USE OF MOBILE MAPPING TECHNOLOGY FOR POST-DISASTER DAMAGE INFORMATION COLLECTION AND INTEGRATION WITH REMOTE SENSING IMAGERY

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ABSTRACT

In the aftermath of natural disasters such as earthquakes and hurricanes, the collection, evaluation, and dissemination of damage data is critical for a timely and accurate response. Information concerning the spatial extent and severity of urban damage is demanded by emergency response personnel, and also by reconnaissance teams conducting post-disaster impact assessments. Data requirements have traditionally been met through ground-based damage surveys during the days and weeks following the event. However, the integration of remote sensing data and geo-referenced damage information collected in the field can effectively streamline, accelerate, and increase the volume and diversity of data captured during post-disaster reconnaissance. Specifically, the integration of these two damage detection technologies offers advantages including: the fusion of multiple perspectives on a given structure from the ground and air, yielding a more complete and highly detailed picture of damage sustained; and capturing a permanent visual record of the post-disaster situation for decision support in the immediate aftermath of the event, and for subsequent recall as ground truth for ongoing research activities. In terms of specific applications, geo-referenced ground damage information has recently been used to develop remote sensing-based damage scales, and to calibrate and validate the information obtained using semi-automated remote sensing-based damage detection algorithms that are applied across a wide geographic area to provide a 'quick-look' initial estimate of damage and potential loss. This paper describes mobile reconnaissance and mapping applications recently developed to support urban damage scale development, and to validate damage detection activities following major disasters including the 1999 Marmara earthquake, 2003 Bam earthquake, and 2004 Hurricane Katrina.

1. INTRODUCTION

Geo-information technologies offer an opportunity to enhance real-time situation management, disaster response, and subsequent post-event research activities

Current disaster management activities utilize large and diverse volumes of geo-information that various organizations around the World systematically create and maintain. For example, information can be made available from Geo Information Infrastructures, such the Infrastructure for Spatial Information in Europe (INSPIRE, http://www.ec-gis.org/inspire/), or the TIGER® street network database (U.S. Census Bureau, 2002). While the use of this kind of information is widespread in normal management situation, there has been limited integration into real-time disaster management practises. To help improve the usefulness of geo-information in a post-disaster context, information should be freely available, up-to-date and provided in a geo-referenced format; for example, with GPS position collecting units, which are the basis of modern survey techniques (Bitelli et Al., 1998 and 2003a).

One of the most valuable sources of pre-disaster and post-disaster information is satellite images. Their pre-disaster value may be illustrated by considering systems such as Google Earth (http://earth.google.com), where imagery serves as a general base map for studying the characteristics of urban development around the World. It is also valuable when existing cartographic information for a given nation is limited in terms of resolution, registration and informative content (Bitelli et Al., 2004b).

In a post-disaster context, the use of remotely sensed data for assessing building damage offers significant advantages over cartography based sources. The qualitative information offered by images are generally more up-date than cartography, and the integration with other GPS-referenced data sets is straightforward. Furthermore, where the affected area is extensive and access limited, remote sensing image presents the possibility of a low-risk, rapid overview of an extended geographic area. Although the characteristics of satellite images (principally resolution and the birds-eye point of view) may not substitute a full macroseismic survey, remote sensing technology can provide a useful and complementary integration.

Remote sensing imagery also has a valuable role to play when integrated within and used in conjunction with mobile mapping technology. Mobile mapping technologies enable the collection of digital in-field data. In a post-disaster context, mobile mapping supports reconnaissance activities, and the rapid collection of detailed information about damage sustained by structures throughout the affected area. Remote sensing data may form a base layer within the system, guiding teams to hard-hit areas and providing navigational support. As described in this paper, it may also be integrated with the mobile mapping ground-based perspective to develop and validate remote sensing-based building damage scales, and to assess the accuracy of damage assessment results.

2. MOBILE MAPPING TECHNOLOGIES

In terms of in-field data collection, two alternative technologies for disaster impact assessment are reviewed here: (1) the

VIEWS (Visualizing Impacts of Earthquakes With Satellites) field reconnaissance system; and (2) QTVR Quick Time Virtual Reality technology.

VIEWS™ is a notebook-based system, developed by ImageCat, Inc. (www.imagecatinc.com) in collaboration with MCEER (www.mceer.buffalo.edu) to capture and visualize data for assessing the impact of disasters. The application integrates real-time Global Positioning System (GPS) readings, with various map layers ranging from pre- and post-disaster satellite images to thematic maps showing infrastructure or damage state. It is used in conjunction with a digital camera and digital video recorder. Current hardware requirement for the system are here reported:

- Computer: Notebook PC with serial port
- Operating system: Windows XP
- GPS Device: NMEA0183 output
- Digital video or HDV: USB or firewire connection
- Digital camera: USB or firewire connection

The VIEWS system is deployed from a moving vehicle (car, boat, plane), or during a walking tour, making it easy to collect information useful for damage assessment. The lag between an event and damage interpretation depends on the speed of field team deployment to the site, access to affected areas once the team arrive, and if required, post-disaster imagery acquisition.
Following data acquisition, collapsed buildings are easily identified on the high-resolution 'before' and 'after' Quickbird imagery. VIEWS also provided easy recall for observations made in the field. All team members' comments such as building damage descriptions and photograph ID number, and all additional information, are linked back to their current GPS location. Additional datasets such as accessibility (e.g. roads, railways, bridges...), urban building types, and possible locations for relief camps can also be mapped and integrated into this GIS-based reconnaissance system. Integrated ground and remote sensing-based damage assessment is ready performed through replaying the video and photographs in the GIS interface. The colour of the GPS route changes to track the footage location within the satellite imagery.
The VIEWS system was first deployed following the 2003 Bam, (Iran) earthquake (Adams, 2004a), then following the 2004 Niigata and Parkfield earthquakes (ImageCat, 2004; EERI 2005). It has also been deployed for hurricane, flood, and surge following hurricanes Charley, Ivan, Dennis, Wilma and Katrina.

The Quick Time Virtual Reality (QTVR, Apple, 2007) technology permits to produce virtual reality scenes by the acquisition and the generation of 360° digital panoramic images, making possible a virtual exploitation of the scene. The QTVR has the primary advantage in providing not-interpreted data and allowing each user to perform a virtual navigation inside a damaged neighbourhood (Mucciarelli et Al., 2001). This technique may help in obtaining a damage description, also providing the possibility of a navigation in complex scenes, permitting to get closer to the ideal situation of being in that place at the same time.

3. DEVELOPING DISASTER DAMAGE SCALES USING MOBILE MAPPING AND REMOTE SENSING TECHNOLOGIES

In the immediate aftermath of an event, damage mapping is typically undertaken to support the response phase: in CEOS, (2002), the response phase is recognized as "all actions succeeding a seismic event, with the objective of saving human life, secure buildings and restoring".
Traditional methods of damage assessment involve walking surveys, where damage indicators together with the overall damage state, are logged on a spreadsheet. Commonly used indicators are employed within the hurricane and earthquake domains.
Those employed by the Wind module of the FEMA (Federal Emergency Management Agency) HAZUS-MH loss estimation software, include: roof cover failure, roof structure failure, window/door failure, roof deck failure, wall failure and the occurrence of missile impacts on walls. The Saffir-Simpson Scale of potential hurricane damage (Saffir, 2003), is based on velocity and characteristics of the windstorm, which can cause damage to building. This scale spans category 1 (No real damage to buildings, damage primarily to unanchored mobile homes, shrubbery, and trees; some damage to poorly constructed signs) to category 5 (complete failure of roofs on many residences and industrial buildings).
The EMS98 European Macroseismic Scale (Grünthal, 1998) for earthquakes measures intensity based on several factors including buildings, living things and ordinary objects. In particular, buildings are classified according to typology of construction (brick, simple stone, frame with earthquake design system…), vulnerability as a function of material (masonry, reinforced concrete, wood and steel), and finally damage grade (from 0, not damaged, to 5, completely collapsed). The classification of buildings into damage classes are aided by example photographs.
By using a weighted mean of vulnerability classes and grade of damage, it is possible to resume the macroseismic intensity of an earthquake in twelve grades, from I, only instrumental, to XII, completely devastating earthquake.
During post-disaster reconnaissance activities, mapping disaster affected zones is thus typically based on the detection of damage sustained by individual buildings. With the integration of remote sensing and ground survey techniques, the impact of a disaster can be more effectively and rapidly determined. The role of satellite and mobile mapping technology in this process has recently been emphasised by the collection of post-disaster damage data using mobile mapping technology and the subsequent development of remote-sensing based damage scales that are consistent with existing damage scales such as HAZUS-MH and EMS98.

3.1 A remote sensing-based damage scale for hurricane

With the integration of remote sensing and ground survey techniques, the impact of a disaster can be effectively and rapidly determined, particularly when using the same damage scale on remote sensing image interpretation and on ground survey. For example, by analysing a large archive of satellite and ground truth data collected in the aftermath of recent hurricanes including Charley and Ivan, Womble et Al. (2005) propose a HAZUS-MH compatible classes that may now be used operationally to provide a rapid overview (from RS-A to RS-D) of hurricane damage. These comprise:
<u>RS-A: No Apparent Damage (HAZUS-MH level 1, Minor Damage)</u>
- No significant change in texture, colour, or edges.
- Edges are well-defined and linear.
- Roof texture is uniform.
- Larger area of roof (and external edges) may be visible than in pre-storm imagery if overhanging vegetation has been removed.
- No change in roof-surface elevation

RS-B: Shingles/tiles removed, leaving decking exposed (HAZUS-MH level 2, Moderate Damage)

• Nonlinear, internal edges appear (new material boundary with difference in spectral or textural measures).
• Newly visible material (decking) gives strong spectral return.
• Original outside roof edges are still intact.
• No change in roof-surface elevation.

RS-C: Decking removed, leaving roof structure exposed (HAZUS-MH level 3, Severe Damage)

• Nonlinear, internal edges appear (new material boundaries with difference in spectral or textural measures).
• Holes in roof (roof cavity) may not give strong spectral return.
• Original outside edges usually intact.
• Change in roof-surface elevation.
• Debris typically present nearby.

RS-D Roof structure collapsed or removed. Walls may have collapsed (HAZUS-MH level 4, Destruction)

• Original roof edges are not intact.
• Texture/uniformity may or may not experience significant changes.
• Change in roof-surface elevation.
• Debris typically present nearby.

3.2 A remote sensing damage scale for earthquake

In image interpretation following destructive earthquakes, an integration between macroseismic damage scale and image interpretation was necessary. For example, following the 2003 Boumerdes event, Yamazaki et Al. (2004) classify the damage state of structures, employing a visually-based damage scale together with the one employed for ground survey by the local engineering community. The scale comprises:

1 - Only displacement of furniture and broken glasses
2 - Low cracks in inside infill and in ceilings; damage to water lines; non structural and isolated damage.
3 - Moderate important damage to non-structural parts and weak damage to structural parts.
4 - High / important very important non-structural damage and very extensive structural damage. Cracks in X in shear walls; rupture or hinging of beam-column joints.
5 - Very high / very important condemned or collapsed buildings

Integration between EMS 98 damage scale and damage detection from space can be delineated as following table 1 (Gusella, 2006).

EMS description	**Visibility from Remote Sensing**
Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)	No
Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)	No
Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	The dust and debris around buildings can be detected. May be possible to ascertain damage with a side looking image
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	Dust and debris event. Large failures can be detected in off-nadir scenes
Grade 5: Destruction (very heavy structural damage)	Destruction can be detected. If the destruction is not complete (for example the walls collapse but the roof remains), there may be errors in the damage assessment.

Table 1. Correspondence between damage classification EMS98 and characteristics in high-resolution remote sensing imagery (Gusella, 2006)

3.3 Multi-hazard damage scales

Through the collection of perishable post-disaster damage information and its integration with images captured in the immediate aftermath of the event, this remote sensing-based classification has the potential to be extended to other disaster typologies, such as flooding, industrial hazards, and volcanoes.
In a multi-hazard context, Womble et Al. (2006) use ground truth data collected after hurricane Katrina to propose a new combined wind and Flood (WF) damage scale.

• WF-0 - No Damage or Very Minor Damage: Little or no visible damage from the outside. No broken windows, or failed roof deck. Minimal loss of roof cover, with no or very limited water penetration
• WF-1 - Minor Damage: Maximum of one broken window, door or garage door. Moderate roof cover loss that can be covered to prevent additional water entering the building. Marks or dents on walls requiring painting or patching for repair
• WF-2 - Moderate Damage: Major roof cover damage, moderate window breakage. Minor roof sheathing failure; some resulting damage to interior of building from water.
• WF-3 - Severe Damage: Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water.
• WF-4 – Destruction: Complete roof failure and/or, failure of wall frame. Loss of more than 50% of roof sheathing.

Research is ongoing to augment this field perspective with remote sensing-based damage indicators.

4. VALIDATING REMOTE SENSING-BASED DAMAGE ASSESSMENTS USING MOBILE MAPPING DATA

Remote sensing-based approaches to building damage assessment may be categorized as multi- and mono-temporal. Multi-temporal analysis determines the extent of damage from changes between images acquired at several time intervals; typically before and after an extreme event.
Depending on spatial resolution and scene coverage, collecting information from space can span a hierarchy of scales from a city-wide extent, to a per building basis (Adams et Al., 2004b; Womble et Al., 2006). Starting from the city scale, a comparative analysis of Landsat and ERS imagery collected before and after the 1995 Hyogoken-Nanbu (Kobe) earthquake, suggested a trend between spectral change and ground truth estimates for the concentration of collapsed buildings (Matsuoka et Al., 1998, Yamazaki, 2001). The launch of very high-resolution commercial satellites such as Quickbird, IKONOS and ORBVIEW has generated new approaches to multi temporal damage detection (Adams, 2004a), enabling damage to be assessed on a per-building scale.

Huyck et Al. (2005), demonstrate how the rubble and debris accompanying building collapse are characterized by dense and chaotic edges. A pixel-based change detection algorithm has successfully been used, identifying urban damage based on different textural characteristics with the 'before' and 'after' event images as a function of the distinctive signatures of debris and collapse. This kind of algorithm was deployed following the 2003 Bam and Boumerdes earthquakes.

An alternative methodological approach is the object oriented technique, introduced by Baatz and Schäpe (2000) and applied to a wide variety of applications, from forestry (de Kok et Al., 2000), to change detection, (Niemeyer et Al., 2005) and to building recognition using lidar and high resolution Photogrammetry (Lemp, 2005). From a methodological standpoint, object oriented analysis differs from the traditional pixel-based analysis by the use of an object (such as a building), instead of a pixel, as the minimum calculating unit.

Three cases study are presented, following the development and integration of remote sensing damage assessments and mobile mapping survey data. These track technology enhancements from the first case, following the 1999 Marmara earthquake, where only a limited resolution (up to 5 meters) of satellite imagery was available, through ground survey after the 2003 Bam earthquake when the VIEWS technology was first deployed, to 2005 Hurricane Katrina, when detailed VIEWS footage was collected for flood and wind damage within New Orleans.

4.1 Izmit Earthquake

The Mw 7.4 Izmit (Turkey, Marmara region) earthquake occurred at 3:10 am local time 17 August 1999 on the east-west trending north strand of the North Anatolian Fault Zone (NAFZ), about 100 km SE of Istanbul.

In this area, there is a long history of earthquakes (the 1999 was the 11th earthquake greater than 6.7 Mw since 1939) and a clear pattern of sequential segmented rupturing of the NAFZ. In Izmit, damage ranged from complete collapse to undamaged structures. Many buildings were subsequently found to present defects, such as smooth steel bar, dimensional disproportion between pillars and lofts, and wrong inert granulometry in coastal zone of Golcuk and Yalova (Mucciarelli et Al., 1999).

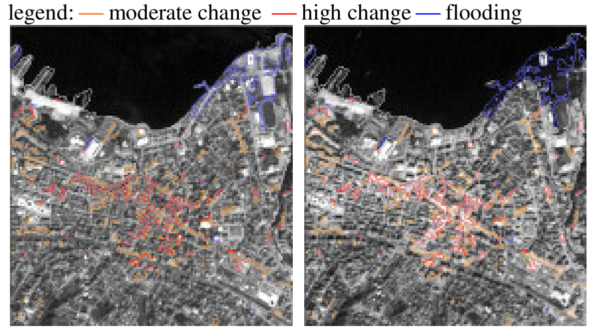
This earthquake represented the first extensive use of geomatic sciences in documenting a disaster event. Studies by Adams and Huyck (2006), Bitelli et Al. (2003b), Eguchi et Al. (2002, 2003) Estrada et Al.(2000), Gusella (2003), Huyck et Al. (2004), and Stramondo et Al. (2002), document the use of moderate resolution pre- and post-event optical imagery and SAR to provide city-wide remote sensing damage assessment.

The dataset used for the present damage assessment study includes two IRS satellite images, with a resolution of 5 meters, one collected ten days before the event (August, 8, 1999) and one several months after (September, 27, 1999). While the image provided before the event was up-to-date and representative of the pre-disaster situation, the after event image was captured more than one month later, and therefore may include clean up effects, such as the clearing of damaged city blocks.

The damage detection algorithm proposed here uses an object oriented approach to identify building collapse. Objects within the before event image were classified by a supervised decision rule into four classes (city, shadows, sea, shadow). Removing shadows from the calculation, a reflectance difference index was then computed. In this manner, flooded areas and damaged areas was delineated (figure 1).

Validation of the damage assessment results was supported in part using mobile mapping data collected using the Quick Time Virtual Reality (QTVR) system. The ground survey was conducted by QUEST (QUick Earthquake Survey Team), with the specific aim of completing a macroseismic survey following EMS98 guidelines (http://www.ingv.it/quest/index.html). In the example in Figure 2, derived from a QTVR movie, two buildings from the same neighbourhood exhibit very different behaviour. One is collapsed due to a structural damage, while the other one is standing. This kind of information helps responders and researchers to correctly understand the distribution of the damage, and, capture the situation in the immediate aftermath of an event, before clean-up operations commence.

legend: — moderate change — high change — flooding



(a) (b)

Figure 1. Before (a) and after (b) IRS images from Golcuk, overlaid with the damage assessment results.

Figure 2. Panoramic QTVR views of the centre of Golcuk. Two identical buildings, 1 and 2, are showing a different resistance to shaking (QUEST).

4.2 Bam Earthquake

A magnitude 6.6 (Ms) earthquake struck the city of Bam in southeast Iran at 5:26:52 AM (local time) on Friday, December 26, 2003. The Bam earthquake was widely studied by the remote sensing community, in particular focusing on different approaches to damage assessment. For example, for mono temporal high-resolution imagery, see Chirou (2005), for multi temporal high-resolution imagery see Gusella et Al., (2005), Huyck et Al. (2005); for multitemporal moderate resolution imagery see Masayuki (2005); and for Synthetic Aperture Radar, see Mansouri et Al. (2005).

Figure 3 outlines the object-based methodological approach, employed by Gusella et Al. (2005) to count the number of collapsed buildings. Quickbird images were used with a resolution of 61 cm, acquired before (September 30, 2003) and soon after (January, 3, 2004) the earthquake. In summary, the damage detection employed a two phase procedure (Figure 3).

(1) Building inventory

(2) Damage detection

An inventory of the pre-earthquake situation was initially conducted. As shown in Figure 4, this involved identifying and classifying buildings within the 'before' image. Potential buildings were identified through segmentation, considering the closest correspondence between building and segment. The segments were then classified using a nearest neighbour supervised approach (Definiens Imaging, 2004).

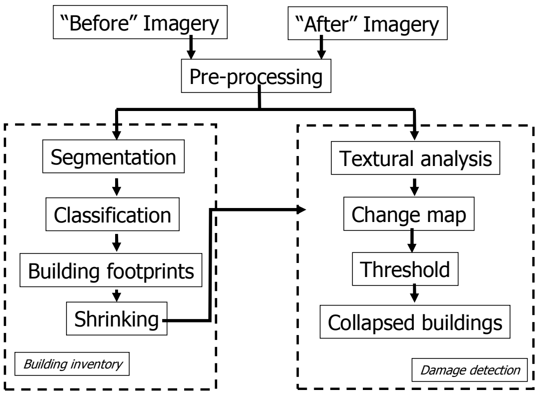
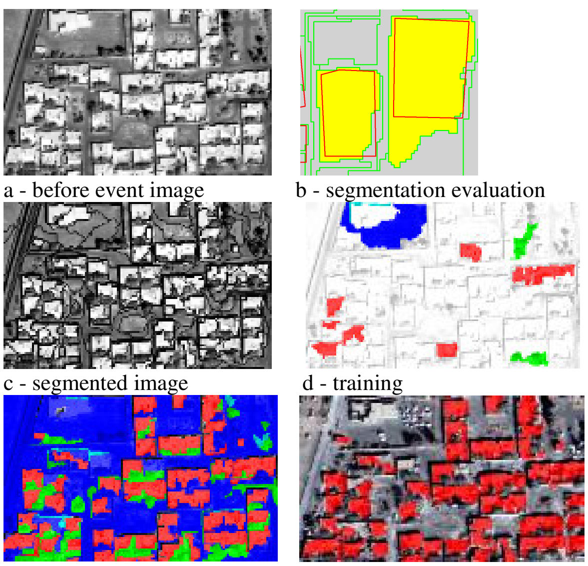


Figure 3. Damage detection from Quickbird imagery



a - before event image b - segmentation evaluation

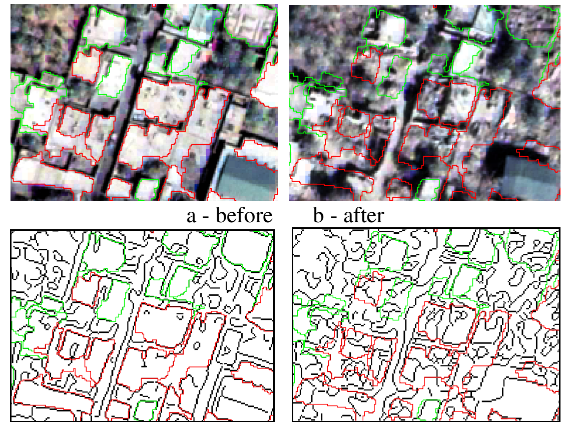
c - segmented image d - training

e - classification f - building inventory

Figure 4. Flow diagram for building inventory.

Having identified the full set of structures within Bam, damage detection was then conducted. The intact building footprints were superimposed on the "after" image, which visibly distinguishes damaged from non-damaged structures. Footprints throughout the city were then categorized as either collapsed or non-collapsed, based on the unique statistical characteristics of these respective damage states within the post-earthquake scene.

In this instance collapsed versus non-collapsed buildings ere distinguished in terms of the different frequency of edges present within the footprints. From a theoretical standpoint, intact buildings are characterized by a homogenous outline with few edges, where collapse produces a chaotic concentration of edges. Edge statistics (Canny, 1986) within the building outline were computed between the image acquired before and after the earthquake. To minimize errors due to mis-registration between the images, a shrinkage factor of 1 pixel (0.6 meters) was applied to the building outline, thereby avoiding border effects (Figure 5).



a - before b - after

a - before Canny b - after Canny

Figure 5. a) Before event image, b) after event image, c) Canny filtered before image, d) Canny filtered after image. In red, damaged buildings identified

Validation of the Bam damage assessment in part employed data collected through mobile mapping. The Bam earthquake saw the first in-field deployment of VIEWS (Adams et Al., 2005). The data collection system was equipped with the same optical imagery as in the damage detection, (Quickbird imagery, one acquired before September 30, 2003 and soon after the event January 3, 2004). Several additional image layers were loaded into the system, including a remote sensing-based visual image assessment, and a textural change map (Huyck et Al., 2005). These information layers helped direct survey teams to the most impacted area. A library of geo-coded photos was collected, reporting the exact location of damage further investigation and damage assessment. Validation for selected structures captured using the VIEWS data suggest a strong correspondence between the object-oriented damage assessment of building collapse and in-field observations (Figure 6).

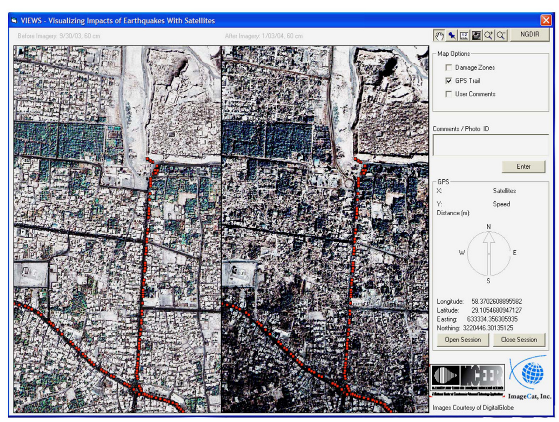


Figure 6. User interface of the VIEWS™ system used in Bam by the EERI reconnaissance team. GPS points are overlaid in the "before" and "after" satellite imagery, corresponding with routes driven through the city. GIS layers, such as texture based damage maps (Huyck et Al., 2005) can also be displayed.

The same zone is presenting major damage also in the change detection results, showing a qualitative agreement between the procedures (figure 7).

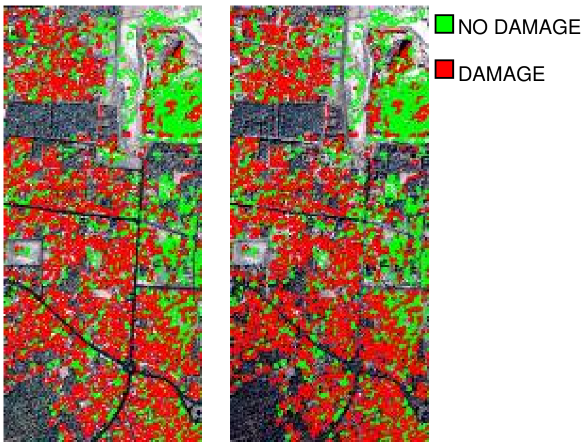


Figure 7. Results from change detection damage assessment. The before and the after event images are respectively in the left and in the right.

4.3 Hurricane Katrina

Hurricane Katrina first made landfall in the U.S. on August 23, 2005 in southern Florida as a Category 1 hurricane. On August 28, Katrina reached peak intensity with sustained winds exceeding 170 mph. Various kinds of remote sensing and aerophotogrammetric data were captured in the days following Hurricane Katrina, including imagery by: IKONOS, Orbview, Quickbird, Landsat; and NOAA. NOAA aerial images and Quickbird scenes were loaded into VIEWS reconnaissance system in order to provide field teams with a synoptic perspective on damage sustained through the affected areas.

The data survey was conducted taking into account several key features:

- Damage assessment for buildings, other infrastructure and lifelines;
- Hazard-specific technical observations related to the cause of the event (e.g., wind speed, hurricane central pressure, earthquake intensity);
- Assessment of the socio-economic situation.

As described in Section 3.3, the mobile mapping data was used to develop a multi-hazard wind-flood damage scale. Research is currently ongoing to establish a further association between the damage scale and damage signatures on remote sensing imagery for New Orleans. Figure 8 illustrates the complementary damage signatures within the VIEWS ground-truth archive and the post-disaster Quickbird scene, which together provide a holistic perspective on damage. Nadir images are ideally used to visualize horizontal surface, such as roofs. For vertical surfaces, such as façade, side views, or off-nadir imagery is necessary to complete the interpretation. Subsequent research will use these damage states to validate the results of object-oriented damage assessments conducted using pre- and post-disaster imagery.

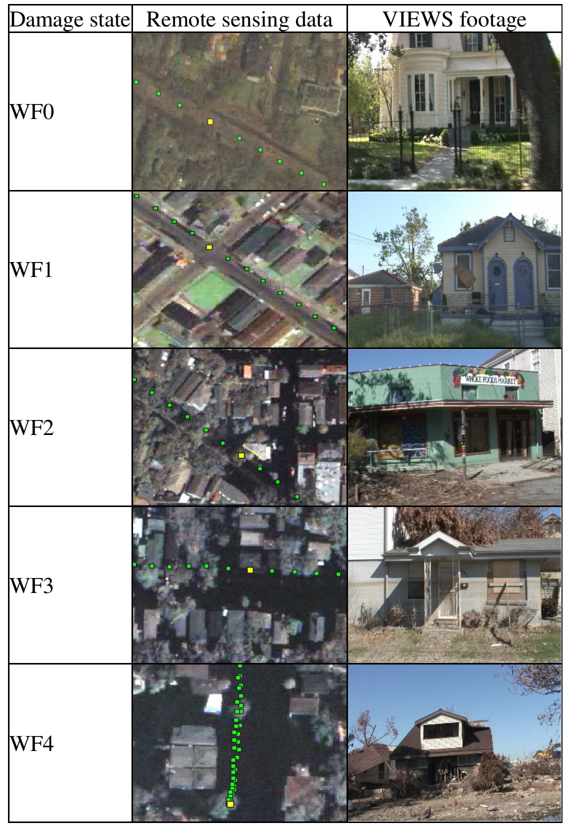


Figure 8. Extending the multi-hazard wind-flood damage scale to include remote sensing characteristics. Quickbird imagery courtesy of DigitalGlobe (www.digitalglobe.com). VIEWS footage courtesy of ImageCat, Inc. (www.imagecatinc.com).

5. CONCLUSION

This paper described the application of mobile mapping technology to collect post-disaster damage information, and the integration of this data with remote sensing imagery to develop remote sensing-based damage scales and to validate semi-automated damage assessment results.

Two mobile mapping systems are described: (1) the VIEWS field data collection and visualization system; and (2) the QTVR visualization environment. Remote sensing data serves as a fully integrated base layer within the VIEWS data collection environment, to guide field teams to hard-hit areas, and provide navigational support.

The application of these technologies is described for several case studies. Following Hurricane Katrina, VIEWS data has being used to develop a multi-hazard wind-flood damage scale, which is now being extended to include signatures within remote sensing imagery. Following the 1999 Marmara earthquake, QTVR data was used to visualize damage within neighbourhoods of Golcuk and to validate object-oriented damage assessment results. Following the 2003 Bam earthquake, VIEWS footage was used to assess the accuracy of object-based count of building collapse.

These technologies and damage detection methodologies have the potential to enhance and accelerate post-disaster response activities, through rapid, complete and robust damage assessment.

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