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HOW CAN NEW TECHNOLOGIES HELP US WITH EARTHQUAKE RECONNAISSANCE?

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ABSTRACT

Earthquake reconnaissance missions have been very successful in identifying the specific causes of failure for individual buildings and the deficiencies in building codes or local construction practices that have led to these; however, their ability to capture robust statistics on patterns of failure is usually beyond their scope. Furthermore, the success of these endeavours in establishing poor construction designs and practices, means that if we are to continue to learn new lessons we will need to gain fresh insights using new data streams. Recent technological advances have the ability to enable us to both increase the amount of data collected and to improve on the precision of these measurements. Furthermore, social media has the potential to provide entirely new data streams and to significantly add value to collected data by harnessing an army of data manipulators and interpreters. How to do this in a reliable way however, is the subject of much debate. In this paper, we explore the potential for a number of trialled and potential technologies to collect better and new information in earthquake reconnaissance, including virtual damage surveying - where results from damage surveys completed in the field, are compared to omnidirectional images collected during the mission and interpreted by a virtual surveyor based in the UK, data collected through aerial images taken by UAVs and 3D models created from a series of drone or other images. Finally, we describe the potential of social media such as Twitter to collect data streams on damage and other impacts. Examples of impact data such as road closures, landslips and infrastructure service failures collected for flooding and landslide will be presented to show the potential of this technology for earthquakes.

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How Can New technologies Help Us With Earthquake Reconnaissance?

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ABSTRACT

Earthquake reconnaissance missions have been very successful in identifying the specific causes of failure for individual buildings and the deficiencies in building codes or local construction practices that have led to these; however, their ability to capture robust statistics on patterns of failure is usually beyond their scope. Furthermore, the success of these endeavours in establishing poor construction designs and practices, means that if we are to continue to learn new lessons we will need to gain fresh insights using new data streams. Recent technological advances have the ability to enable us to both increase the amount of data collected and to improve on the precision of these measurements. Furthermore, social media has the potential to provide entirely new data streams and to significantly add value to collected data by harnessing an army of data manipulators and interpreters. How to do this in a reliable way however, is the subject of much debate. In this paper, we explore the potential for a number of trialled and potential technologies to collect better and new information in earthquake reconnaissance, including virtual damage surveying - where results from damage surveys completed in the field, are compared to omnidirectional images collected during the mission and interpreted by a virtual surveyor based in the UK, data collected through aerial images taken by UAVs and 3D models created from a series of drone or other images. Finally, we describe the potential of social media such as Twitter to collect data streams on damage and other impacts. Examples of impact data such as road closures, landslips and infrastructure service failures collected for flooding and landslide will be presented to show the potential of this technology for earthquakes.

Introduction

The goal of earthquake reconnaissance is to obtain field data that can lead to new insights into how earthquakes impact society and therefore set priorities for developing strategies to reduce these impacts. The old saying goes "earthquakes don't kill people, buildings do", and it is for this reason that much of earthquake reconnaissance (especially by engineers) has concentrated on identifying "killer" buildings and the "reasons why they kill". Earthquake reconnaissance has been conducted by a number of organizations for over 50 years and, by observing individual instances of building failures, they have been instrumental in understanding the deficiencies in local building codes and practices. Additionally, they have been invaluable sources of evidence for how earthquake forces impose themselves on a structure and how good design can resist these. This information can then be used to explore alternative earthquake resistant strategies and build better for future events.

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The second thing that earthquake reconnaissance does is provide useful but usually very limited damage statistics. Like all statistics, damage statistics provide no information about how a single building may perform but rather enable probabilities of certain damage states occurring as a result of a given earthquake intensity and then by aggregating these over an exposed population, risk estimates can be made for future events in locations that have a similar building stock. This information can be used to set priorities and budgets for code improvements, retrofit strategies and disaster response preparations.

Lastly, they enable researchers to unearth narratives of societal disruptions and highlight areas of effective response and unforeseen social vulnerabilities and the causes of these. In short, earthquakes reconnaissance provides the evidence base for developing earthquake risk reduction strategies and, in terms of life-safety (as opposed to damage levels) the Christchurch earthquake has demonstrated the success of our endeavours. However, the success in developing good new construction designs that are now being implemented in the developed world, means that future findings in this area will begin to be less significant and that if we are to continue to learn new lessons relating to the impacts relating to earthquake hazard, then we will need to shift our attention from forensic type engineering to producing robust statistical data on the likely performance of entire building stocks as well as better quantifying the human impacts of building and infrastructure failures. This latter point in particular will require us to answer new and deeper questions about how earthquakes affect society and this can only be achieved using new data streams to gain fresh insights into the consequences of earthquakes.

How to do this, is the subject of much debate and in this paper, we explore the potential for a number of trialled and potential technologies to collect better and new information in earthquake reconnaissance, including virtual damage surveying - where results from damage surveys completed in the field, are compared to omnidirectional images collected during the mission and interpreted by a virtual surveyor based elsewhere, data collected through aerial images taken by UAVs and 3D models created from a series of drone or other images, satellite based observations and finally, we describe the potential of social media such as Twitter to collect data streams on damage and other impacts.

Specific Technologies

GPS cameras

This technology is now reasonable mature and is arguably the main piece of technology on any mission. Compact versions are relatively cheap and take good images and therefore remove the need to have a time synchronized GPS unit to geo-tag the photographs at a later date. As these units are relatively cheap, it is recommended that all members of the survey team use them and while it can be difficult to persuade a team member to part with their favourite non-GPS SLR, efforts should be made as post-mission geotagging often gets overlooked. A few important notes on using GPS cameras. Geo-tagged images are great for knowing the location of the image (or more correctly the location of the camera that took the image) because it not only enables identification of the site at a later date, but is a far more convenient way of cataloguing photos and enables post mission investigation on relationships between location and effects. For this reason users should be aware of the limitations of the GPS on their cameras as they often have slow acquisition rates. A camera that displays the accuracy of the GPS reading is essential (preferably one that includes this information in the metadata of the photograph) and one with a quick acquisition rate is desirable. It is not unusual for a unit to take 20 minutes to lock onto a satellite or sometimes not at all. SLR GPS cameras have much higher acquisition rates and often have a tilt meter and a compass and so you can not only tell where the camera was, but also what it was looking at. It is strongly recommended that at least one high quality GPS camera with GPS error, compass, tilt meter and especially fast GPS acquisition be taken with each survey group.

Omni-directional cameras and 3D images

Omni-directional cameras have extremely wide angle lenses which enable the capture of images in a very wide range of view. This can then be stitched together to produce a streetscape similar to that available through Google Street-view. Not not only does the capture of a street scene increase the geospatial context of the images capture, but it also enables much more rapid collection of images with few, if any, gaps in the building inventory (although this only extends to the frontage of the buildings. Using appropriate software, it is possible for these scenes (as well as any photographs that have taken the same image from multiple viewpoints) to be rendered into a 3D image and then experienced in an immersive environment using a virtual reality headset. Again this technology is relatively cheap with both cameras and headsets available for less than $1000. This new technology (and much of the technology described in the rest of the paper) presents us with a new problem; namely, that mission members can now capture images more quickly than they can describe them and their damage state in the field. This results in needing to describe them post-mission or potentially enlist other people to do this. While this has the promise of helping us to collate comprehensive damage statistics, then is also the danger in unvetted interpreters mistakenly categorizing damage states or images of facades not adequately displaying the actual damage state of the building. [1] has investigate the accuracy of using this technology and while very promising, this is an area that needs further work to ensure valid results, especially for the lower damage states.

UAVs

Unmanned aerial vehicles have dramatically come down in price and size and improved enormously in utility. The latest version of amateur UAVs (although they could also be considered to be semi-professional) can be purchased for less than $2000, come with stabilized 4k cameras, GPS for both safe flight control and geo-tagging and additional sensors for collision avoidance. The author's of this paper have taken DJI phantom II to recent earthquakes to obtain landslide information and this has proved successful. This particular UAV has all of the above features and mapping software is available that can be used to preprogramed the flight and image capture rates to produce sufficient overlapping images for a full photogrammetric survey. While the camera is of sufficient quality to produce images that can produce a photogrammetric survey of sufficient accuracy for earthquake landslide mapping purposes, it should be noted, that the on-board GPS is not sufficiently accurate for linking the obtained survey information onto national map grids.

The UAV we have used is very quick to learn how to fly and relatively fail-safe, with features like automatic return to base when a switch is flicked, or the batteries are running low, as well as the ability to use the GPS to maintain position unless controller inputs signals a move (this can be important in windy conditions).

While we have successfully used this unit, there are difficulties associated with flying permissions (for example the Nepal government placed restrictions on UAVs and so the EEFIT Nepal mission could not use them) flying time and physical size of the unit which is best transported in a rugged box that measures 600mm x 500mm x 300mm and with spare batteries and chargers etc weighs approximately 5 kg. While this is easily transported as hold luggage (make sure you check the carrier's rules about transport of batteries) it poses significant challenges if the survey area is to be reached by foot. This system can have a range of around 1km; however this requires flying the device out of visual contact and therefore using the unit's camera for visual information and this is not recommended for inexperienced users.

A newer version of this technology, for example, the DJI Mavic pro has come down further in size (it fits in a SLR camera bag, weighs 734g and has approx. 25 minutes of flying time on a 240 g battery. Another feature of this unit is it has sensors that will stop it flying into objects; however, as these sensors are only located on the front of the unit, there is still some room for pilot error. This unit is easily transportable, if the site has to be reached on foot. Other systems exist such as the GoPro Karma drone amongst others and as this technology is moving forward so quickly, potential adopters are strongly advised to do their own research on what meets their needs and not just rely on the three units mentioned in this paper.

Other uses of UAV is to quickly capture images of buildings by flying down a street, or capturing inaccessible images (say at the top of a building or a roof) and as 4k video is being captured, the video can be used to produce a very large quantity of excellent still photographs or with the correct image processing software 3D immersive street scenes (see later).

Terrestrial Laser Scanner

While photogrammetric surveys can produce quantitative information, the best technology to produce 3D data sets are Terrestrial Laser Scanners. Again these are coming down in price and more importantly size (with units now available that can be mounted on a UAV). They can produce 3D point clouds relatively quickly and very accurately and when combined with reflected intensity laser information and/or photographs can be used to reconstruct a very accurate 3d models that can inform later modelling work (assuming that all the building is accessible – which is often not the case for the tops of buildings and the rear side). An example of a data set collected using this technology is shown in Figure 1.

Figure 1. A point cloud of Nepalese temples after the Gorkha earthquake captured using a terrestrial laser scanner and a photographic image of the same

Remote sensing using Satellites

There are many new satellites orbiting the earth that can provide high-quality remotely sensed data. Images from satellites can be easily and freely obtained using Google Earth and other products; however these may be out of date and therefore re unlikely to show post disaster images. Post disaster images can be purchased, and due to the rate which satellites circle the globe, means these should be available within days of the event. While images are useful to understand how the built environment may be affected they are likely to miss damage. For example, [2] shows how aerial based photography underestimated building damage due to collapse mechanisms such as soft-storey collapse. However for other phenomena, such as landslides, satellites have the potential to make an enormous contribution. Recent earthquakes have shown how landslides can have a devastating effect on communities [3] [4] [5] and it is the satellites ability to produce quantitative data that can help engineers to understand landslide risk. Attempts have been made to do this [6][7] as well as using satellites to identify locations of building damage [8] , but there is still much research to be done. There are a number of satellites available for reconnaissance work of which Synthetic Aperture Radar is the most relevant and three of these are now described.

Synthetic Aperture Radar

The important parameters to know when choosing which SAR product is best for your purposes is the accuracy, resolution, it band, time for global coverage and cost. Accuracy refers to the vertical deformation it can resolve while resolution refers to the horizontal area that one pixel represents, its band it the frequency it operates at which gives it different abilities. In general the shorter the wavelength, the more accurate the measurement; however the less able it is to penetrate things like cloud and vegetation. L band radars operate on a wavelength of 150-300 mm, S band radars operate on a wavelength of 80-150 mm, C band radars operate on a wavelength of 40-80 mm and X band radars operate on a wavelength of 25-40 mm. Time for global coverage is how long the satellite takes to completely survey the globe and so how quickly you can get these images.

Interferometric synthetic aperture radar, abbreviated InSAR (or deprecated IfSAR), is a radar technique used in geodesy and remote sensing that uses two or more synthetic aperture radar (SAR) images to generate maps of surface deformation or digital elevation, using differences in the phase of the waves returning to the satellite. The technique can potentially measure millimetre-scale changes in deformation over spans of days to years. There are a number of these satellites available with different benefits.

Sentinel-1 European Space Agency satellite fund by the European Union, It carries a C-Band Synthetic Aperture Radar in C band that provides continuous imagery (day, night and all weather) and produces accurate images with a horizontal resolution of 5m every 6-12 days. The main advantage of this system is that the images are freely available, it is high resolution and global coverage is updated in the order of a week. While the accuracy is good enough for measuring earth movements due to an earthquake, some research applications may require different abilities.

TerraSAR-X, is a joint venture between the German Aerospace Center (DLR) and EADS Astrium and uses an X-Band radar to provide the highest accuracy of all the products reviewed in this paper, has a high resolution (horizontal resolution of 1m) and is updated every few days. There is usually a cost for each image which covers 35km x 35km.

ALOS 2 Advanced Land Observing Satellite 2 (ALOS 2), also called Daichi 2, Japanese satellite launched in 2014. It has an LBand, PALSAR-2 radar allowing higher-resolution (1x3m per pixel) spotlight modes in addition to the 10m resolution survey as well as the ability to penetrate vegetation. This later feature enable detection of ground movements in highly vegetated areas
While useful for accurately measuring ground movements, these satellites are not able to measure building movement or damage (unless the entire building has moved uniformly). This is because the radar works by measuring the difference in the coherence of the back scattered radar and a significantly damaged or collapsed building will have a different surface leading to totally different back-scattering. This means no quantification of the movement can be made; however, it should be possible to identify regions with buildings that have significantly changed surface properties and assume that this is due to building damage.

All of the above technologies have the potential to dramatically increase the amount of data that we currently collect during earthquake reconnaissance missions and therefore produce more robust damage statistics; however without interpretation or incorporation into models or other research, this data is not much use. For example, collected images by themselves cannot be used to calculate probabilities of failure and so interpretation of the damage state must be made as well as an estimate of the earthquake intensity at that location. As the data becomes more quickly collected, it will become increasingly difficult to make these damage assessments in the field. While it is possible for damage assessment to be made post-mission, the validity of this is yet largely untested. 3D images and streetscapes have the potential to increase the accuracy of these assessments, but even if accurate assessments are possible, then mechanisms to motivate volunteers to make be involved in these endeavours need to be found.

Social Media

The technologies previously described are very useful for collecting large amounts of data about what happened to the built environment in terms of failure; however, the more important question is “how did these failures impact on society?” This question has typically been tackled by social scientists and there is an extensive literature dealing with narratives of how people and society faired after an earthquake and while statistics are often presented, there is not much quantitative data on how a specific infrastructure failure, for example, affected cohorts of people. The reason for this is that societal impacts are far more complex than a simple number, such as damage expressed as a percentage of replacement cost, and so narratives are better at capturing the complex chain of events that disrupts daily lives; however narratives are difficult to quantify or to incorporate into scientific models. Recently; however, social media has been used to produce not only data on damage, but also data on societal impacts. The state of the art in disaster monitoring is looking at an integrated multi-variate approach utilising the deployment of the Internet of Things (IoT) sensing, social media and volunteered information, remote sensing and traditional measurement techniques. The most familiar of these is the “Did You Feel it” App [9] developed by the USGS and this has resulted in millions of datapoints that can feed into models such as PAGER [10] but work has also been done on whether crowd-sourcing and geo-location of photographs helps to remotely assess damage to buildings from earthquakes and therefor validate damage level classifications [11]. This work demonstrates that there is promise in categorizing damage post-mission, but additional work needs to be done. Other applications of crow sourced data are demonstrated in [12] where, due to the UAV ban after the Gorkha earthquake UAV images sourced from the internet and taken before the UAV ban were successfully converted to 3D images; however the accuracy of these images was not verified.

New developments in big data frameworks, cloud storage and edge processing will enable a structured approach to monitoring and managing the structured/unstructured content of the data and the variety and velocity of data. Analytics require the development of means to query both large scale historic data, real-time data streams and other data sources (radar, imagery) to develop heuristic processes for management of systems that can feed into early warning and response. Examples where this technology has been used non earthquake related earthquakes can be found in [13, 14, 15, 16].

Conclusions

The world is experiencing a technological revolution. Miniaturization, increases in bandwidth, computing and storage has enable a range of new technologies to advance at an unprecedented rate. Some of the products of this technological revolution are now small and cheap enough to routinely deploy on earthquake reconnaissance missions and doing this will not only increase the quantity and quality of data, but also has the potential to fundamentally change what we want to collect. While future improvements in image processing technologies may one day remove the need for humans to interpret the data that we do collect during earthquake reconnaissance missions, the current situation requires us to be able to connect suitably experienced people with the new large datasets that are becoming increasingly available, as well as finding ways of motivating them to add value to this data, whether it be through expert interpretation, use in future models or other means. Additionally, this work will only be valuable if we identify mechanisms to validate post-mission interpretations and this will be a very valuable future area of research.

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