ASSESSMENT OF STORM-INDUCED COASTAL MORPHOLOGIC CHANGES AND DAMAGE USING REPEAT LIDAR REMOTE SENSING SURVEYS

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1. INTRODUCTION

Hurricanes and tropical storms represent severe threats to coastal properties, settlements, and infrastructure [3][6]. Until recently, the assessment of hurricane-induced damages has been based on ground surveys and aerial photography. Although these conventional damage assessment methods provide reliable qualitative information about the hurricane damages, they are often inadequate for accurate quantitative assessment of hurricane damages to human settlements, shoreline, beaches, sand dunes and coastal infrastructure. Conducting ground surveys and visually interpreting aerial photographs are time-consuming and labor-intensive, which may delay corrective actions initiated by coastal managers. Recent advent of airborne LiDAR technology offers an extraordinary capability for gathering highly accurate and densely sampled coastal topography data [7]. Airborne LiDAR surveys conducted before and after storm events allow for an entirely new level of analysis of coastal geomorphologic and sediment volumetric changes induced by hurricane hazards [1][2]. This research presents a numerical method for representing and quantifying hurricane-induced damages to buildings, beaches and sand dunes, coastal vegetation canopy, and infrastructure. This method has been successfully applied to assess the Hurricane Ike damages to the Bolivar Peninsula based on pre- and post-storm airborne LiDAR and color infrared (CIR) aerial photographs.

2. ANALYTICAL FRAMEWORK AND METHODOLOGY

A general analytical framework is established for object-oriented representation and analysis of coastal changes induced by hurricane hazards. The detected volumetric changes are conceptualized and represented as two types of objects: bona fide objects, and fiat objects. Bona fide objects are associated with buildings and other man-made structures, which have determinate and prominent boundaries that enclose them and separate them from their backgrounds. Fiat objects are associated with beaches, sand dunes, and vegetation canopy, which have vaguely defined boundaries and are created by spatial analysis and human cognition. The hurricane damage to buildings and other man-made structures is detected and evaluated by the volume changes associated with destruction, collapse, and relocation. The damage to beaches and sand dunes is represented by sediment redistribution due to erosion and deposition. The vegetation damage is assessed by examining Normalized

Difference Vegetation Index (NDVI) changes from CIR aerial photographs and volumetric changes from repeat LIDAR surveys. The method consists of four consecutive computational steps: pixel-based elevation differencing, object identification through multiple-threshold segmentation, attribute derivation, damage type classification and assessment.

The first step is to evaluate the volume change on a cell-by-cell basis by subtracting the pre-storm LiDAR DEM from post-storm LiDAR DEM. Second, a multiple threshold segmentation algorithm is developed to detect initial change patches, in which threshold values are optimally determined through local statistical analysis. Morphology operations are applied to enhance the boundaries of change patches. Then, each change patch is delineated through a connected component identification algorithm and explicitly represented as an individual spatial object with a unique identification number. Instead of individual grid cells, these discrete objects are subsequently used as the basic spatial units for the damage assessment. A set of geometric, morphologic, and volumetric attributes are derived to characterize and quantify objects (patches), including location, perimeter, area, compactness index, fractal dimension, elongatedness, orientation, surface slope and curvature variation, erosion or deposition depth, sediment removal or accretion volume, and volume change rate. NDVI values are also calculated for vegetation damage assessment by incorporating high-resolution CIR aerial photographs. The quantitative analysis of attribute values renders the capability of discriminating and classifying individual change objects into different damage classes: building damage objects, sediment erosion objects, sediment deposition objects, and vegetation damage objects. Summary statistical attributes, including the number of change objects, average size of change objects, total change area, total change volume, are calculated to depict the overall magnitude and spatial pattern of the hurricane damages.

3. APPLICATION RESULTS

The object-based method and algorithms have been tested and evaluated with a case study of Hurricane Ike damage to the Bolivar Peninsular, Texas. Hurricane Ike made landfall as a strong category 2 storm on September 13, 2008. Pre-storm LiDAR data used in this analysis were acquired in September, 2007, and post-storm LiDAR data were acquired during December 12-13, 2008 (Figure 1c and 1d). The LiDAR data sets have a spatial resolution of 1 m and vertical accuracy of 10-20 cm. CIR aerial photographs (0.5 m resolution) used in this analysis were acquired by Texas General Land Office in July and August, 2008 (pre-storm) and in May, 2009 (post-storm) (Figure 1a and 1b). The surface morphology changes caused by Hurricane Ike are represented by the elevation changes (differences) in Figure 1e.

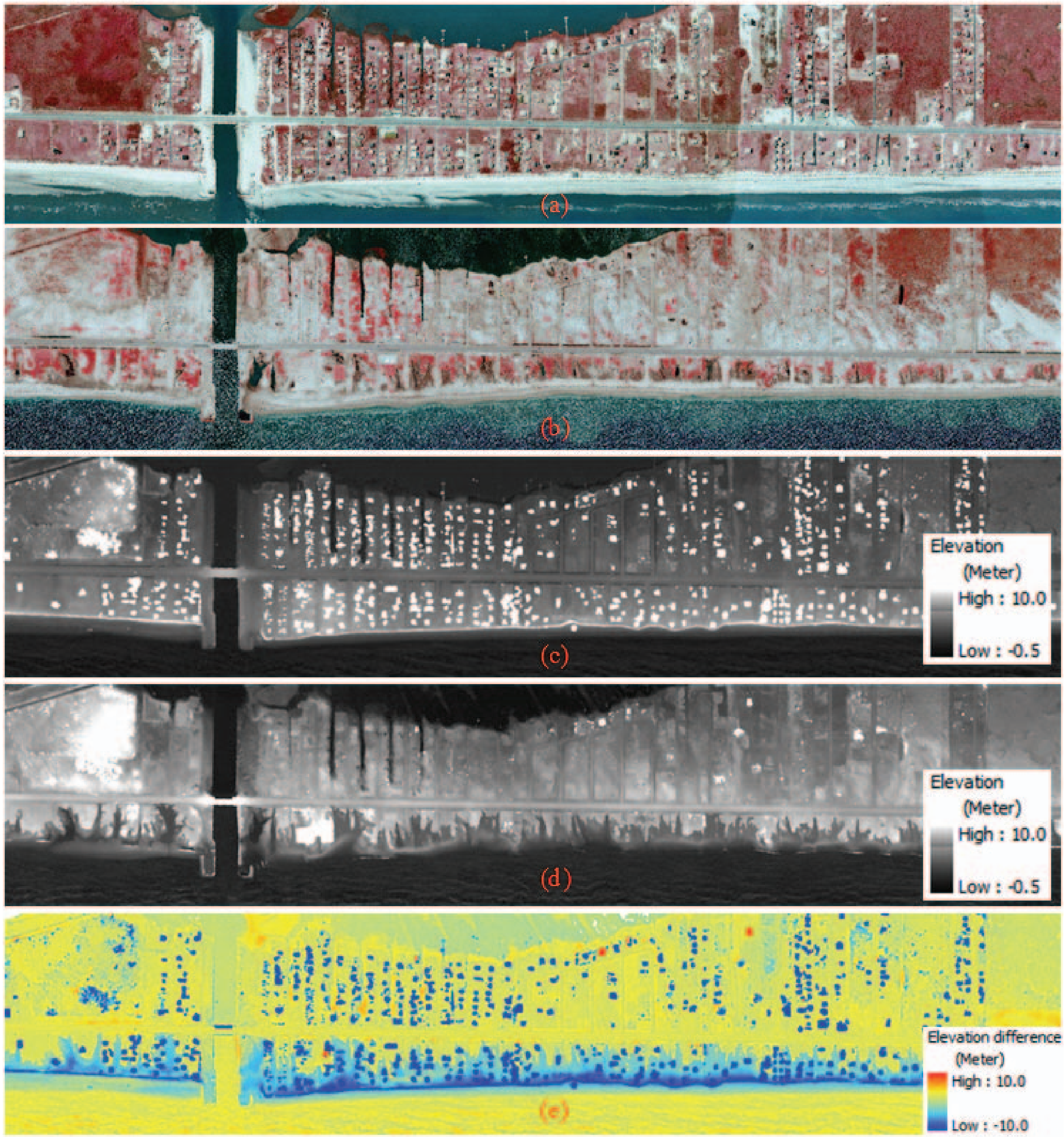

Figure 1: CIR aerial photographs, LiDAR DEMs and the elevation difference grid. (a) Pre-hurricane CIR acquired in August, 2008; (b) Post-hurricane CIR acquired in May, 2009; (c) Pre-hurricane LiDAR DEM acquired in September, 2007; (d) Post-hurricane LiDAR DEM acquired in December, 2008; and (e) Cell-by-cell elevation changes during 2007-2008.

By applying the object-oriented method to pre-storm and post-storm LiDAR and aerial photographs, accurate quantitative information about the hurricane damage to buildings, beach and sand dunes, geotubes, and vegetation cover is derived and represented. Compared with the cell-by-cell differencing approach [5][8] and object-tracking method [4], the object-oriented method proposed in this research has a number of desirable properties. The use of change objects as the basic spatial unit reduces the influence of data noise and enhances the reliability of extracted morphological change information. The explicit object representation of change patches makes it possible to localize and depict damage hot spots.

4. CONCLUSIONS

As demonstrated, multi-temporal LIDAR surveys provide effective and powerful means to acquire land cover change information for assessing natural hazard damage in a rapid and timely fashion. In contrast to grid cells in the field-based representation, objects are much better information carriers. The object oriented method is efficient for processing repeat LiDAR data, extracting scientific information and knowledge, and providing reliable assessment of hazard damages to support emergency response planning, rescue and recovery activities.

5. REFERENCES

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