Introducing a new approach for buildings detection using LiDAR data and aerial image

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Our Method in Six Steps:

*A. **Data Pre-processing***

In pre-processing as the first step, two important corrections were applied: a) removal of a specific type of LiDAR noises, and b) ortho-rectification and geo-referencing of input aerial images. In the correction type (a), LiDAR points that significantly had last return (LR) higher than their corresponding first return (FR) were considered to be noises. Thus, based on Equation 1 and a threshold value of "Th_1", this type of noise was removed.

$$Point = \begin{cases} Noise & IF\ LR - FR > Th_1 \\ Pure & Else \end{cases} \tag{1}$$

Detected noises were removed and replaced with an interpolated elevation from the neighboring points. For elevation interpolation, nearest neighbor (NN) method was used to keep the elevation leap along the edges of buildings. In the correction type (b), input aerial images were ortho-rectified using DSM and interior- and exterior-orientation parameters. Collinearity model was used to remove relief displacements and ortho-rectification. Finally, ortho-rectified images were geo-referenced using ground control points (GCPs) which were manually extracted from the input DSMs.

*B. **OTOs Detection***

Digital elevation model (DEM) was generated from the range image of last return based on scan labeling algorithm. Normalized digital surface model was obtained from the difference between digital surface model (DSM) and DEM, according to Eq. 2.

$$nDSM = DSM - DEM \tag{2}$$

Then, Off-Terrain Objects (OTOs) were obtained using a threshold from nDSM, according to Eq. 3.

$$OTOs = \begin{cases} 1 & IF\ nDSM > Th_2 \\ 0 & Else \end{cases} \tag{3}$$

C. Feature Production

In this section, a number of features are produced from DSMs and aerial images. These features would be inputs of the classification process for separating buildings from trees. For this purpose, four features from aerial images including two different enriched vegetation indices (EVI) and saturation and hue bands from IHS transformation, and five features from DSMs including gradient, variance, roughness, laplacian, and SSD were produced.

D. Separating Buildings and Trees

Here, the produced features were overlapped with OTOs binary image to identify feature areas related to trees and buildings. Then, the identified feature areas were classified independently using SVMs to detect buildings and trees. To increase the automation level of the proposed algorithm, an approach was automatically developed to select the training data of SVM. The concept of automatic training data selection lies in the fact that feature values for trees are higher than the buildings ones.

E. Post-Processing and Integration of Classification Results

In post-processing, morphological opening and closing operators were applied to remove small objects and fill holes of buildings and trees in each SVM classification result. Afterwards, nine post-processed binary images were obtained for each class. If building (or tree) and non-building (or non-tree) pixels in each processed binary image were labeled with "1" and "0", respectively, then nine post-processed binary images would be merged together to obtain the building and tree classes according to Equation 4.

$$\text{Pixel} = \begin{cases} \text{Building} & \text{IF } SL_B \geq Th_4 \\ \text{Tree} & \text{IF } SL_T \geq Th_4 \\ 0 & \text{Else} \end{cases} \qquad (4)$$

where SL_B and SL_T is the sum of labels for a pixel in the processed binary images of building and tree respectively.

F. Separation of Clung Buildings

Separated buildings took different labels by connected component analysis (CCA) algorithm; but, clung buildings had the same label. For separating clung buildings, a k-means clustering algorithm with two classes was applied to the buildings. nDSM of the detected buildings was used as a feature layer in k-means clustering algorithm; so, the clung buildings that had different elevations could be separated. After labeling the buildings by CCA, each labeled object could include one or more buildings. If k-means clustering algorithm were applied to the clung buildings with different elevations, these clung buildings would separate and each building would take a different label; moreover, if k-means clustering algorithm was applied to one building, this building would not split into two sections; instead, it would split into true positive and false positive pixels and, by removing false positive pixels, correctness of building detection would increase. However, it might decrease the completeness of results. So, mathematical morphological operations were applied to each cluster to remove small areas (false positive pixels) and fill small holes.