Integration of Remote Sensing and GIS for Tree Damage Estimation from Natural Disasters

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Abstract – The goal of this study was to use LiDAR data to assess damage to trees from a December, 2007 ice storm affecting the city of Norman, Oklahoma (USA). Pre- and post-storm LiDAR data was collected for the city and it was processed and analyzed in a GIS platform. Results indicate that for single standing trees, LiDAR data can accurately assess and quantify damage with an accuracy of 90%. However, it is yet to be examined how the accuracy would change if the proposed methodology was applied to grouped trees or with trees with overlapping branches. The proposed method suggests that in the future, LiDAR data would allow foresters and researchers to assess tree damage from not only ice storms, but also other natural disasters.

Keywords: LIDAR, Ice Storms, Urban Vegetation, Hazards, Forestry.

1. INTRODUCTION

Every year throughout the world, natural hazards such as hurricanes, floods, wild fires, droughts, volcanic eruptions, and ice storms destroys millions of trees and cause extensive damage to their species composition, structure, and dynamics (Bragg et al., 2003). Over the last several decades, rapid improvements in geospatial technologies such as Geographic Information Systems (GIS) and Remote Sensing (RS) technologies have allowed foresters and city planners to rapidly create tree inventories in natural forests and urban settings. It also allows them to analyze the risk as well as estimate their damage and changes from different natural hazards in a cost-effective and efficient manner by comparing the pre- and post-disaster data.

Numerous studies have been carried out in using different optical remote sensors to monitor changes in vegetation and tree structures over various landscapes. However, most of these optical sensors observe change (or damage) in change/no change basis. Due to the medium to large spatial resolution of these sensors, their usability is also limited when damage needs to be detected in an individual tree by tree basis (as in the case of urban neighborhoods) rather than a small to large forest area. For such cases, active remote sensing data such as Light Detection and Ranging (LiDAR) data can be used to resolve some of the limitations. LiDAR data has been used extensively within the last several years to create highly accurate forest inventories by isolating the location and canopy size of individual trees and measure their heights with high degree of accuracies. Once their location and canopy extent is separated, they can also be used to detect damage to individual trees by monitoring the changes (increase or decrease) in their heights and canopies by comparing pre-and post-disaster height inventory data. Therefore, LiDAR data allows researchers and urban foresters to not only monitor tree loss/growth but allows damage to be quantified from a single disaster event.

The primary goal of this research was to use LiDAR data to assess damage caused to the trees of the city of Norman, Oklahoma from the December 8-11, 2007 ice storm. The data was processed and analyzed on a GIS platform (ArcGIS v. 9.3). For simplicity, damage will be examined only for isolated individual large trees with heights greater than 6 m.

2. DECEMBER, 2007 ICE STORM & THE STUDY AREA

Between 8 and the 11th of December, 2007, a massive ice storm struck and caused extensive damage in the state of Oklahoma and the neighboring states. Almost 2.54 to 3.81 cm thick ice formed on trees and power lines. The extra weight of the ice on the branches of trees and power lines caused them to break and tear apart and resulted in leaving over 1.5 million people without electricity for several days. A total of 48 out of Oklahoma's 77 counties were affected and the damage to properties and crops valued over $250 million. Over 100 structural fires from broken power lines and hundreds of auto accidents were reported. The storm also killed 27 people across the state (NOAA).

The center of the city of Norman with an area of approximately 18 sq. km was chosen as the study area (Figure 1). Situated approximately 32 km south of Oklahoma City, Norman is a small city with an area of 492 sq. km and population of around 102,827 (U.S. Census, 2006). Over the past decade, Norman has been exposed frequently to ice storms. The City enjoys a humid subtropical climate and annually receives about 15-23 cm of snow with freezing temperatures starting around the first week of November and ending during the first week of April (Oklahoma Mesonet, 2009). Most of the ice storms typically affect the City during the months of December and January.

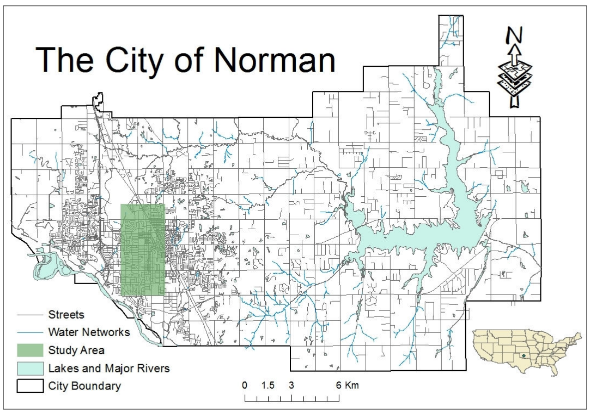

Figure 1. Study area within the City of Norman.

3. DATA AND METHODOLOGY

3.1 Data Collection

Two primary LiDAR datasets (pre- and post-storm) were required and collected to assess tree damage from the ice storm. The pre-storm data was collected by Merrick & Company of Aurora, Colorado from February 27th through March 3rd of 2007. It was obtained from the City of Norman's GIS Department. The post-storm data was collected by Airborne 1 Corporation of El Segundo, California on July 10, 2008. Table 1 highlights the details about the two data sets.

Table 1. Description of the two Used LiDAR Data Sets.

	Pre-Storm Data	Post-Storm Data
Date of Data Collection	Feb. 27th-March 3rd 2007	July 10, 2008
Sensor Type Used	Leica GeosystemsALS50	Optech (ALTM) 33k LiDAR
Avg. Flying Altitude (m)	2100 m	1978 m
Scanning Frequencies	100 Hz	21 Hz
Scan Angle	5 – 75°	18°
GSD	~1 m	~1 m
RMSE	< 15 cm	~ 22 cm

3.2 Methodology

The proposed methodology for this study can be divided into four primary categories: (1) processing the raw LiDAR data points to create Canopy Height Models (CHM), (2) Extracting/isolating individual trees from the pre-storm CHM and comparing heights and canopy size of trees with the post-storm CHM, (3) calculating the canopy and height damage percentage, and (4) measuring the accuracy of damage estimates from the LiDAR data with field-surveyed results. Creation of CHMs required importing the raw pre- and post-storm LiDAR data points in ArcGIS (v. 9.3) and using the Inverse Distance Weight (IDW) interpolation method to create Digital Elevation Models (DEM) and Digital Surface Models (DSM) of the study area. Once DEM and DSMs were generated, pre- and post-storm CHMs were produced by simply subtracting the DEM from the DSM layers.

The focus of several previous studies has been to accurately extract location and canopy size from the CHMs (Leckie et al., 2003; Maltamo et al., 2004; Popescu, 2007). For this study, the tree extraction methodology proposed by Koukoulas and Balckburn has been modified and applied to the pre-storm CHM to extract the individual urban tree locations and the outlines of their canopies (Koukoulas and Blackburn, 2005). Figure 2 illustrates the processing steps for the modified method. The parameters used in steps 3, 6, and 7 of the methodology were suitable for the study area and were based on different combinations of the data. Once the tree canopy outlines were extracted, maximum heights and summation of all pixel values within the outlines (indicating the canopy size) of each tree were calculated for both pre and post-storm data sets. Finally, the differences between these pre- and post-storm values were calculated to estimate the damage each tree sustained due to the storm.

Measuring the accuracy of the damage estimation from the LiDAR data depended on two factors: extraction of accurate crown outlines (diameters) and their heights. The accuracies of these two factors were examined through field surveys conducted between August of 2008 and September of 2009.

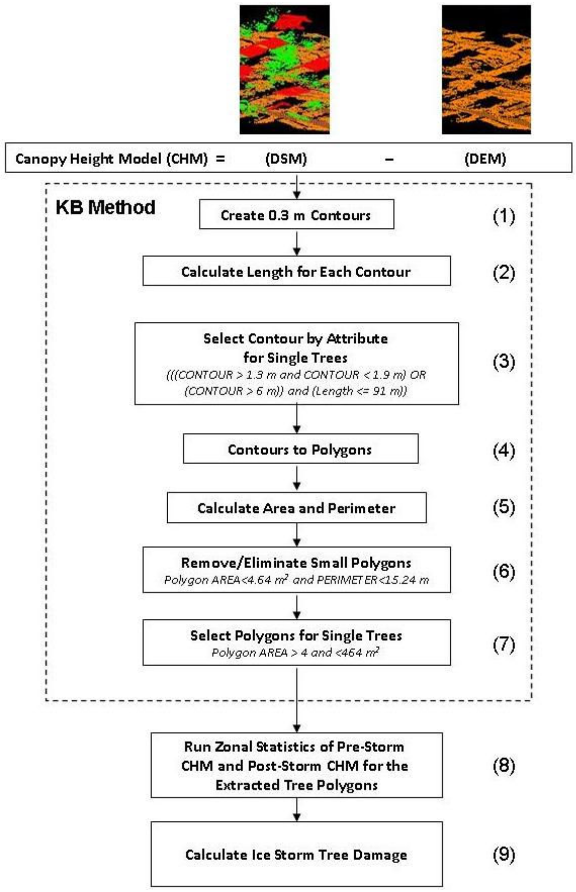

Figure 2. Procedure used to extract location and canopies of individual urban trees.

First, a sample of 524 trees were selected within the study area by using stratified random sampling method. The species type of each tree was recorded. Their pre and post-storm heights and canopy diameters were obtained from the LiDAR data and were used as the *test data*; and percent changes in tree heights and canopy diameters were computed to obtain *test tree damage* data. Because the outline of the individual tree canopies resembled a circle, their perimeters were calculated in ArcGIS and their diameters were calculated using the equation

$$D = P / \pi \quad (1)$$

where D is the diameter of the tree crown and P is the calculated perimeter. Second, using a Brunton compass and a measuring tape, the post-storm heights and canopy diameters of the sampled trees were manually measured in the field to obtain the *reference data*. Tree heights were calculated by conventional method of measuring distance and angle to the top of trees and then using geometric equation. RMSEs were calculated based on the test and reference data. Third, the post-storm *reference* tree heights and canopy diameters were separately subtracted from the LiDAR extracted pre-storm *test* heights and canopy diameters; and their percentage changes were computed to obtain the *reference tree damage* data. Finally, the *reference tree damage* data were correlated with *test damage data* to test the accuracy of the latter. High degree of positive correlation between the test and reference damage data and high R^2 value indicated high degree of accuracy of the LiDAR estimates.

4. RESULTS AND DISCUSSION

A total of 6,790 trees were identified and outlined by the modified Koukoulas and Blackburn Method (KBM) in this study. These trees were fairly large with average heights of 14 m and crown diameter of 21 m. Most of these trees were broadleaf trees such Shumard Oaks, Pin Oaks, Bur Oaks, Silver Maples, Sweetgums, American Elms, Hackberries, and Sycamores. Approximately 73% of single trees were accurately identified. In some cases, group tree species that grow very close to each other (i.e. Loblolly Pines) were identified as one single tree. From a field sample of 47 pine trees, about 74% were identified accurately. In some cases, large trees that grew between 2-3 m from each other such as Silver Maple or American Elm with overlapping branches or understory smaller trees were identified as one single large tree. Around 24% of the identified trees contained 2 to 3 trees and 3% contained 4 to 5 separate trees. Figure 3 shows some of the tree outlines on top of the pre-storm CHM data layer.

Figure 3. Locations of individual trees with shaded colors indicating amount of damage.

Comparing the pre- and post-storm CHMs in terms of their height and canopy size indicated that 519 trees were completely destroyed or cleared because of the storm. On the other hand, 8.4% of the trees did not sustain any damage. Approximately 8% of the trees suffered minor (<1%) height or stem damage but major (27%) canopy damage. Around 23% of the trees had experienced decrease in their canopy sizes due to the storm. Among them, 36% had severe (>67%), 37% had moderate (26-66%), and 27% had minor (<25%) damage. Around 6% of trees had suffered only canopy damage but no damage to their stem; and about 2% of the trees had experienced canopy growth after the storm although their stem height declined during the storm. However, their branches are very susceptible to breakage since their larger branches have greater surface areas resulting in the accumulation of more ice loadings. In terms of withstanding the storm and gaining height and canopy, 26% of identified trees had experienced up to 8% increase in both height and canopy size as indicated by the LiDAR data collection. Figure 4 shows the distribution of tree damage in terms of heights and canopy size.

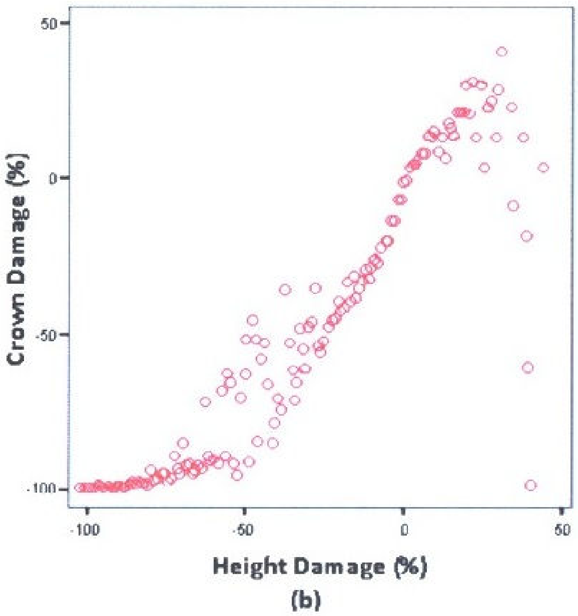

Figure 4. Distribution of crown and height damage for the extracted trees.

There were two factors that determined the accuracy of the damage estimates from the LiDAR data. First, accurate crown outline determined the boundary through which the heights of each individual trees were suppose to be extracted. As previously stated, the accuracy of the crown outlines were determined by comparing the actual field measured diameters (reference data) of the randomly selected trees with the diameters obtained by the LiDAR data. Results showed that correlations between these two data sets were r=0.85 and R^2=0.721 indicating that approximately 72% of the tree outlines were extracted accurately. The second factor that determined the accuracy of the damage estimate was the pre- and post-storm heights obtained for each tree from the LiDAR data. Comparisons of the test tree damage data with the reference damage data indicated that they were 90% correlated. Hence, the damage estimates obtained from the proposed methodology had a high degreed of accuracy (R^2 = 0.81) with RMSE= 1.3m.

These results indicate that using the method proposed in this study, LiDAR data would be an ideal technique estimating tree damage from disasters. However, the accuracy of the damage estimates would depend on two factors: obtaining accurate outlines or diameters of individual trees and measuring the true height from the LiDAR data. The results suggest that both of these measurements can be obtained very accurately for individual single standing trees. However, in urban neighborhoods, tree branches may be overlapping with each other or there may be several understory trees below one big tree. For such cases, other algorithms need to be used and developed. Also, a key to achieving high level of accuracy in obtaining tree heights was using an appropriate interpolation method that would produce DEMs and DSMs with very low RMSE.

5. CONCLUSIONS

This study has processed and analyzed raw LiDAR data in a GIS platform in order to assess damage from the December 8-11, 2007 ice storm. Although the results show that the data and the proposed methodology may be used for accurately assessing damage to individual single standing trees, further studies needs to be conducted that would be useful for estimating damage caused to urban group trees. With the increasing availability and reduction in the price of collecting new data, LiDAR in the future will surely be very useful in assessing damage and changes to urban trees caused not only by ice storms, but also from other disasters including hurricanes, tornadoes, and floods.

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