, such as an earthquake, accurate and locationally precise information on the damage caused is of vital importance for rescue and relief operations and to mobilise resources for repair and recovery. Conventional methods of information gathering relying on teams studying the damage on the spot are slow and incompatible with immediate relief. There is today considerable interest in the acquisition, interpretation and use of information from remote sensing because of the opportunity it presents to gather information over a wide area quickly, in a consistent fashion, and independently of the situation on the ground. The occurrence of recent damaging earthquakes, in Gujarat, Italy, Turkey, Algeria and Iran for all of which high-resolution satellite images are available has offered a unique opportunity to make progress towards the aim of rapid post-disaster damage mapping. The overall aim of the project described in this paper is to develop a new tool for rational planning of emergency operations, damage assessment studies, and early reconstruction planning. Specific aims are to develop visual assessment techniques, enhanced by newly available software; to demonstrate that rapid post-event damage mapping is now possible using unrectified high-resolution satellite images obtained after the event; and to establish a link between the damage interpretation team and image suppliers on the one hand, and the user community on the other. Using a variety of image assessment techniques, preliminary post-event damage maps have been produced, which were subsequently tested against ground-truth data collected by others in the days immediately following the event. The paper discusses the comparison between ground-observed and satellite-observed damage, and proposes a range of possible applications for the damage maps, should they be produced immediately after the earthquake, and considers the logistics of such an approach.

INTRODUCTION

The use of satellite images for disaster management is a topic that has been discussed over the last decade among remote sensing and disaster management specialists. The recent development in the spatial resolution of the optical satellite images that have become commercially available since 2001 has further

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increased the potential usefulness of optical satellite images in post-disaster situations. These images can clearly show individual buildings, as well as cars and trees. Among the images taken by sensors onboard a satellite, currently these optical high-resolution images provide the highest spatial resolution. It is considered that these images will be particularly useful in identifying and assessing the damage to buildings and other man-made structures in urban areas in the immediate aftermath of an earthquake.

The ongoing research into the application of these high-resolution optical satellite images for post-earthquake building damage assessment at the Martin Centre, University of Cambridge, aims to develop various methodologies, both qualitative and quantitative, to rapidly create a damage map that can visualize the distribution of damage and types of damages observed on buildings to an accuracy suitable to support early emergency and rescue planning. After experimenting with various methods, a final assessment will be carried out in an attempt to define the best method (or combination of methods) for creating a rapid post-earthquake damage map using optical high-resolution satellite images to support post-disaster recovery.

To create a rapid damage map, the following three processes are required;

1. Obtaining information on the building stock, e.g. footprints, function of the building, height, area size, material of building.
2. Assessment of the damage to buildings, such as total collapse, heavy damage to the structure, tilt, overturn, lower storey collapse and damage to the building appendages.
3. The creation of damage maps. The maps could take the shape of grid-based damage maps or building-by-building damage maps, when possible.
4. Road usability maps

By combining these elements, it is envisaged that information useful in the post-earthquake reconstruction process as well as in rescue and relief operations can be produced. To date, our main effort has focused on developing methods for assessing damage to the buildings and the creation of damage maps. This paper will firstly review the damage assessment methods (qualitative and quantitative) that are currently being considered and present some results from the experiments carried out. Through the experiments The usability of the high-resolution optical satellite images for such purposes will also be presented through the experiments.

While conducting the study, it has become clear that pre-earthquake satellite images are not always available. Therefore the intention here is to develop a damage assessment method that only uses a post-earthquake image.

OVERVIEW OF THE QUALITATIVE DAMAGE ASSESSMENT METHODS AND EXPERIMENTS

Introduction

Qualitative damage assessment, i.e. visual interpretation is a technique that relies on the function of the human brain to recognize features through its vision. The interpreter tries to associate what he can see in the image with real objects on the ground.

Visual damage assessment of two cities in Gujarat, India, namely Bhuj and Ahmedabad were carried out following the Gujarat earthquake in 2001 by the authors (Saito et al [1]). One post-earthquake panchromatic image of Bhuj and pre- and post-earthquake panchromatic images of Ahmedabad were acquired. All three images were taken by the satellite IKONOS-2 and were cloud free. Using these images, three visual damage assessment experiments were carried out. In these experiments, all of the images were used "as is" without any further rectification, in other words they conform to the spec provided by the vendor, i.e. CE±50 m in terms of positional accuracy. This is mainly due to the lack of information necessary to improve the positional accuracy of the imagery, which is often the case in a disaster struck developing country. The summary of the three experiments are as follows;

Experiment 1
24 buildings in the satellite image were compared with a set of photographs of the same buildings taken from the ground on the same date. The purpose of this comparison study was to see the extent of the damage satellite images can reveal. It became clear that severe structural damage to the buildings, debris and failure to building appendages could be identified, if the view is not obscured by shadows or the presence of nearby buildings.

Figure 1. Photo (left) and satellite image (right) of a collapsed single building in the north of Bhuj. The remains of the building are visible in the satellite image. The white arrow in the satellite image shows the look angle of the photo.

Experiment 2
Grid-based damage assessment was carried out to see if the damage distribution pattern could be identified using these images. The post-earthquake Bhuj, India, image was used to carry out this experiment. The resulting area-based damage map was compared with damage data collected on the ground through surveys of the buildings in Bhuj after the earthquake. The assessment was carried out by overlaying a grid consisting of 100 m by 100 m grid-squares on the satellite image and estimating the proportion of the number of buildings with damage level D4 or D5 (EMS 98 [2]), i.e heavy structural damage or total collapses, among the total number of buildings within the grid-square. Four different damage levels were assigned to each grid-square according to the proportion of the damaged buildings i.e. 0 < 25%: damage level 1, 25 < 50%: damage level 2, 50 < 75% damage level 3 and 75 = 100%: damage level 4. Comparison of the two datasets (experiment and ground truth data) showed that the general damage distribution pattern can be derived from the visual interpretation of the satellite image. The general tendency in this experiment was to underestimate the proportion of damaged buildings by 1 damage level. The assessment of the area (1.26km^2) took approximately 4 hours by one interpreter.

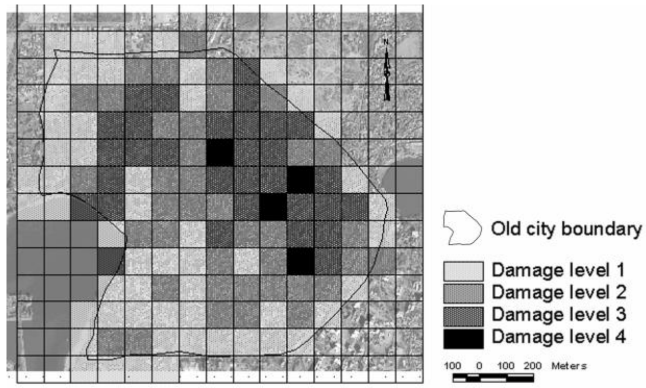

Figure 2. **Result of the area-based photo interpretation using post-earthquake IKONOS image of Bhuj. Light gray represents grid squares interpreted as damage level 1, meaning that 0-25% of the buildings suffered severe damage or total collapse (D4 or D5), gray 25-50%, dark gray 50-75% and black 75-100%**

Experiment 3

Pre- and post-earthquake images of Ahmedabad, India, were compared side-by-side to see if changes caused by the earthquake are visible. Again, a grid was overlaid on the pre- and post-earthquake images and each grid-square was compared. A total of 121 km^2 was assessed (west half of Ahmedabad), which took 15 hours to complete by one interpreter. The result, followed by ground truthing proved that completely collapsed buildings can be clearly identified when pre- and post-earthquake images are compared.

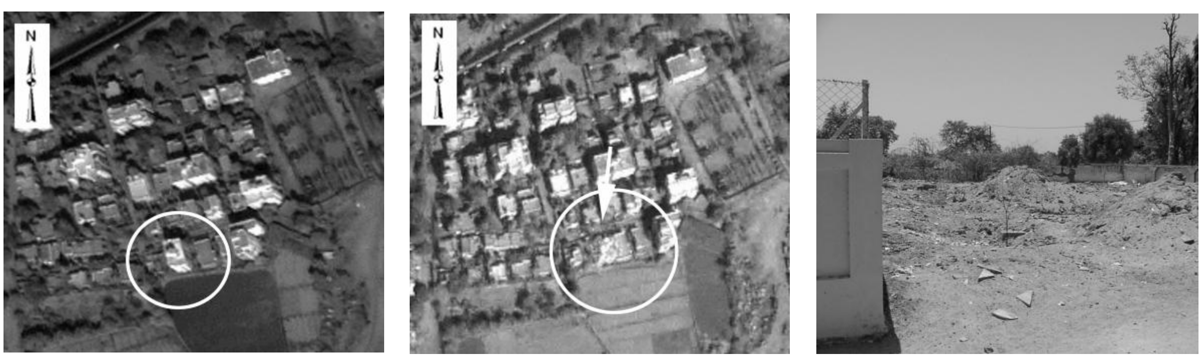

Figure 3. Example of an image of a collapsed building. ***Left:*** **pre-earthquake image;** ***middle*****: post-earthquake image;** ***right*****: ground photograph of the same site 15 months after the earthquake. The ground photograph was taken by the authors.**

Implications

The results show that visual interpretation can indeed produce relatively accurate, if not 100% accurate, damage assessments. This on the other hand indicates that whenever research is carried out (especially when verifying the results of digital image classification algorithms), assessments derived by visual interpretation alone should not be used as "ground truth" data, since it is likely to include a degree of inaccuracy. It has also been concluded that detecting damages less than damage level D3 in the EMS scale is unlikely using high-resolution optical satellite images.

Other experiments

Further complementary experiments on the visual interpretation of high-resolution optical satellite images have been carried out using images from the Molise earthquake in Italy (31 Oct, 2002), the Bourmerdes earthquake in Algeria (21 May, 2003) and the Bam earthquake in Iran (26 Dec, 2003). The results of these experiments will be reported elsewhere, but they appear to broadly confirm the results of the experiments on the Bhuj and Ahmedabad images.

QUANTITATIVE DAMAGE ASSESSMENT METHODS

Texture analysis

Following the experiments using visual interpretation, currently several quantitative damage assessment methods using digital image processing techniques are being explored. In theory, digital image processing techniques should assist in speeding up the process of identifying damaged buildings. Conventional pixel analysis that relies solely on the spectral profile of the individual pixels would not be appropriate in this case since buildings are made of many different kinds of materials and this information is not likely to correlate with the degree of damage to a building, especially when only the post-earthquake image is being used. However, the spectral information will be useful in masking out non-buildings e.g. vegetation, water bodies in the image. The image processing technique identified to be most promising is texture analysis.

The term texture can be described as the roughness or the smoothness created by the variation of tone or repetition of patterns across a surface (Tso and Mather [3]). Texture analysis is a technique that takes into account the values of neighboring pixels in an attempt to uncover a pattern, in other words a measure of roughness or smoothness that can be attributed to a particular type of feature within an image. In the first instance, developing methods to identify the existence of rubble is the primary goal since rubble can be expected to be associated with collapsed and heavily damaged buildings.

There are several standard approaches to automatic texture classification, which includes Grey Level Co-occurrence Matrices (GLCM), neighborhood analysis using first-order statistics (average, standard deviation, entropy etc), Texture Unit analysis, Pattern analysis, Multiplicative Autoregresive Random Fields (MAR model) and Semivariograms (Jensen [4], Tso and Mather [3], Chica-Olmo and Abarca-Hérnandez [5], Carr [6]). Work is in progress on pattern analysis applied to the IKONOS image of Bhuj, India, taken a week after the Gujarat earthquake. The same image was used for the first and second visual interpretation experiment described in the previous section. Experiments using other textural analysis methods will follow the pattern analysis experiments.

Other quantitative methods under consideration

Other potentially useful techniques for image classification include Fourier analysis and multifractal analysis (Jensen 1996), which will be experimented with in due course. Another completely different approach under consideration is a method called *rectification in the horizontal and vertical planes*. This is an application of a method developed by Criminisi, whereby the distortion in an uncalibrated image is corrected without any camera information (Criminisi [7]). This calibration technique will be used in an attempt to visualize the façade of a high-rise building from an oblique high-resolution satellite image to see if the damage to the façade can be seen. The calibrated image is expected to reveal lower-storey collapses that are difficult to be seen from above due to the nature of the damage. This technique will mainly be suitable for high-rise buildings.

DEFINING THE FORMAT OF THE DAMAGE MAPS

To date, the damage maps produced in the experiments have focused on building damage. These maps have either taken the shape of an area-based damage map using grids and assigning damage levels to grid-squares according to the estimated proportion of the sum of the collapsed and partially collapsed buildings, or a map that pin-points the location of the collapsed buildings. In Bhuj where the damage was extensive, a grid-based damage map was considered to be appropriate (figure 2). For the Ahmedabad damage map, pin-point maps were chosen due to the fact that only a small proportion (in the tens) of the total (several million) buildings had collapsed (figure 5). The final format of the damage map to be used in our method is still under consideration but would need to take into account the level of damage suffered by the area.

However, with the current grid-based system, a grid-square with only one building that has also completely collapsed will receive the same damage level as a grid-square with all 75 buildings totally collapsed. To correct this inadequacy in the system, some kind of measure representing the density of the buildings or the total number of buildings within a grid square should be introduced which will be reflected in the damage level. It may also be necessary to introduce another damage level (5) that is assigned when all the buildings within the grid-square have totally collapsed. This would be a measure that could be used to prioritize rescue and relief efforts. It may also be necessary to mark the location of totally collapsed buildings within grid-squares that are assigned damage level 1 and 2. (Refer to experiment 2 for the description of the damage levels used in this project.)

It is possible that street block level information would be more suitable for rescue and relief operations compared to grid-based information. From the point of view of carrying out visual interpretation, it is easier to work on the image systematically following the order of the grid-squares. However a grid-square may cover areas that belong to neighboring street blocks which may not be useful to those using the map on the ground in relief operations. Thus damage information aggregated at the street block level may be more suitable for use in rescue and relief efforts. Figure 4 is a sample of such map, created by Environmental Planning Collaborative (EPC). A NPO based in Ahmedabad, EPC collected building-by-building damage data that was subsequently aggregated into this format.

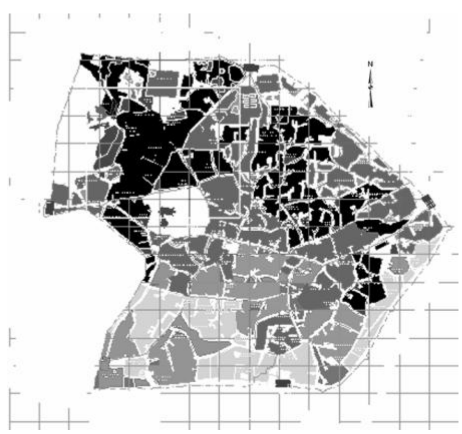

Figure 4. Damage map of Bhuj, aggregated at the street block level by Environmental Planning Collaborative (EPC), a NPO based in Ahmedabad. Dark areas are the most heavily damaged with 75-100% of the buildings collapsed or heavily damaged. Lighter shades of gray indicate less damage.

DISCUSSION

Range of possible applications for the damage maps

The damage maps created using the various techniques mentioned above could be used to identify the areas that need to be prioritized in terms of allocating resources for rescue and relief efforts. In addition to this, the image could be used to assist in the planning of the temporary shelters for the victims. In case of a remote village, the usability of the road network to reach the village could be assessed using these satellite images.

Use as a base map

High-resolution satellite images could also be useful as a base map in areas where accurate large scale maps are not readily available, as well as detecting damage on the ground. However, using them as a base map in areas where large scale maps are already available may introduce a minor inconvenience, since the images with CE±50 will not align to these large scale maps, which may create confusion among the users. In such cases, it may be beneficial to spend some time to further rectify the image so that they align better with the existing detailed datasets. However, this will result in a delay of delivering the imagery to the users on the ground.

During a field trip in Ahmedabad, one of the collapsed buildings was reached relying solely on the instruction of a handheld GPS. The coordinates of the collapsed building were registered in the GPS beforehand. The GPS provided the directions and distance to the site, which was conveyed to the driver.

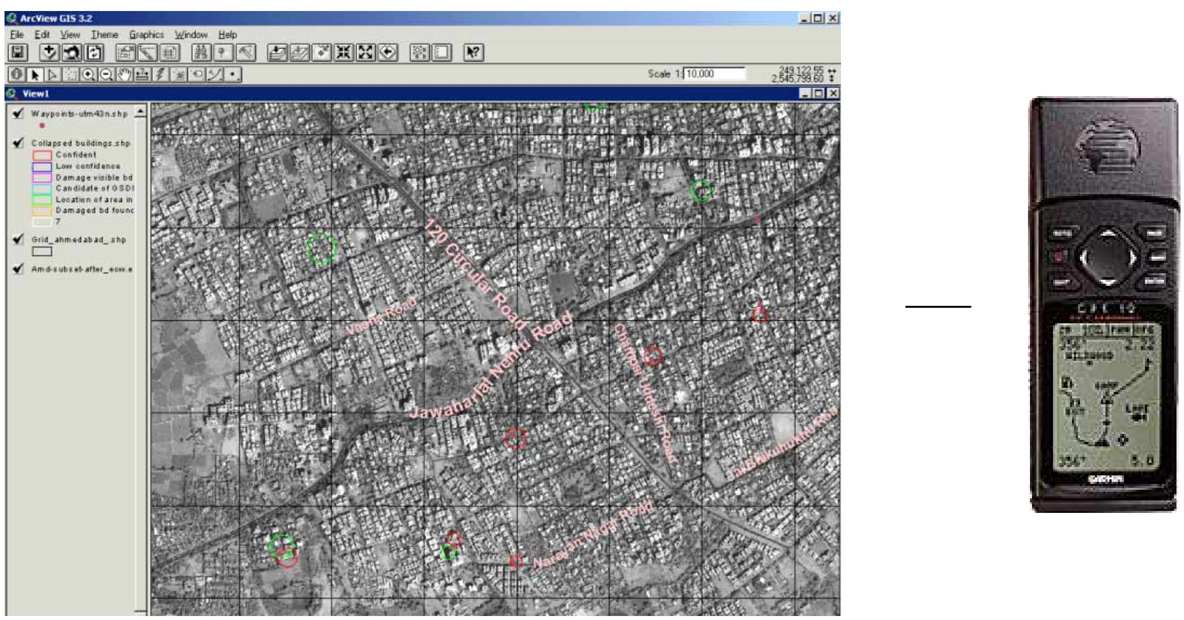

Figure 5. Satellite image of Ahmedabad that was used as a base map during a field trip. The locations of the collapsed buildings were marked on the image and the coordinates were read from the image and registered in the GPS.

Acquisition of high-resolution satellite images and time constraints
For rescue and relief purposes, it is critical to provide information within 24-48 hours after the earthquake. However, currently the quickest delivery time of the satellite images, which includes tasking the sensor, creating the image and georeferencing it to an accuracy of CE±50m and sending it to the customer, is 24 hours. This means that another additional 24 hours would be needed for the analysis of the satellite image to take place by interpreters and/ or using digital image classification techniques. The damage information extracted from the image also needs to be delivered to the users. Research needs to be undertaken into identifying the format in which the users would prefer to receive the image/ information (e.g. paper format or in a GPS enabled PDA) and how the information can be sent.

CONCLUSION

Research to date indicates that the use of optical high-resolution imagery to produce rapid assessments of damage is feasible, even in cases where only post-event images are available; several techniques are available to further enhance what is possible by purely visual assessment, forming part of an ongoing research programme currently supported by EERI (EERI [8]). Research collaborations can also help with the efficient and rapid acquisition of satellite images (both pre and post-event) to develop and test emerging techniques in new situations. However all attempts to produce remotely-sensed damage maps need to be tested against ground-truth data, and for this another kind of collaboration is needed, between the researchers and the teams, usually assembled by local administrations, who gather and store the damage data assembled after each earthquake. This collaboration too can be assisted by the support of international organisations such as EERI and the European Association for Earthquake Engineering, but the negotiation can be delicate and time-consuming, and agreements offering reciprocal benefits are likely to be needed.

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