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Cyclone damage detection on building structures from pre- and post-satellite images using wavelet based pattern recognition

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ABSTRACT

The majority of building structural losses during the past few decades has been due to wind induced damage, especially tropical cyclone damages. Rapid identification of damage locations as well as damaged buildings, and appropriate maintenance, can diminish the impact of such natural disasters. This paper describes detection of damage to cyclone-prone building roof structures from pre- and post-storm satellite images of the shores of Punta Gorda before and after the Hurricane 'Charley' 2004 disaster using a wavelet-based change detection method. Damaged buildings are automatically identified using wavelet-extracted statistical features and by edge detection, and classification using Artificial Neural Network (ANN) and Support Vector Machine (SVM). A comparison analysis is then carried out by comparing these results with results obtained using conventional change detection methods. It is observed that the wavelet-based change detection method yields identification information of damaged buildings superior to that obtained using conventional methods. In this work, the percentage of the damaged area of each damaged building is also calculated by a newly introduced texture-wavelet analysis on roof-tops, and the results are validated by counting the damage pixels manually. A positive increase in the extracted statistical features is observed as the percentage area of damage increases, which adds to the accuracy of the identification method.

1. Introduction

From caveman times to the present day, wind disasters and damage to structures and buildings has been a fact of life. Of the dreadful hurricanes of the 2004 Atlantic hurricane season, Hurricane Charley was the third named storm and the second major hurricane. It made landfall on Friday, August 13, 2004 on the southwest coast of Florida at Charlotte Harbor. It was the strongest hurricane to hit the United States since Hurricane Andrew struck Florida twelve years earlier in 1992. With a wind speed of 240 km/h at peak intensity, Hurricane Charley became a strong Category 4 hurricane in the Saffir–Simpson Hurricane Scale. It also became the second costliest hurricane in United States history after Hurricane Andrew (Womble, 2005), with estimated damage of $15.4 billion. Obtaining information on such catastrophic damage from ground surveys (ground truth data) is time consuming and costly. To achieve a quicker response and thus provide near-instant help to widely damaged locations, computational analysis will become necessary. Exploitation of remote sensing technology along with the latest pattern recognition knowledge and image processing techniques creates a new route for such computational analysis.

Past researches have been done on other types of natural disasters such as earthquakes using aerial images (Hasegawa et al., 2000; Mitomi et al., 2001; Sumer and Turker, 2004; Ozisik, 2004), and a major contribution using satellite imagery was made by Matsuoka and Yamazaki (2000) and Vu et al. (2005). Various research have also been done on other natural disasters such as wild fires (Ambrosia et al., 1998), floods (Groeve and Riva, 2009), landslides (Danneels et al., 2008) by computational identification using low-resolution satellite images. Tornado damage path tracking has been accomplished from low-resolution satellite imagery by detecting changes from pre- and post-storm imageries (Soe et al., 2008; Thomas et al., 2002) and using post-storm imageries alone (Radhika et al., 2011, 2012). But the introduction of high-resolution satellite imageries has created a breakthrough in identification of disaster affected areas for rescue purposes as well as reconstruction of wind disaster damaged buildings. In Womble et al. (2007) and Womble (2005), computational analysis was done for building damage detection mainly using statistical analysis of the histogram of the satellite image pixel radiance value in four spectral bands. Damage to building structures is rated by ground truth data into an RS-Scale (Remote Sensing Scale) table.

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Wavelet analysis, a novel technique for pattern recognition of high-resolution satellite images, is introduced in this paper to identify damaged buildings after the passage of hurricane Charley. Damaged edge extraction using texture-wavelet analysis as well as wavelet feature extraction aided rapid and accurate identification of damaged buildings. Once the damaged buildings are identified, the percentage area of damage of roof structures, which is very difficult to obtain in a ground level survey, is calculated automatically, rather than classifying the buildings under different damage scales. This makes the damage identification more informative. More accurate and faster damage identification can provide near-instant help to widely damaged locations by handing over the information immediately to the emergency managers as well as the first aid responders. The detailed and precise information on the damaged buildings and percentage area of damage provide data to the insurance provider for a faster building structures restoration.

2. Data pre-processing

2.1. Data acquisition

Hurricane Charley made landfall on Friday, August 13, 2004 on the southwest coast of Florida at Charlotte Harbor. Two QuickBird Satellite Imageries of the disaster location, Punta Gorda, FL, before and after the hurricane passed, provided wider coverage of information about the area where the hurricane had a severe impact. Fig. 1(a) shows the multi-spectral pre-storm imagery (pre-disaster image) taken by the optical probes of the QuickBird Imagery satellite on March 23, 2004. Fig. 1(b) shows the multi-spectral post-storm imagery (post-disaster image) taken by the same satellite on August 14, 2004, just a day after landfall. The QuickBird imagery used in this study was bought from Digital-Globe Co., Ltd., and was licensed and provided by the Remote Sensing Technology Center of Japan (RESTEC). The imageries have a spatial resolution of 1 m/pixel.

Some field investigation information was also collected to support the validation procedure. Fig. 1(c) gives some of the ground truth information of Punta Gorda, FL Hurricane Charley struck (Womble, 2005). Although Womble (2005) demonstrated that a GIS-based video driving survey can increase the amount of ground truth data capture, the limitations still exist due to time restrictions and inaccessibility of the disaster location just after such a major wind disaster event.

2.2. Image enhancement

As the pre- and the post-storm images were collected at different instances, the images have apparent misalignment as well as varied illumination. Initially, in the current work proper image enhancement was carried out, such as illumination normalization (Womble, 2005) for the two images as well as image registration for adjusting the image alignment (Lakshminarasimhan, 2004).

An image registration procedure was accomplished using a geometric transformation procedure (Lakshminarasimhan, 2004), with the pre-storm image as the reference image and the post-storm image as the image to be registered. Eqs. (1) and (2) give the new transformed position (x', y').

$$x' = H_x(x,y) \tag{1}$$

$$y' = H_y(x,y) \tag{2}$$

where (x, y) is the location of the tie points in the reference image, which is manually identified and H_x, H_y are the transformation polynomial functions. Surviving features in both imageries are adopted as tie points. Here, road junctions are mainly chosen. Based on these tie points, pre- and post-storm imageries are registered using geometric transformation.

2.3. Sample selection

After image registration, buildings are automatically identified and separated (Radhika et al., 2011, 2013) and selected as damaged or undamaged, from the satellite imageries for classification. Visual recognition from satellite images helps in this step of sample selection, aided by available limited ground truth information. The samples thus collected are for two purposes. The feature extracted from the first set of samples is used for training the Artificial Neural Network (ANN) and Support Vector Machine (SVM) classifier and the feature extracted from the next set is used for validation.

Each building sample collected is represented as a matrix of pixels for each spectral band. The number of rows and columns in each sample depends on the size of the building as the spatial resolution of the given imageries remains constant. Both pre- and post-storm imageries collected are multi-spectral 16-bit imageries. As a result, each pixel contains pixel radiance information about 4 channels or bands, i.e. three visible channels, red, green and blue (RGB channels or bands), and one near-infrared channel. For the present work, only RGB visible channel pixel information is

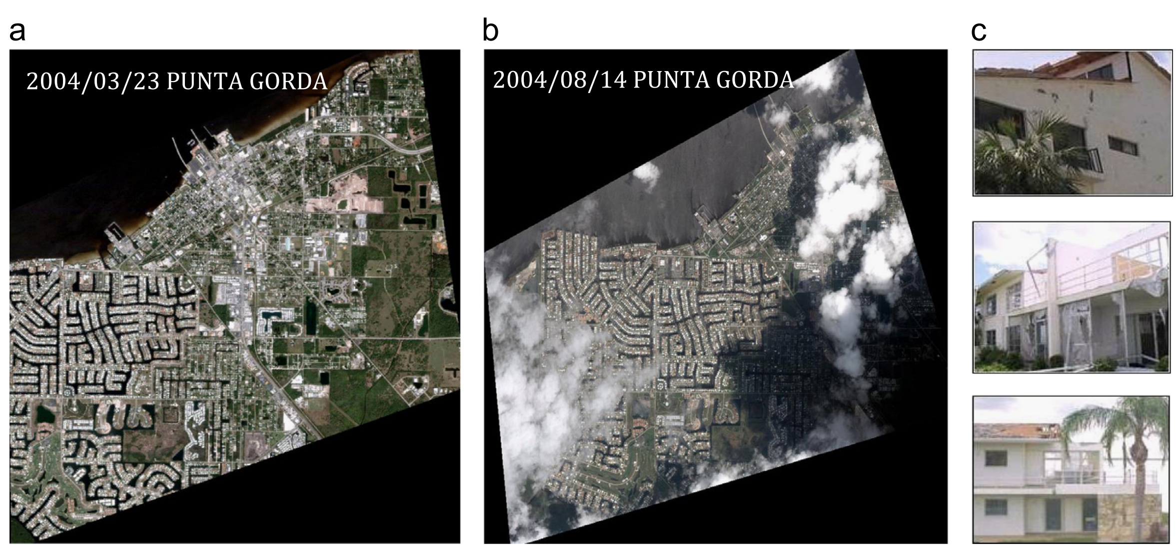

Fig. 1. (a) Pre-storm image (source: DigitalGlobe Co., Ltd.). (b) Post-storm Image (source: DigitalGlobe Co., Ltd.). (c). Field investigation information (source: Womble, 2005).