EXTRACTION OF URBAN BUILDING HEIGHTS FROM LIDAR DATA: AN INTEGRATED REMOTE SENSING AND GIS APPROACH

Muhammad Tauhidur Rahman

1. King Fahd University of Petroleum and Minerals, Department of City and Regional Planning, Dhahran, Kingdom of Saudi Arabia; mtr(at)kfupm.edu.sa

ABSTRACT

Although passive remote sensing technology allows us to detect and map urban buildings and infrastructures, they have several limitations when it comes to extracting their heights. However, by using a combination of data from passive and active sensors, it is possible to overcome some of those limitations and produce highly accurate 3-D height maps of urban areas. In this paper, a combination of IKONOS and LiDAR data is used and processed through integrated remote sensing-GIS based method to extract individual building heights in the urban central part of Norman, Oklahoma. Results show that while the method extracts the location of buildings with moderately high (75%) degree of completeness, the accuracy level in estimating the area and height was lower and depends mostly on the presence of trees surrounding the buildings. Future research should focus on using the method on IKONOS and LiDAR data collected during winter seasons when the leaves of trees are not present.

INTRODUCTION

Over the past several decades, rapid improvements in passive remote sensing technologies have allowed us to detect and map buildings and infrastructures in various urban settings. Detection of these features is not only important for classifying land use and land cover and their changes, but they are also important for many Geographic Information Systems (GIS) applications including assessing damages from natural and man-made disasters (i.e., earthquake and terrorist activities) and planning, monitoring, and modelling future growth of urban areas. While various algorithms and techniques have been proposed to detect building features in different physical and urban settings from passive remote sensing imageries, there are several limitations that deter their usage by city planners and disaster response teams. First, imageries with low-to-medium spatial resolution can detect urban buildings and infrastructures, but not in an individual basis. Second, while high resolution imageries can detect individual buildings, techniques and algorithms used to classify them can be quite complicated (1). Finally, and most importantly, these imageries cannot be used to measure individual building heights, which are often necessary to create 3-D models of the cities and accurately assess building damages from disasters.

Airborne Light Detection and Ranging (LiDAR) data can resolve some of the above mentioned limitations and rapidly acquire precise height data of large-scale areas by emitting and receiving laser pulses. Different methods to extract heights of buildings in urban and sub-urban areas using LiDAR data has been reviewed and proposed by (2,3,4). The goal of this paper is to propose an additional method based on an integrated remote sensing-GIS approach. Specifically, it will examine the accuracy of the proposed method in detecting heights of residential, commercial, and high-rise buildings within the city of Norman, Oklahoma (USA). In the next section, different aspects of the study area, data, and the proposed methodology are described. The results are given and the paper concludes by discussing the drawbacks of the study and layout a path for further research.

METHODS

Study Area

Located about 32 km south of Oklahoma City in Cleveland County, Norman is a suburban community with an area of 492 km^2. Established in 1890, the city transformed from a small town in the

DOI: 10.12760/02-2014-1-11

early 20th century to the present day city with an estimated population of 115,562 (U.S. Census, 2012). The study site was in the urban centre of the city with an area of approximately 18 km^2, Figure 1. This area was chosen because it contains various types of commercial and residential buildings with variable heights and ages along with diverse features (i.e. roads, highways, open fields, etc.).

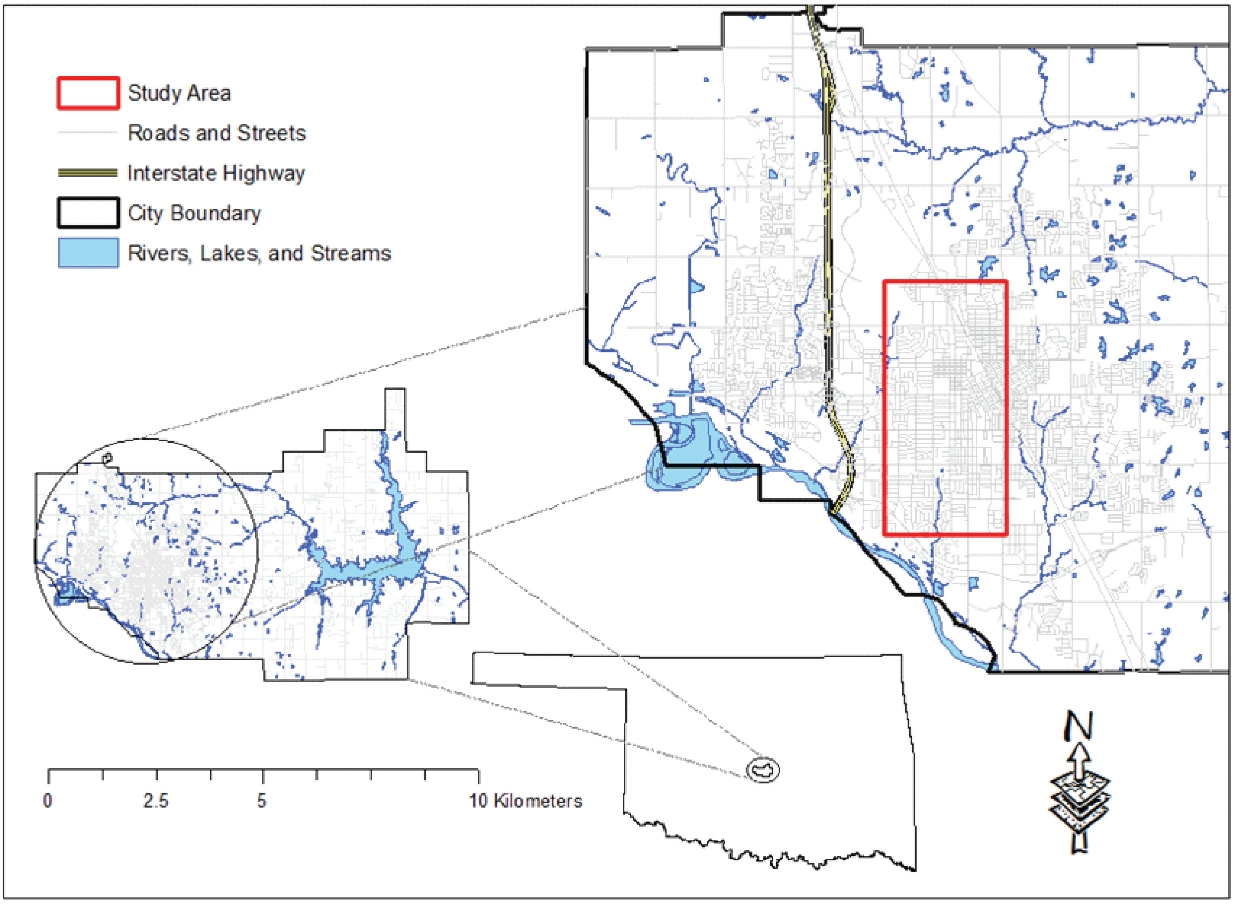

Figure 1: Study area within the City of Norman, Oklahoma.

Data and Methodology

For this study, two separate data sets were used. First, a LiDAR data was obtained freely from the City of Norman's GIS Department. The data was collected by Merrick & Company of Aurora, Colorado from February 27th through March 3rd 2007 for the entire city of Norman. Using the dataset, a digital surface model (DSM) representing elevations of trees, buildings, and other surface features was created in ArcGIS v. 9.3 by using the inverse distance weight (IDW) interpolation technique with grid cell size of 0.3 m on the first return points received by the LiDAR sensor. Along with the LiDAR data, Norman's GIS Department also provided a digital elevation model (DEM). By calculating the differences between the DEM and DSM, a normalized digital surface model (nDSM) showing the heights of buildings and other features were also created. In addition to the LiDAR data, a high resolution IKONOS image provided by the GeoEye foundation was also used in the study. Table 1 summarizes the details about the two datasets.

Table 1: Characteristics of the two major data sets.

LiDAR Data	IKONOS Imagery
Sensor: Leica Geosystems ALS50	Spectral Resolution: R, G, B, and NIR
Density: ~1 meter	Spatial Resolution: 1.0 m
Acquisition Date: February 27th – March 3rd, 2007	Acquisition Date: August 28, 2008

To extract the individual buildings and their specific heights, the trees and vegetation were first needed to be separated. Using the IKONOS image and the SPEAR Vegetation Delineation tool of ENVI v. 4.8 image processing software, the pixels containing trees and vegetation were first detected. The SPEAR Vegetation tool uses normalised difference vegetation index (*NDVI*) to find pixels containing trees and vegetation. *NDVI* is measured by calculating the ratio between the difference of red and near-infrared (NIR) and the sum of red and near-infrared reflectance. The *NDVI* values ranges between -1 and +1. Pixels containing healthy vegetation will result in high *NDVI* values closer to 1 while not healthy vegetation will yield lower *NDVI* values. Negative *NDVI* values will indicate no vegetation. In this study, pixels with *NDVI* values exceeding 0.249 were considered to contain trees and vegetation.

Once the areas and pixels containing vegetation were extracted from the IKONOS image, these areas/pixels in the nDSM data containing the vegetation were then subtracted from the nDSM resulting in the nDSM having only residential and commercial facilities. The nDSM was then exported into an ArcGIS v. 9.3 shapefile containing polygon outlines of the buildings. Based upon field surveys, it was found that the majority of houses and buildings were more than 2 m high. Because many small polygons (which are not vegetation, residential houses, or commercial buildings) were created in the process, they needed to be separated and excluded from the analysis. The zonal statistics function of ArcGIS (to calculate the minimum and maximum heights of the polygons from the nDSM) was used and polygons with maximum heights below 2 m were eliminated. The areas of each polygon were also calculated and any polygon with an area below 21 m^2 was eliminated from the analysis as well. This final step resulted in polygon outlines corresponding to individual houses and buildings along with their minimum, maximum, and average heights from the nDSM data set.

In order to assess the accuracy of the methodology, a random sample of 100 buildings which included both residential houses and commercial facilities were selected as reference buildings. Their heights were measured through field survey and compared with the results from the LiDAR data in order to assess the accuracy of heights obtained by the LiDAR data. A GIS shapefile (created in 2012) containing the outline of all the houses and buildings within the city was also obtained from the City of Norman. The building outlines in this shapefile were used as the reference buildings and they were compared with the outlines generated by the proposed building extraction method. In the initial comparison, the location of the centroid for each extracted building was calculated and examined to know if they are within the corresponding reference building (they were designated as true positive (TP)). Based on their condition, each of the building outlines were placed and labeled into one of the following four categories:

- True Positive (TP): Our method classified the building correctly when they are present.
- True Negative (TN): Our method classified the building correctly as not present.
- False Positive (FP): Our method classified the building but it is not present in the reference data.
- False Negative (FN): Our method did not classify the building but it is present in the reference data.

Once the number of buildings was classified in each category, the following statistical measures developed by McGlone and Shufelt (5) were calculated to evaluate the accuracy of the proposed building detection method:

- Branching Factor: FP/TP
- Miss Factor: FN/TP
- Building Detection Percentage: 100×TP/(TP+FN)
- Quality Percentage: 100×TP/(TP+FN+FP)

These statistical measures have been used in other studies as well (4,6). Furthermore, the area of the extracted buildings were compared with the area of the reference buildings to assess whether the size of the buildings were identified accurately.

RESULTS AND DISCUSSIONS

The reference shapefile from the City of Norman indicated that there are a total of 13,723 buildings within the study area. The proposed method detected a total of 13,154 buildings. Figure 2 shows the outlines of some of the buildings within the study area that have been detected (in dark brown) by the proposed building detection method while extra areas are shown in light brown.

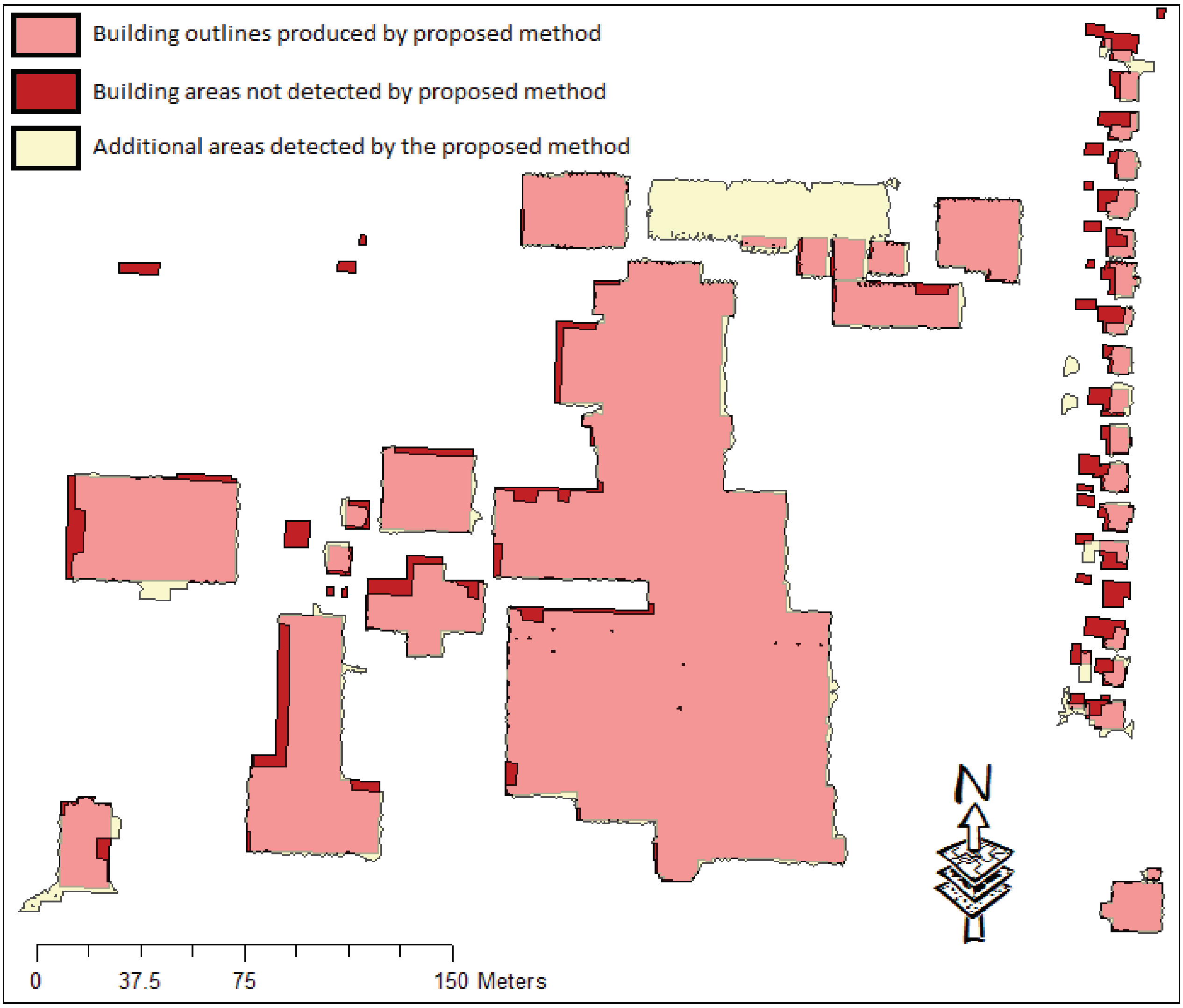

Figure 2: Outlines of the individual buildings extracted by the proposed method. Non-overlapping areas with the reference building outlines are shown in red.

The quality assessment results of the 100 chosen sampled buildings are given in Table 2. With the 75.32% buildings detected, it can be said that the proposed methodology performed moderately in detecting individual houses and buildings. Of the 58 TP sampled buildings that were detected, the areas of 68% of them were determined accurately. It was found that the presence of trees surrounding the buildings and houses was the determining factor in determining the accuracy level of the areas of the buildings. The study area contains wide variety of urban trees and vegetation with different shapes and sizes. Some of these trees are partially or completely covering the rooftops of surrounding houses and buildings. While the 68% accuracy level in detection of the areas of the buildings can be considered to be moderate, it may be further improved if a high resolution image taken during the winter season (when the leaves of the trees are absent) is used to extract the outline of the buildings. This is due to some areas of the building rooftops that contained large branches of trees with leaves being eliminated by the SPEAR tool during the vegetation reduction procedures. Also, it was observed that when trees were covering some portion of the area of a rooftop of a building, the outline (and hence the area) of the houses would also decrease by that portion as well. In some cases a single house would be outlined as two separate houses since tree branches would cover the rooftops from the front to the back of the house. The coverage of rooftops by tree branches and canopies was also the reason for the low percentage quality found in this study and in other studies (4) as well. If there were no trees surrounding a house or building, it was found that the buildings were identified with high level of accuracy.

Table 2: Quality assessment results for the sampled buildings.

Classification Category	Number of Buildings	Miss Factor	Branching Factor	Building Detection %	Quality Percentage
TP	58	0.32	0.39	75.32	58
FP	23				
FN	19				

When the heights obtained from LiDAR data were compared with the heights obtained through field survey for the 58 TP sampled buildings, it was found that the difference between them had minimum and maximum values of 0.78 m and 4.2 m with a *RMSE* of 2.4 m. Similar to the area of the buildings, the outline of the buildings again played a major role in determining their heights as well since the height of the buildings were calculated based on the maximum height value (obtained from the nDSM) within each building polygon outline. Therefore, trees again played a major role in reducing the accuracy level of the building heights.

CONCLUSIONS

This study attempted to extract individual buildings and their heights in the central urban area of the city of Norman, Oklahoma. It did so by using a combination of LiDAR and high resolution IKONOS data in an integrated remote sensing and GIS platform. While the proposed method moderately detected the location of individual buildings, it detected the shape of the buildings with a lower degree of accuracy. It was found that the presence and the quantity of tree branches surrounding the buildings and residential houses was the contributing factor in such accuracy levels. To overcome this issue and improve the detection of individual buildings in building blocks, this study recommends that future studies should be carried out using LiDAR data along with high resolution satellite imagery collected over the area during winter leaf-off condition. Also, further studies should focus on using newer classification techniques (such as object based image classification) to extract buildings in urban areas at higher accuracy level.

ACKNOWLEDGEMENTS

The author would like to thank the Deanship of Scientific Research at King Fahd University of Petroleum and Minerals for providing their generous financial support to attend the EARSeL 2014 conference and present this paper. He is also very grateful to Mr. Farhan Iqbal for processing the remote sensing data.

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