Building extraction by attribute filters from LiDAR data

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1. Initialization

LiDAR raw point data is shown in Figure 1(a), and connectivity between points is established by the construction of a grid g with a finite rectangular subset I. The extent of I is related to the scope of LiDAR points and p denotes a grid point. The construction of g is done over the following three steps (Mongus *et al.* 2014):

1) R_g defines the resolution of g, estimated according to the LiDAR data density D_L,
2) *g[p]* is the value of g at p given by the lowest elevation point contained within the corresponding grid-cells, and
3) $p*$ denotes an undefined grid-point obtained when no points are contained within the corresponding grid-cell. In this case, *g[p*]* is estimated by the Nearest Neighbor Interpolation to guarantee the authenticity of the original data.

Finally, as shown in Figure 1(b), the LiDAR derived DSM is obtained by initializing from LiDAR point cloud.

2. Extraction of building candidate regions

Therefore, LiDAR derived DSM can be considered as a gray-level image, so the gray-level connected operators (Salembier and Wilkinson 2009, Heijmans 1999) can be applied to it to extract building regions. To perform this, two major issues need to be solved: (1) making structure of tree in the hierarchical representation; and (2) discriminating connected components of interest in this hierarchy. At first, threshold decomposition is transformed to grid g. Thresholding grid g in an increasing order from $h_{min}+1$ to h_{max} will generate a stack of nested binary sets:

$$T_h(g) = \{p \in I \mid g(p) \geq h\}. \quad (8)$$

The area difference of one parent node C_k^f and its child node $\widehat{C_k^f}$ is utilized to discriminate building regions. So we only need to know the relation between the parent node C_k^f and its child node $\widehat{C_k^f}$. To separate building from other objects completely, the attribute-space connectivity (Wilkinson 2007) is introduced to each level of grid g, namely that each level of gird g is clustered by the elevation value of each grid. Thus, each node of tree represents a clustered region of each level in grid g. Then, the max-tree will be constructed.

Once the max-tree has been established, the filtering criterion is introduced to analyze each node and takes a decision on the elimination or preservation of the node (Salembier *et al.* 1998). Based on the falling gradient difference of buildings and grounds, an area difference based filtering criterion is introduced. The filtering criterion is defined as:

$$\Delta(S) = S(C_k^f) - S\left(\widehat{C_k^f}\right) < TS \tag{9}$$

$S(C_k^f)$ is the area of C_k^f, $S\left(\widehat{C_k^f}\right)$ the area of $\widehat{C_k^f}$, $\Delta(S)$ the difference of two, and *TS* the threshold of $\Delta(S)$. Namely, if the value of $\Delta(S)$ is less than *TS*, the corresponding connect components will be considered as building object.

In this process, the ground regions which are surrounded by buildings will be considered as building regions. To eliminate these regions, ground regions are masked in LiDAR derived DSM data. First, LiDAR derived DSM is clustered by the elevation of each grid. Then, the ground regions are discriminated based on the relation between the region and its adjacent regions. For one region from clustered regions, if the ratio P of the number of its adjacent regions whose average elevation are smaller than its average elevation to the number of its adjacent regions is not more than the threshold TP, the region is considered as ground region and masked by 0, and otherwise not and masked by 1. Finally, all the ground regions are masked.

Thus, for node C_k^f and its child node $\widehat{C_k^f}$, if $S(C_k^f) - S\left(\widehat{C_k^f}\right) < TS$ and its masked value $\mathrm{M}(C_k^f) = 1$, the corresponding connect components of node C_k^f will be considered as building object. In addition, although the area is decreasing attribute, the area difference is not. This means that the area difference between a child node and a parent node can be above the given threshold, while the area difference between the parent node and a grandparent node is below the threshold and will make the filter unstable (Salembier and Wilkinson 2009). To solve this problem, the nodes from node C_k^f to leaf are all classified active node, if the node C_k^f satisfies the citation. The result of building extraction is shown in Figure 1(c).

3. *Removing Vegetation Regions*

Building candidate regions contain buildings and vegetation which should be removed. Usually, spectrum, area, elevation, roughness and the number of echoes are adopted to distinguish building and vegetation areas (Lee *et al*. 2008). Even though we make many efforts to distinguish buildings from trees based on LiDAR data only, we haven't got a satisfactory result till now. Some complex buildings will be taken as vegetation using texture of feature, and some high vegetation will also remain if a height threshold is applied to maintain the buildings. Under these conditions, a color feature based on the image is introduced to discriminate buildings from trees (Lee *et al*. 2008, Kabolizade *et al.* 2010, Vu *et al.* 2009).

And the average NDVI value *PN* and area *A* of every region is calculated. If *PN* < *TN* and *A*>*TA*, this region is building or tree. "*TN*" and "*TA*" are the thresholds of "*PN*" and "*A*".

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