EVALUATION OF AUTOMATICALLY GENERATED 2D FOOTPRINTS FROM URBAN LIDAR DATA

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ABSTRACT:

Over the last decade, several automatic approaches have been proposed to extract and reconstruct 2D building footprints and 2D road profiles from ALS data, satellite images, and/or aerial imagery. Since these methods have to date been applied to various data sets and assessed through a variety of different quality indicators and ground truths, comparing the relative effectiveness of the techniques and identifying their strengths and short-comings has not been possible in a systematic way. This open contest was designed to overcoming this shortcoming. Specifically, participants were asked to submit 2D footprints (building outlines and road profiles) derived from ALS data from a highly dense data (approximately 225 points/m²) across a 1km² of central Dublin, Ireland. The proposed evaluation strategies were designed to measure not only the capacity of each method to detect and reconstruct 2D buildings and roads but also the quality of the reconstructed building and road models in terms of shape similarity and positional accuracy. The evaluated methods will represent those submitted as part of IQPC15.

1. INTRODUCTION

The availability of three-dimensional (3D) point clouds offers a potential resource for wide ranges of applications (e.g. environmental planning and monitoring, computational simulation, disaster management, security, telecommunications, location-based services). Urban, two-dimensional (2D) footprints, which primarily include 2D footprints of buildings and the road network, play important roles in these applications and can be a major resource for generating final 3D models. For example, Laycock and Day (Laycock and Day, 2003) generated 3D building models by extruding 2D building footprints with the building height derived from aerial laser scanning (ALS) data. Furthermore, a part of the digital road map can be subsequently generated based on a 2D road profile. A number of researchers have addressed the problem of extraction and reconstruction of 2D building footprints and 2D road profiles from ALS data, satellite images, and/or aerial imagery (Boyko and Funkhouser, 2011; Clode et al., 2005; Kwak and Habib, 2014; Lafarge and Mallet, 2011; Zhang et al., 2006). Proposed methods have been tested on different data sets, and the authors have also used various evaluation criteria and ground truth resources. For example, Boyko and Funkhouser (Boyko and Funkhouser, 2011) manually generated ground truth of a road network and proposed five comparative quantities (completeness, correctness, quality, average spill size and prevailing spill direction) to evaluate extracted roads. This causes difficulty in generating a consistent comparative assessment of the methods. Thus, this contest is called participants to submit resulted 2D footprints (building outliers and road profiles) from ALS data provided by the contest organizers for evaluation. The contest also opens a challenge in detecting and reconstructing road profiles from ALS data only because several current methods required fusion data. The success of this contest can possibly provide useful information for establishing strategies for automatic urban 2D footprints from ALS data.

The contest uses a highly dense point cloud (225 million points covering approximately 1km² area) of Dublin, Ireland’s city centre. The data has Cartesian system coordinates and intensity values and was merged from 44 flight strips. The flight plan was design to maximize data acquisition on the building facades.

The participants are asked to submit the results of automatically generated 2D building footprints (Task A) and/or 2D road profiles (Task B) from three pre-designated sub-areas of the study area. The contest organizers will evaluate submitted results based on the ground truth provided the Ordinate Survey Ireland (OSI) and OpenStreetMap (OSM). The task description, ground truth, and evaluation for each task are presented in Section 3-5. Finally, a winner and two runners up for each task will be selected based on the overall evaluation scores.

2. DATA DESCRIPTION

The test area is approximately 1km² and consists of 205 blocks, each of which may contain in excess of a dozen buildings per block, as shown in Figure 1. The typical building is 11–15m in height, less than 5m in width, and 6–10m in length (Clarke and Laefer, 2012). The buildings are mostly closely spaced or abutting each other, with some sharing an adjoining wall, commonly referred to as a “party wall”.

The dataset was acquired by ALS using the FLI-MAP 2 system, which generated 1000 pulses for each scan line. The system operated at a scan angle of 60 degrees. The quoted accuracy of the FLI-MAP 2 system is 8 cm in the horizontal plane and 5cm in the vertical direction, including both laser range and navigational errors (Hinks, 2011). Acquired points were provided in a global coordinate system with reference to the

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The dominant directions of the flight tracks were chosen as north-east, north-west, south-east and south-west. The flight attitude varied between -380-480 m (as low as possible with respect to approval by the Irish Aviation Authority), with an average elevation of ~400m. A total of 2,823 flight path points were collected during data acquisition. As a result, a point cloud was merged from 370,154 scan lines resulting in a typical density of 225 points/m². The echo distribution is shown in Table 1. The vast majority of points were first echoes. Secondary echoes constituted only a small portion of the points, as the overwhelming majority of surfaces in the study area was formed of solid objects (i.e. streets and buildings). For further information about this ALS data, participants are referred to Hinks (2011). The data set was organized into 9 tiles, each covering 500m x 500m (Figure 1), which is 5.8 Gb in size and stored with a LAS format. The data set is now publicly available.

<table>
<thead>
<tr>
<th>Echo</th>
<th>Count</th>
<th>Percentage (%)</th>
</tr>
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<tbody>
<tr>
<td>1st</td>
<td>217,497,975</td>
<td>96.33</td>
</tr>
<tr>
<td>2nd</td>
<td>7,902,595</td>
<td>3.50</td>
</tr>
<tr>
<td>3rd</td>
<td>383,840</td>
<td>0.16</td>
</tr>
<tr>
<td>4th</td>
<td>4,028</td>
<td>0.001784</td>
</tr>
<tr>
<td>Total</td>
<td>225,788,438</td>
<td>100</td>
</tr>
</tbody>
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Table 1. Echo distribution of acquired ALS points

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Three subsets of the data are used for this competition (Figure 2). Area 1 contains sparse buildings, a large green area, and trees. Area 2 has both building blocks and buildings sharing walls, as well as some trees. Area 3 contains mostly low brick buildings and no trees.

The data of each area (Area 1, 2 and 3) were extracted from the original data set and is 1.1 Gb in size in an ASCII file (Zip file), where each row represents x-, y-, z-coordinates and intensity of each data point, or in a LAS format (3.8 Gb). Either the data sets of the study area or these of the the contest are can be downloaded through the webpage of IQmulus project.
For the level of shape similarity and positional accuracy, the building footprint from ExB will be considered, if this building overlaps any building from the GtB. To measure a shape similarity, the differences in area and perimeter of each building are computed, which are given in Eq. 4 and 5.

\[ \sum_{i=1}^{m} (A_{GtBi} - A_{ExBi}) \]  
\[ \sum_{i=1}^{m} (L_{GtBi} - L_{ExBi}) \]

where

- \( A_{GtBi} \) = the areas of the building footprint from GtB
- \( A_{ExBi} \) = the areas of the building footprint from ExB
- \( L_{GtBi} \) = the perimeter of the building footprint from GtB
- \( L_{ExBi} \) = the perimeter of the building footprint from ExB

\( m = \) the number of the buildings

Finally, summing the absolute, mean, and standard deviation of these differences (area and perimeter) are used to express the shape similarity.

For details of determining a pair of \( L_{GtBi} \) and \( L_{ExBi} \), readers can refer to Truong-Hong and Laefer (Truong-Hong and Laefer, 2015). In addition, the vertices’ corners’ error (d) is defined as the Euclidean distance between the corners of the ExBi to its nearest corner derived from the GtBi. The evaluated indicators are expressed as Eq.6 and 7:

\[ E_{\text{corn}} = \sum_{j=1}^{m} \frac{L_{GtBi} \alpha_j}{L_{ExBi}} \]  
\[ E_{\text{corn}} = \sum_{k=1}^{m} d(p_{ExBi}, p_{GtBi}) \]

where

- \( L_{ExBi} \) = the side length of ExBi
- \( \alpha_j \) = the angle between the \( L_{ExBi} \) and the \( L_{GtBi} \)
- \( L_{GtBi} \) = the side length of GtBi
- \( m = \) the number of the boundary lines in the building footprint of interest
- \( n = \) the number of the corners in ExBi

In these error measurements, \( L_{ExBi} \) was introduced to avoid a heavy penalization for short, extracted, boundary lines (Okorn et al., 2010). Subsequently, average and standard deviations are used to measure distributions of these quantities.

### 5.2 Task B

Similar to Task A, the evaluation process of Task B identifies the level of locational deviation and the positional accuracy of the extracted road profile (ExR), with respect to the ground truth road (GtR). Based on the minimum bounding box of GtR, a 2D grid with the cell size of 1m x 1m is generated. When the GtR is mapped onto the 2D grid, the cell, \( C_{GtR}(x,y) \), has a value of 1, if any pavement edge or road surface of the GtR overlaps the cell.
The positional accuracy can be determined through differences in location and orientation of the road edges between the ground truth and extracted roads. A distance and angle between the road edges from the ground truth and the extracted results are proposed to measure those differences. A pair of road edges \((L_{\text{GRI}}\text{ and } L_{\text{ExR}})\) is initially extracted. For that, if \(C_{\text{GRI}}(x,y) = 1\), a pavement edge segment from \(GtR\) overlapping \(C_{\text{GRI}}(x,y)\) is computed, which is called \(L_{\text{GRI}}\). Then, if the angle between the \(L_{\text{GRI}}\) and a horizontal direction \((n_i = [1,0])\) is less than or equal to 45 degrees, a pavement edge segment of the \(GtR\) on the same vertical grid to the \(C_{\text{GRI}}(x,y)\) closest to the \(L_{\text{GRI}}\) is the \(L_{\text{ExR}}\). Otherwise, the pavement edge segment of the \(ExR\) on the horizontal grid to the \(C_{\text{GRI}}(x,y)\) closest to the \(L_{\text{GRI}}\) is the \(L_{\text{ExR}}\) (Figure 7).

The locational deviation, completeness, correctness, and quality indicators mentioned in Task A are measured, where these parameters can be determined from Eq.1-3. True Positive (TP), False Positive (FP) and False Negative (FN) are computed by comparing cell values from two 2D grids represented by \(GtR\) and \(ExR\), as expressed in Eqs.8-10 and Figure 6.

\[
\begin{align*}
\text{TP} &= C_{\text{GRI}}(x,y) \cap C_{\text{ExR}}(x,y) \quad \text{if } C_{\text{GRI}}(x,y) = 1 \quad \text{and } C_{\text{GRI}}(x,y) = 1 \quad (8) \\
\text{FP} &= C_{\text{GRI}}(x,y) \setminus C_{\text{ExR}}(x,y) \quad \text{if } C_{\text{GRI}}(x,y) = 1 \\
\text{FN} &= C_{\text{ExR}}(x,y) \setminus C_{\text{GRI}}(x,y) \quad \text{if } C_{\text{ExR}}(x,y) = 1 \\
\text{TP} &= 0 \\
\text{FP} &= 0 \\
\text{FN} &= 0
\end{align*}
\]

where \(C_{\text{GRI}}\) = the cell value from \(GtR\)
\(C_{\text{ExR}}\) = the cell value from \(ExR\)
\(C_{\text{GRI}}\) = the areas of a part of \(C_{\text{GRI}}\) inside \(GtR\)
\(C_{\text{ExR}}\) = the areas of a part of \(C_{\text{ExR}}\) inside \(ExR\)

From the pair of the road edge segments, the distance and orientation errors \((L_{\text{GRI}}\text{ and } L_{\text{ExR}}\) respectively) can be computed according to Eqs.11 and 12, where the distance between \(L_{\text{GRI}}\) and \(L_{\text{ExR}}\) is the distance between the middle of the \(L_{\text{GRI}}\) and the \(L_{\text{ExR}}\).

\[
E_{\text{dist}} = \frac{1}{n} \sum_{i=1}^{n} L_{\text{GRI}} \cdot L_{\text{ExR}}
\]

\[
E_{\text{orient}} = \frac{1}{n} \sum_{i=1}^{n} \alpha_i
\]

where \(n\) = the number of pairs of the road edge segments
\(\alpha_i\) = the angle between the \(L_{\text{GRI}}\) and the \(L_{\text{ExR}}\)

Finally, the winners of each task are selected based on the overall evaluation of the output quality, where all evaluated quantities are weighted equally.

**6. CONCLUSION**

Automatic approaches have been proposed to detect and reconstruct building and road profiles from ALS data. Previously, these methods were evaluated by using different data sets associated with various different criteria and ground truths. That precludes a rigorous comparison of the advantages and disadvantages of each method. This paper presents the objectives of the track in the IQPC 2015 contest related to automatic building and road detection and reconstruction. The contest was run on dataset consisting of ALS data captured over 1km\(^2\) of the Dublin’s city centre with a typical data density of 225 points/m\(^2\). The success of this contest can possibly provide useful information for establishing strategies for automatic urban 2D footprints from ALS data.

An evaluation strategy was proposed to benchmark the results in terms of the capacity of the submitted results in detecting and reconstructing building and road outlines. The evaluation
process identifies the level of locational deviation, the level of shape similarity, and the positional accuracy of the extracted building footprints and road profiles, with respect to the ground truth building and road. The contest was launched in March 2015. The test datasets remain available on the webpage of the track. Participants are welcome to submit for future evaluation.

ACKNOWLEDGEMENTS

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REFERENCES


Clode, S., Rottensteiner, F., Kootsookos, P.J., 2005. Improving city model determination by using road detection from lidar data, Joint Workshop of ISPRS and the German Association for Pattern Recognition (DAGM); Object Extraction for 3D City Models, Road Databases and Traffic Monitoring - Concepts, Algorithms, and Evaluation' (CMRT05).


