Rapid damage assessment using high-resolution remote sensing imagery: Tools and techniques

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7 authors, including:

Ranga Raju Vatsavai
North Carolina State University

Leena sarkar Bhaduri
□□□ □□□□ □□□□□□□□□□□

Anil Cheriyadat
Oak Ridge National Laboratory

Varun Chandola
University at Buffalo, The State University of New York

RAPID DAMAGE ASSESSMENT USING HIGH-RESOLUTION REMOTE SENSING IMAGERY: TOOLS AND TECHNIQUES

R. Vatsavai, M. Tuttle, B. Bhaduri, E. Bright, A. Cheriyadat, V. Chandola, J. Graesser

Computational Sciences and Engineering Division,
Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA.

ABSTRACT

Accurate damage assessment caused by major natural and anthropogenic disasters is becoming critical due to increases in human and economic loss. This increase in loss of life and severe damages can be attributed to growing population, as well as human migration to disaster prone regions of the world. Rapid damage assessment and dissemination of accurate information is critical for creating an effective emergency response. Remote sensing and geographic information systems (GIS) based techniques and tools are important in disaster damage assessment and reporting activities. In this review, we will look into the state of the art techniques in damage assessment using remote sensing and GIS.

***Index Terms*—** Change detection

1. INTRODUCTION

Remote sensing data plays a key role in disaster mapping of human settlements. The contributions of these types of data range from delineation of affected population areas to the assessment of structural damages to buildings and critical infrastructures. The study reported in [1], shows that remote sensing technology has been most widely utilized in mapping and monitoring of hazards, identification of damages, and effects of disasters. Remote sensing is also useful in (near) real time assessment of damages caused by floods, forest fires, and other temporal phenomena. The integration of remote sensing, GIS, and other modeling and simulation systems can provide valuable assistance to a comprehensive decision support system. Our objective in this study is twofold. First, we review the state of the art in damage assessment, and second, we present our ongoing research, which compares major damage assessment techniques using the datasets collected in the aftermath of hurricane Katrina. The Federal Emergency Management Agency (FEMA) defines several types of disasters [2] that can cause severe damage to humans, as well as man-made structures and the environment. A few of the common major disasters include landslides, earthquakes, and hurricanes. Figure 1 shows the damages induced by these types of catastrophic events.

2. TOOLS AND TECHNIQUES

Remote sensing data plays an important role in delineating the affected areas due to natural and anthropogenic disasters discussed in Section 3. Several organizations specifically created, or mandated, to deal with disasters are using remote sensing and GIS technologies to provide detailed information on the affected regions around the globe. One such organization, the International Charter [3] provides a unified system for space data acquisition and delivery of information about the regions affected by natural or man-made disasters. For example, activations map (see Figure 1(e)) created by the International Charter, shows different disasters in 2010. This interactive map provides links to the available image data products to authorized users. Similarly, the United Nations Institute for Training and Research (UNITAR) [4] through its UNOSAT delivers satellite solutions and geographic information on the communities exposed to poverty, hazards, and other crises.

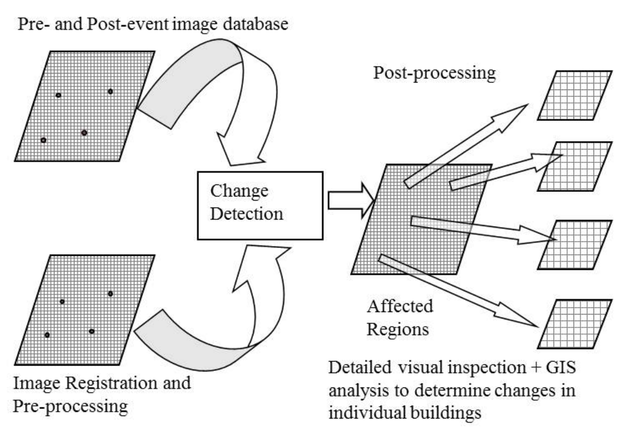


Fig. 2. Change detection framework

Traditionally, damage assessment to the individual buildings and other critical infrastructures has been carried out manually by visual interpretation of pre- and post-event aerial photos. Manual photo interpretation is still used, for example, in a recent study by the Government of Haiti (2010) in the aftermath of magnitude 7.0 earthquake on 12 January 2010. Image analysts at UNITAR/UNOSAT categorized buildings

(a) Major California landslide damage sites 1997-1998 (Source: USGS)

(b) Damaged buildings due to 1998 Laguna Niguel landslides (Source: USGS)

(c) Submerged village near Sumatra after the 2004 Indian ocean earthquake (Source: US Navy)

(d) New Orleans after Katrina, 2005 (Source: US Coast Guard)

(e) Activations map showing major disaster events in 2010 (Source: International Charter)

Fig. 1. Various types of damage events

into destroyed, severely damaged, moderately damaged, and no visible damage based on European Macroseismic Scale - 98 definition [5]. Such detailed studies are required for accurate assessment of damages; however, it takes much time and effort. More timely damage assessment and delineation of disaster affected areas can be achieved with high-resolution satellite imagery and automated change detection techniques. One of the more important functions of disaster assessment of human settlements includes rapid estimates of affected regions so that rescue and recovery operations can be carried out in an effective manner. Change detection [6] is widely used for rapid assessment of the affected areas. Figure 2 shows a generic change detection framework. First, suitable high-resolution imagery from pre- and post-event dates must be obtained. These images should then be geo-registered so that one to one (pixel) correspondence may be established between the set of images. Once the images have been registered, change detection techniques can be applied to obtain a map that shows possible changes (affected regions). Typically, further analysis is needed to accurately identify damages to individual structures. We now briefly describe major techniques that are widely used in damage assessment studies.

Image Differencing: Image differencing is one of the most widely used automatic change detection techniques. This technique involves two steps: 1) given two univariate images, the first image (time 1) is subtracted from the second (time 2), 2) each pixel is assigned a label of change or no change by checking if the magnitude of the difference is above a certain threshold. The main advantage of image differencing is that the technique is computationally cheap. The major disadvantage is setting an appropriate threshold value requires careful fine-tuning and interpretation of results. Typically, a threshold value is set in terms of standard deviations (see Figure 3). Image differencing is part of a more general setting, known as image algebra-based change detection.

Change Vector Analysis: While the image differencing

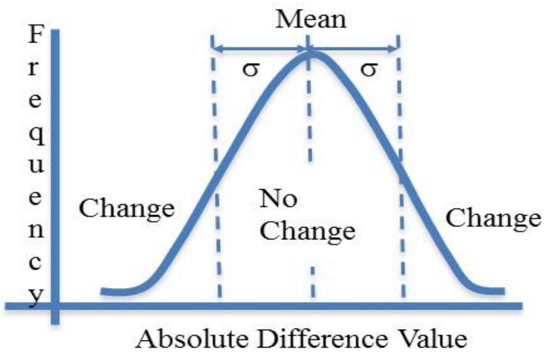


Fig. 3. Image differencing (Mean and SD thresholds)

technique is limited to univariate (single band) images, the change vector analysis is designed to analyze changes in multi-spectral and multi-temporal image sequences. The change vector is simply the vector difference between time-trajectory of successive time periods. As shown in Figure 4, the length of a change vector is given by $S = \sqrt{[(B_2 - B_1)^2 + (G_2 - G_1)^2]}$ and direction of change is given by $\alpha = \arctan\left[\frac{(B_2 - B_1)}{(G_2 - G_1)}\right]$, where B and G are two spectral bands. The length of the change vector indicates the magnitude of change and the direction indicates the nature of change [7, 8]. Typically, threshold segmentation is carried out on the change vector's magnitude image.

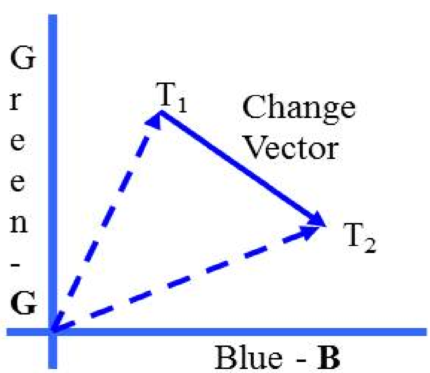
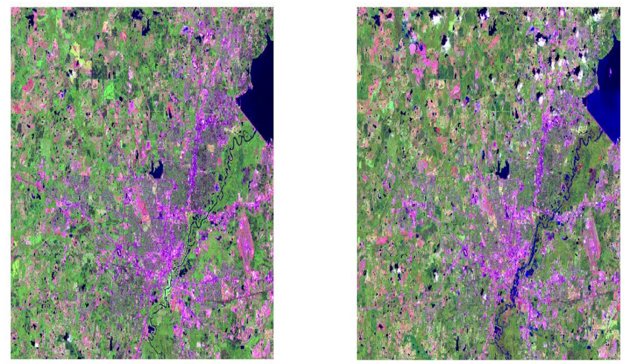


Fig. 4. Chage vector analysis

Inner Product and Spectral Correlation Analysis: In the inner product analysis, the spectral values of a pixel in an image are considered as vectors (as in change vector analysis). The difference between two multispectral vectors is measured as the cosine of the angle between them. The basis for using cosine measure is that if two multispectral vectors are coincident with each other, then their inner product is 1. If there is a change between the images, then this quantity varies between -1 and +1. Spectral correlation analysis is similar to the inner product analysis, the main difference being that the correlation method takes into account the means of the multi-spectral vectors. Using means instead of absolute difference values has the potential to reduce atmospheric and other imaging effects. The correlation coefficient, or spectral signature similarity, in the change image is given by $y = ax + b$, where a and b are two constants such that value of y can be scaled to an appropriate non-negative range. The spectral correlation method was used in several land cover change studies [9].



(a) FCC (5,4,2) May 2005

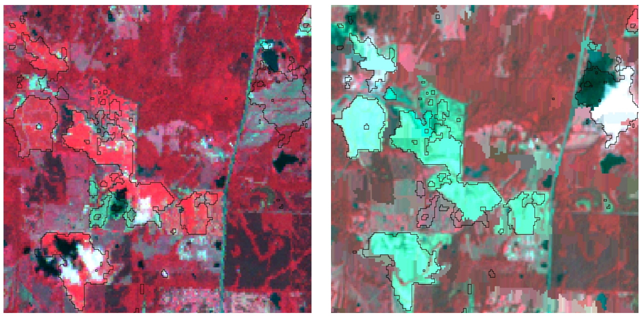
(b) FCC (5,4,2) September 2005

Fig. 5. Landsat 7 pre and post Katrina FCC images

3. RESULTS

We have collected a large number of optical imagery (digital ortho images, ASTER, IKONOS, LANDSAT 5 and7, Quickbird and SPOT) before and after hurricane Katrina. Currently, we are evaluating various change detection techniques against this database to understand the performance of each technique in identifying various types of damages. We briefly present the preliminary results of change detection on Landsat 7 images. Figure 5 shows two false color composite (FCC) images acquired before and after Katrina. First, we applied the image differencing procedure on six of Landsat 7 image bands (thermal IR band excluded). One of main problems with image differencing is the interpretation of results from six difference images. We developed a simple scheme borrowed from the multiple classifier systems literature. First, each difference band image was subjected to the thresholding scheme ($\mu \pm 2 * \sigma$). This thresholding works well if the change (difference) values are normally distributed. However, many times the change values are highly skewed. If the distribution is skewed, then thresholding can be applied on the % differences, or on the magnitude of difference. A majority voting procedure is then applied to each pixel (change vector) generated by the thresholding procedure to create a single band change image. Figures 6 (a) and (b) show a small portion of pre- and post-Katrina Landsat 7 FCC images with change polygons overlaid on them. A closer look at these polygons reveals significant differences between pre- and post-images.

A second approach that we tested to generate a single band change image from the multi-band difference images is based on the chi square transformation. The chi square transformation is given by $Y = (X - \mu)^t \Sigma^{-1} (X - \mu)$, where X is the six dimensional change vector generated by image differencing. Apart from the methods described here, we have applied several other variations (e.g., pre and post image classification comparison; unsupervised clustering based methods) on these datasets, and the results are currently under evaluation.



(a) FCC (5,4,2) May 2005 (b) FCC (5,4,2) September 2005

Fig. 6. A small portion highlighting changes

4. CONCLUSIONS AND FUTURE DIRECTIONS

In this review, we presented only the major categories of change detection techniques. There are many hybrid techniques [10, 11, 12] which utilize variations of unsupervised, supervised, and object-based techniques. Our review is mostly focused on techniques for identifying damages caused by natural or human-induced disasters using high-resolution remote sensing imagery. A more general review of change detection approaches can be found in [13]. In addition to the review, we have presented some preliminary results. A detailed evaluation of the results generated by applying various techniques described in this paper is in progress. We hope that this research will help to understand the suitability of various change detection techniques in characterizing damages which result from extreme natural and human-induced events.

5. ACKNOWLEDGMENTS

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