Footprint extraction of urban buildings with LIDAR data

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ABSTRACT: Building information is extremely important for many applications within the urban environment. Sufficient techniques and user-friendly tools for information extraction from remotely sensed imagery are urgently needed. This paper presents an automatic and manual approach for extracting footprints of buildings in urban areas from airborne Light Detection and Ranging (LIDAR) data. First a digital surface model (DSM) was generated from the LIDAR point data. Then, objects higher than the ground surface are extracted using the generated DSM. Based on general knowledge on the study area and field visits, buildings were separated from other objects. The automatic technique for extracting the building footprints was based on different window sizes and different values of image add backs, while the manual technique was based on image segmentation. A comparison was then made to see how precise the two techniques are in detecting and extracting building footprints. Finally, the results were compared with manually digitized building reference data to conduct an accuracy assessment and the result shows that LIDAR data provide a better shape characterization of each buildings.

1. INTRODUCTION

Light Detection and Ranging (LIDAR) is a new and emerging remote sensing technology that has a new use in urban environment. It efficiently capture Digital Surface Model (DSM) for large scale, high accuracy mapping. A LIDAR collection system uses a powerful laser sensor comprised of a transmitter and receiver, a geodetic-quality Global Positioning System (GPS) receiver and an Inertial Navigation System (INS) unit. The laser sensor is precisely mounted to the underside of an aircraft. The airborne sensor emits rapid pulses of infrared laser light, which are used to determine ranges to points on the terrain below. Laser can precisely measure distance from a sensor to the ground using speed of light calculation. The position (x, y, z coordinates) and altitude of the aircraft are calculated using integrated GPS and INS technologies. Raw LIDAR data is a collection of mass points with x, y and z coordinates. A high spatial density of data may well provide enough information to define the surface to the required accuracy, however, if the spatial density is low, extra information will be required to accurately define the surface. In this study high spatial density data were used.

DSM, which is a common product of laser data not only represent the terrain surface like Digital Terrain Model (DTM), but also contain buildings and other objects like trees, which are higher than their surroundings. The gray level value changes in the image allow the identification of objects, such as buildings or vegetations. However, DSM cannot represent the breaklines explicitly (Ackermann 1999). The breaklines in DSM is the boundary or the edges for each object that exist on the surface. The breakline information is important in generating a surface model accurately. The extracted breakline will affect the accuracy of the 3D model. Therefore, an effort was undertaken in this study to extract breaklines of buildings using LIDAR data. Studies on the generation of DSM or extraction of breaklines have been carried out for the past few years (McIntosh and Krupnik 2002, Gamba 2000, Altmaier and Kenny 2002). In the present study, a DSM at 1m x 1m resolution of Johor Bahru (South Malaysia) town was generated using Lidar data. Then, the breaklines were extracted from the generated DSM using manual and automatic techniques. The accuracy of the extracted breaklines were then assessed using ground truth data.

2. STUDY AREA

The study area covers the center of Johor Bahru town which is about 119822.8m ^{2} with buildings of various heights and other land use types.

Figure 1. Location map of the study area and some of the tall buildings in the city center.
(Source E-Map Jupem, 2001).

3. DATA AND METHODOLOGY

Secondary LIDAR data were used in this study to generate the DSM. The original LIDAR data which was in ASCII format were atmospherically corrected and geometrically rectified to RSO Malaysian projection by Ground data Solutions Pvt. Lmt. The Lidar data cover the center of Johor Bahru town. Besides Lidar data, field visits were also conducted to assess the accuracy of generated DSM. The methodology adopted in this study is shown in Figure 2.

3.1 DSM generation

The “Surfacing” tool in ERDAS IMAGINE enables to create a three-dimensional surface from irregularly spaced points (using TIN interpolation method). The main data source is LIDAR in ASCII format with x, y, and z values. About 768 242 points were used to generate the DSM. At each point where there is a known value, that known value remains unchanged in the output surface, whereas if the value is not known, it is interpolated from the surrounding known values. After importing all the points in the 3D Surfacing dialog box, the x, y, z values appear on the cell. To generate the DSM, the point data have to be interpolated into regular grid data. There are several surface interpolation methods available such as inverse weighted interpolation, kriging, polynomial regression etc. The purpose of this study is to extract building edges rather than constructing a smooth surface, therefore, a linear interpolation method was chosen because it is quicker and the results are more predictable. It also will preserve the sharp difference between buildings and their surrounding ground. Finally, a 1m pixel size was set and DSM was generated automatically based on the ASCII file.

3.2 Thresholding

The building footprint/breakline extraction is solely from the DSM and therefore the criteria to distinguish buildings from other objects must be geometric ones. Buildings were discriminated from other objects based on the general knowledge about the buildings’ size, height and shape characteristics. Due to the fact that buildings are man-made objects for accommodating human being or articles, it should have enough height and size. Using the height threshold, in this case, 8-10 metres, buildings were separated and objects with lower heights such as cars were removed from buildings.

3.3 Masking

The next step was masking. The output from threshold was used as a mask to mask out other objects. The output of this process is a DSM which contains only tall buildings (Figure 3).

3.4 Breakline extraction /Edge detection

Two types of approaches (Gausion and region growing) were used to extract the buildings breaklines/edges. The first approach extracts edges from generated DSM automatically. Different window sizes and different image add back values were used to extract the optimum edges. A Gaussian filter passes a Gaussian convolution function of specified size

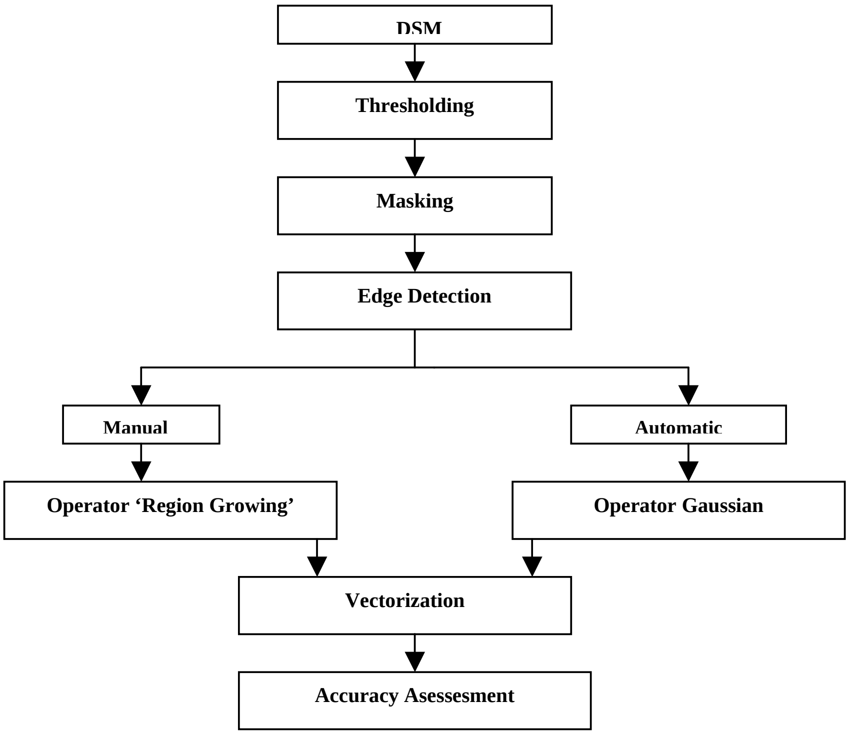
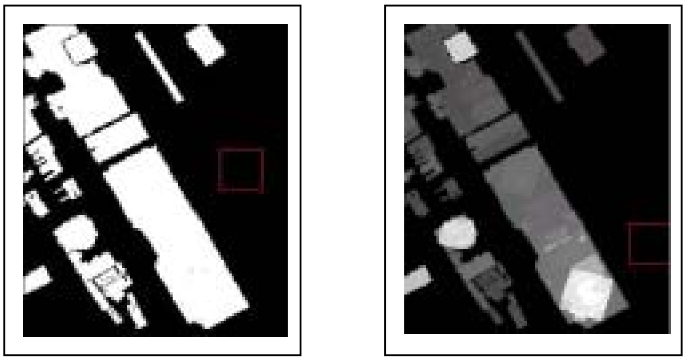


Figure 2. Methodology adopted in the study.



(a) (b)

Figure 3. The segmented image and b) DSM after masking.

over the image. Convolution filters produce output images in which the brightness value at a given pixel is a function of some weighted average of the brightness of the surrounding pixels. "Adding back" part of the original image to the convolution filter results helps to preserve the spatial context and this is done to "sharpen" the image. The "Image Add Back value" is the percentage of the original image that is included in the final output image. For example, if we enter 40%, then 40% of the original image is added to 60% of the convolution filter image to produce the final result.

In the second approach, region growing technique was applied for image segmentation. Firstly, the DSM was classified according to its gray values. An ideal classification was done to differentiate the points on the high buildings and surrounding lower ground surfaces. In the segmentation process, 4 or 8 neighbouring pixels are used to calculate the mean and standard deviation of height values of the laser data and classify the pixels into a group of similar heights. The values are increased in order to segment the objects accurately. 10 categories of height were classified and the result is shown in Figure 6.

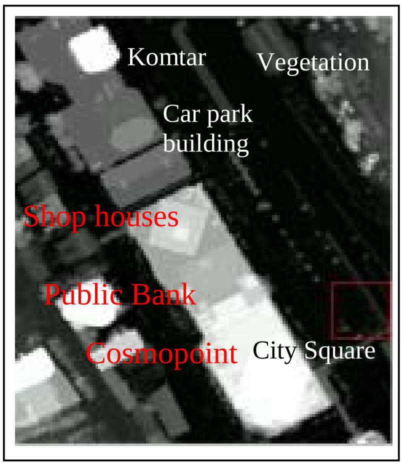
3.5 Accuracy assessment

After extraction, the buildings' edges were transformed into vector format using raster to vector conversion so that it can be integrated with other vector layers for accuracy assessment. Accuracy assessment was the final task of this study. The accuracy assessment was based on the geometry structure of the building. The purpose of this task is to see how good these two techniques are in extracting edges. A vector layer of buildings was manually digitized using AutoCAD Map 2000 and it acts as ground truth. The vector layer was overlaid with the extracted edges to compare between the manually digitized data and the extracted edges.

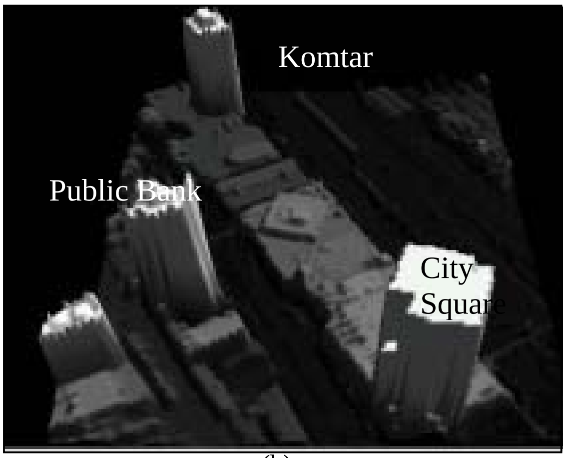
4. RESULTS AND DISCUSSION

4.1 Digital Surface Model

The generated DSM is based on gray level values. The DSM not only represents the terrain surface, but also contains buildings and other objects that are higher than the bare surface. Higher objects such as tall buildings are brighter than the lower buildings. Besides the gray level values, geometrical characteristics of the buildings such as size, height and shape were also used to differentiate between buildings and other objects. For example, buildings have polihedron shape and flat surfaces compared to vegetation which do not have a definite shape. Vegetation area has an irregular shape compared to building that has a geometric shape (Figure 4(a)). It is also possible to discriminate vegetation and buildings based on roughness of the surface measured by differential geometric criteria.



(a)

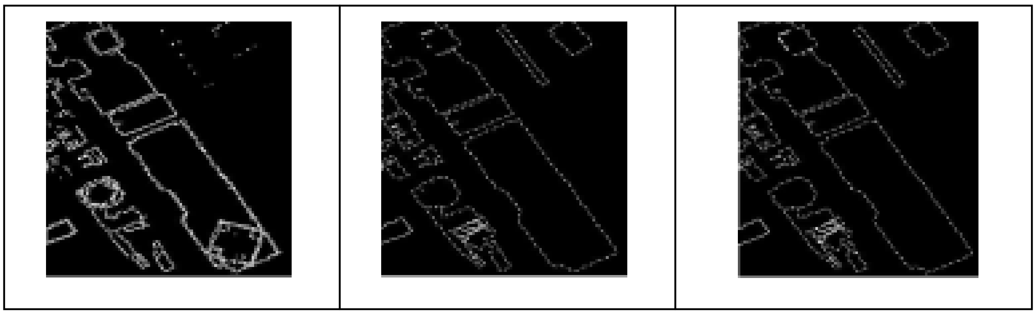


(b)

Figure 4. (a) The generated DSM of Johor Bahru city center and (b) 3D city model of Johor Bahru city center.

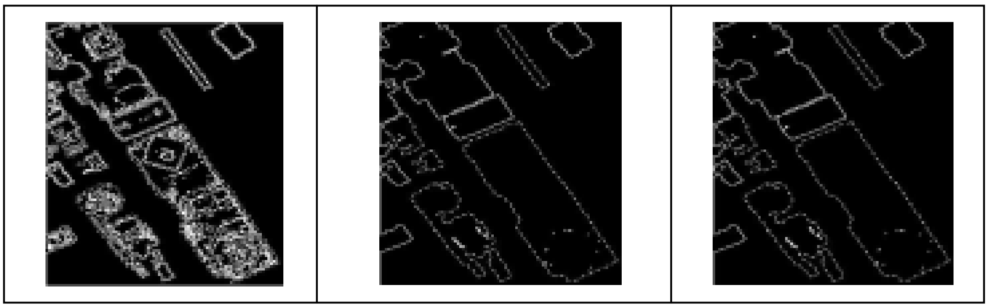
4.2 Breakline extraction

Gaussian operator with different window sizes and add back values used to extract the maximum edges because different window sizes and add back values give different outputs . Building edges can be seen clearly from the vectorized images. The generated DSM is free from shadow effect, mixed pixel, layover and so on. The bigger the window size, more edges are detected. Almost all buildings were successfully extracted and the visual result is rather good. The brighter pixel has larger value (higher elevation). Figure 5 and Table 1 show the output of different window sizes and their efficiencies in extracting buildings breaklines and boundaries. Similarly, the results of region growing techniques visually looks excellent (Figure 6). However, quantitative accuracy assessment is needed to know how good is this result and the assessment was based on building geometry structure.



0% add back 10% add back 20% add back

(a) 3x3 window size



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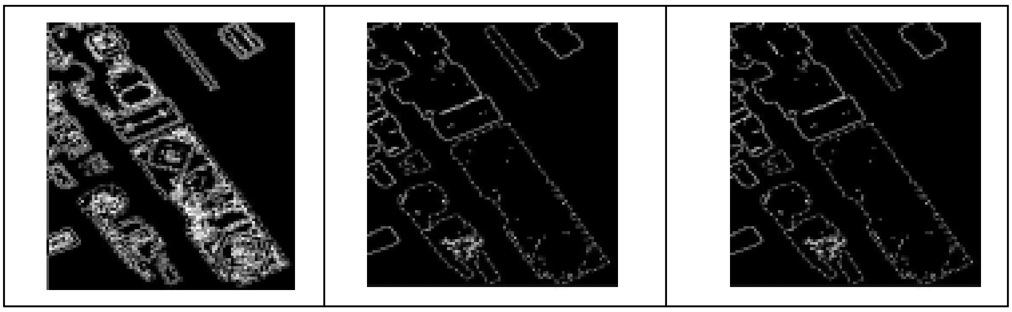
(b) 5x5 window size



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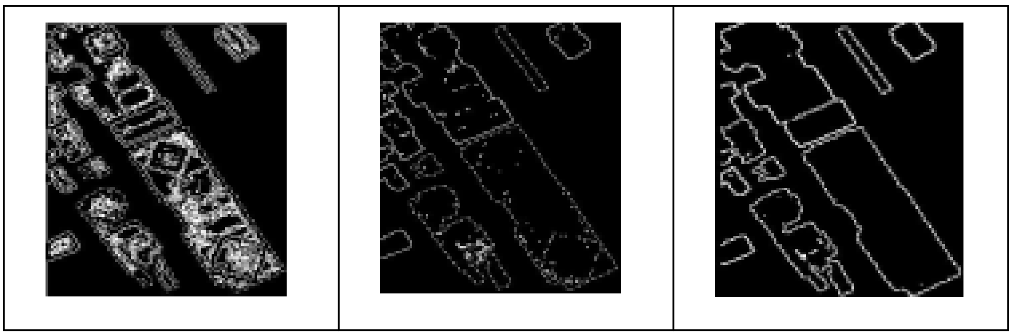
(c) 7x7 window size



0% add back 10% add back 60% add back

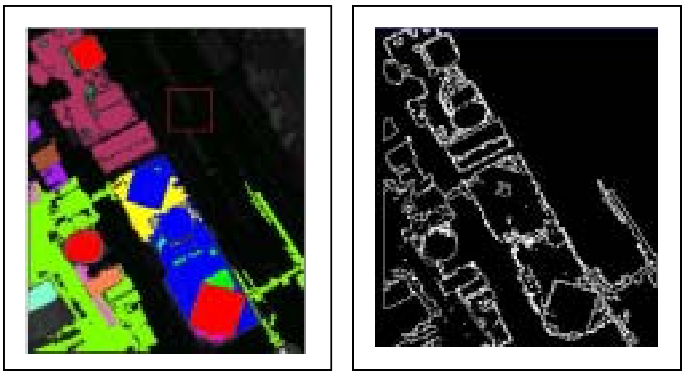
(d) 9x9 window size

Figure 5. Vector images (vectorized from raster DSM) showing the efficiency of different window sizes and add back values in extracting breaklines and building boundaries.

Window sizes	Image add back values			
	0%	10%	20%	30%
3x3	Detect tall buildings	Detect boundary	Detect boundary	Detect boundary
5x5	Detect most of the buildings	Detect boundary	Detect boundary	Detect boundary
7x7	More buildings are detected included smooth edges	Detect boundary	Boundaries are joint	Boundarys are joint

Window size	Image add back values			
	0%	10%	60%	90%
9x9	Detect edge at all level heights	Detect boundary	Break down of the boundary is more clear	Break down of the boundary is more clear than the 60%

Table 1. Function of window size and add back values in Gaussian opeartor.



(a) (b)

Figure 6. The segmented image using region growing technique and b) the vector image.

4.3 Accuracy assessment

The accuracy of the generated DSM was assessed by overlaying vector layer of buildings' polygon digitized from generated DSM (Figure 3(a)) and vector layer digitized from Gaussian and region growing operator's output. After overlaying, 20 points were selected to see the accuracy. For that, the generated DSM was registered to a grid system. Around 20 points were chosen at the edges of the buildings to calculate the distance variable. RMS error for automatic technique is 0.14 while the manual technique is 0.37. Automatic technique that use Gausssian operator gives a better result compared to manual technique that uses region growing operator in extracting edges. Window size 9x9 can extract more edges compared to other window sizes. All the window sizes are able to produce edge images and depends on the parameters that we used. The region growing technique is able to detect the edges but it cannot detect small edges of the buildings. However, the boundary of the buildings can be seen clearly in a region growing technique.

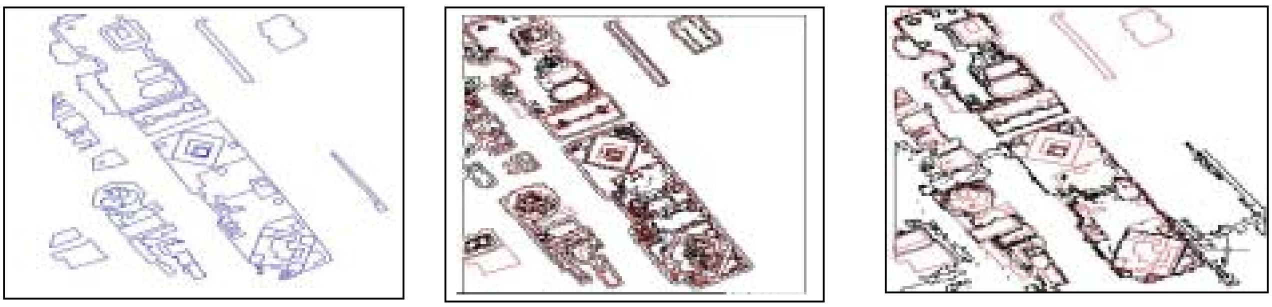


Figure 7. (a) Manually digitized boundaries from the generated DSM (b) boundaries/breaklines detected by Gaussian and overlaid with (a), and (b) boundaries detected by region growing technique and overlaid with (a).

5. CONCLUSIONS

As a conclusion, buildings can be separated from other objects based on derived DSM and general knowledge about the building’s geometric characteristics such as size, height and shape. Automatic technique shows better results compared to the manual technique in acquiring building information from LIDAR data. The results also show that both approaches are suitable for extracting building information from LIDAR data. This work shows that it is possible to develop a common procedure for 3-D building detection and extraction from DSM. LIDAR data has very high potential to produce precise data where with minimum processing, LIDAR data can produce accurate building information.

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