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Object-based extraction of building features from LiDAR and aerial photograph – MORPHSCALE method

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ABSTRACT

The paper describes a newly developed object-based extraction method named MORPHSCALE. It is a multi-scale framework built based on mathematical morphology. First, LiDAR point clouds are classified to obtain Digital Terrain Model (DTM) and Digital Height Model (DHM). Second, the scale-space is generated for the DHM and the aerial photograph. Pulse intensity derived from LiDAR is used as the near-infrared channel and added into red, green, and blue channels of the aerial photograph. Third, the father-child relationship is built across the scale-space for the formed clusters. Based on this relationship, building features can be extracted. New multi-scale database structure is also introduced to store all components of the complex structures. MORPHSCALE is demonstrated using LiDAR and multi-spectral aerial photograph but it promisingly works well with any DHM and spectral sources. Future works will assess the relationship between the extracted spectral property of each building feature and its roof material.

1. INTRODUCTION

Object extraction method from remotely sensed images has been widely developed. Its final goal is to update or revise the geo-spatial database. Recent developments of object extraction image analysis show following typical tendencies: transition to 3D; object-oriented, hierarchical and multi-scale approaches are often used; and more attention to object modeling (Baltsavias 2004). These are the results of advances in computing technologies and also the needs to deal with increasing number and variety of sensor.

Extraction of building features in urban areas requires very-high-spatial-resolution image. Hence, aerial images with three visible bands have been conventionally used as unique data source. Recently, more spectral channels are added and space-borne sensors also provide comparable high-spatial-resolution images. The level of automation in processing spectral image is very low due to diverse spectral information. Derivation of 3D information from a pair of spectral images is even more complicated. Suveg and Vosselman (2004) recommended that the complexity of extraction and then reconstruction could be reduced by the fusion with other data sources. Fortunately, recent development of Light Detection And Ranging (LiDAR) data (Baltsavias 1999, Wehr and Lohr 1999) introduces a better option to improve the level of automation. Dense LiDAR point clouds well present the complex structures of building features. Using LiDAR or its fusion with other data sources has been the dominant trend of researches and practices in object extraction (Haala and Brenner 1999, Maas and Vosselman 1999, Rottensteiner and Briese 2003, Vu et al. 2003). However, while 3D geo-spatial database has not been mature, there is a big gap between the complexity of an object structure can be reconstructed and how to store it in a database. This problem is tried to solve in developing our MORPHSCALE method.

MORPHSCALE is developed as a multi-scale framework for object extraction from multi-data sources. At least, two basic data sources must be provided. These are Digital Height Model (DHM) and multi-spectral data. To improve the level of automation, MORPHSCALE prefers to use LiDAR data. The core algorithm is developed based on the theory of mathematical morphology (Vincent 1992). Detailed description on the core algorithm was presented in our previous studies (Vu et al. 2005a & 2005b). It will not be repeated here. Each following section summarizes the processing of each module in MORPHSCALE. Section 2 describes the classification of LiDAR point clouds into ground and non-ground points to derive DHM. Building extraction is discussed in Section 3. Section 4 presents our new proposed building database. Summary and discussion of further developments will be in Section 5.

2. LIDAR POINT CLASSIFICATION

First, LiDAR point cloud is interpolated into grid format. The cell size is determined based on the point density. Nearest neighbor interpolation method is employed here to preserve the sharp leap in elevation along the edges of buildings. The grid value now represents the elevation. The number of value can be reduced, to speed up the later processing, by slicing the elevation value. Height of a story would be a good threshold for this elevation slicing.

Second, the progressive morphological opening and reconstruction is carried out using the flat structure element (SE) with increasing size ($2^k + 1$, $2^k + 1$), where $k = 0, 1, 2, \ldots, n$. The lower scale limit is the approximate smallest size of building feature and the upper one is the approximate biggest size of building feature. It assumes that the ground forms the biggest cluster. K-mean clustering then is applied to classify into ground and non-ground clusters. LiDAR points that fall into those detected clusters will be separately marked.

Third, the newly marked points along the boundaries of detected non-ground clusters are clarified. Local elevation thresholding is applied (Vu and Tokunaga, 2004) to re-classify the ground points but were classified as non-ground points and vice versa. After this step, all reasonably big objects are removed. However, the LiDAR points of the small objects like trees, poles might still exist in the group of the ground points. Those points show dramatically steep local slope compared to surrounding and can be removed from the group of the ground points by a slope-based thresholding (Vu and Tokunaga, 2004).

Finally, the Digital Terrain Model (DTM) is constructed from the ground point group and the Digital Height Model (DHM) is obtained by taking the difference between original Digital Surface Model (DSM) and that DTM. All cells with lower-than-2m elevation are re-assigned to 0m elevation since building features are targeted and they are usually not lower than 2 meters. Figure 1 presents the results of LiDAR classification by this method using the LiDAR data acquired over Roppongi area, Tokyo, Japan. This data will be used to demonstrate MORPHSCALE throughout this paper.

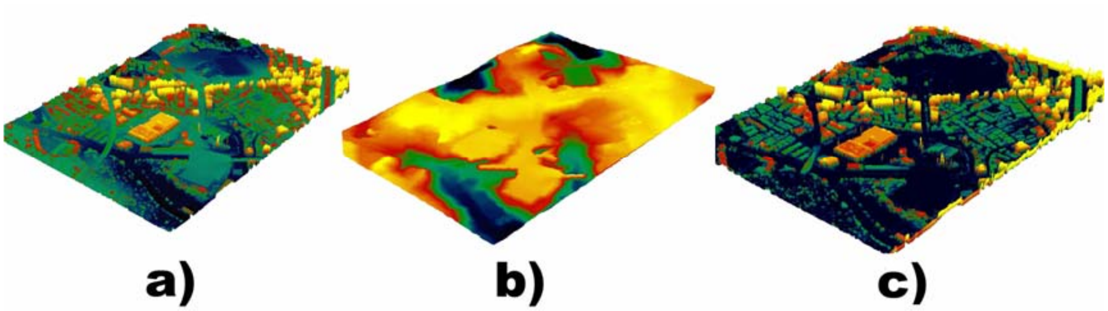

Figure 1. Results of LiDAR point classification a) DSM, b) DTM, and c) DHM.

3. BUILDING EXTRACTION

A LiDAR surveying flight nowadays also provides the ortho-RGB image besides the LiDAR point clouds. Hence, it can be easily co-register with DHM for object extraction. In addition, LiDAR pulse intensity is interpolated and co-registered with both DHM and ortho-image. It forms a 5-bands image. Subsequently, a morphological scale space is generated for this image. Then, the scale-space processing is carried out separately for height and spectral information. It is noted that there is a difference in using the terms *cluster* and *object.* The *cluster* means the formed group of connected pixels that have the same values. And the *object* means the extracted cluster.

In regards to processing spectral information, first, K-mean clustering is carried out for spectral information (4 bands) on each scale. The classified spectral index of a class might be different across the scale-space. It must be re-assigned. Using one scale as the reference (often the finest one). The distribution histograms of each class on the original image are generated. Cross-correlation analyzing these histograms is carried out across the scale-space. The spectral indices then can be re-assigned by finding the maximum correlation. Second, the father-child relationship across the scale-space is constructed based on the same spectral index. Object then can be extracted on its root scale, i.e. the scale on which an object has no father on the coarser one. Since building features are concerned, only relevant spectral indices and scales are used for building extraction here. An example of building extraction based on spectral indices shows in Figure 2. It is noted that the processing here ignores the objects that are lower than 2 meters. Thus, open-space, parking, road, etc. are mostly excluded. However, elevated highway cannot be excluded.

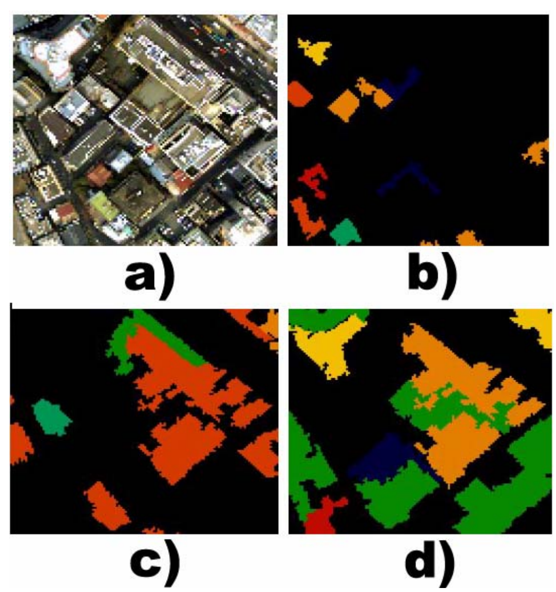

Figure 2. Building extraction solely based on spectral information: a) original RGB

image, b), c) and d) extracted building features from fine to coarse scales.

For height processing on the scale-space, similar to spectral processing, the initial scale link and extraction uses the same elevation as criteria. Next, it is the construction step as follows.

- First, it finds the overlapping objects across the scale space. If the center point of an object on a finer scale is not too far away from that of the object on coarser scale (*distance thres.*) and its area approximately equals that of the object on coarser scale (*area thres.*), this object are removed. Otherwise, the ID of the object on coarser scale and this scale are stored as father's attributes of the object on finer scales.

- Second, the spectral index is assigned to those extracted buildings based on the majority of overlapping between spectral clusters and height clusters. New building database is generated including the following attributes: *scale* (object's scale), *id* (object's id), *superid* (father's id), *superscale* (father's scale), *x0* (starting X), *y0* (starting Y), *area*, *height_index* (number of story), *spectral_index* (spectral class).

Finally, the extracted buildings are converted to vector format to prepare for the construction of the building database. Raster-to-vector conversion includes the detection of building edges and the arrangement of edge vertices to construct the polygon. Then, all polygons are stored into a shapefile (*.shp). All listed attributes above are also attached in the conversion. An example of conversion result is shown in Figure 3. The boundaries of building polygons are represented as the blue lines overlain on extracted buildings in raster format.

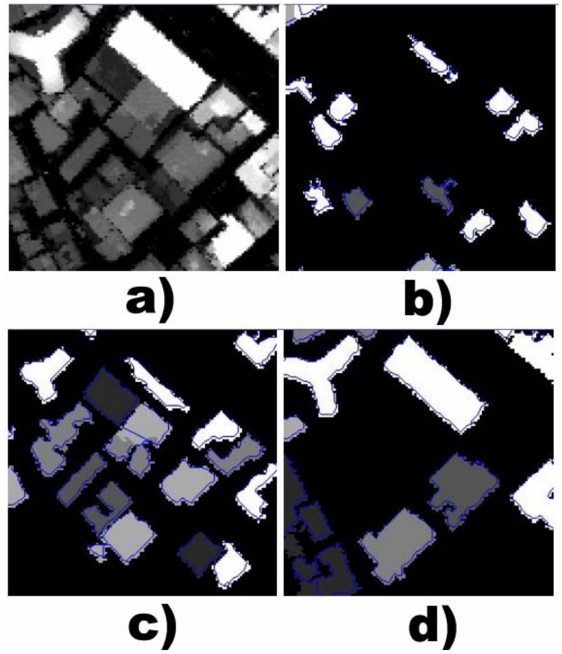

Figure 3. Extracted building polygons overlie on raster images: a) original DHM image, b), c) and d) extracted building features from fine to coarse scales.

4. BUILDING DATABASE

Multi-scale extraction framework, on one hand, simplifies the extraction and construction task. On another hand, it is the guidance for developing a multi-scale building database. The components of each building are separately stored on their scales. It can be easily linked through the father-child relationship, i.e. through *SupID* and *Supscale* attributes (Figure 4). By this way, a very complex structure can be stored and it is also able to match with existing database by extracting only father polygons. The idea is demonstrated through an example in Figure 4.

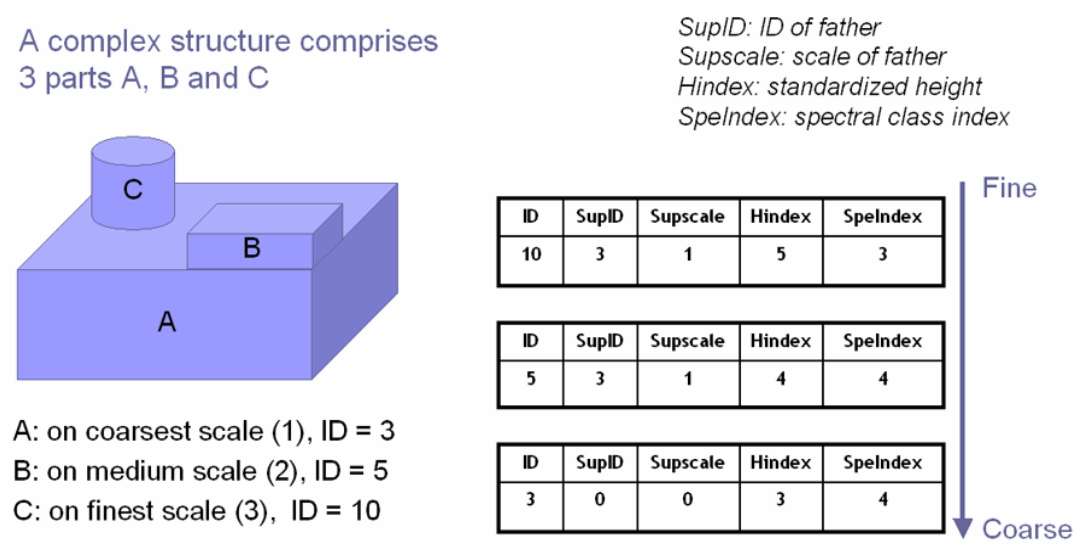

Figure 4. Demonstration of newly developed building database.

5. CONCLUSION

MORPHSCALE, an object-based approach, for building extraction has been developed. It is a fully automated approach making use of both spectral and elevation data. This paper demonstrated MORPHSCALE using the products of a LiDAR surveying flight. However, it can work well with any DHM and spectral data sources. Multi-scale framework is not only the core for extraction but also for developing the building database. Multi-scale relational database is useful in storing a very complex structure and flexibly accessed for matching with existing database. Completeness and quality of extracted building features will reported in next step of development. Furthermore, roof material could be derived from the extracted spectral indices. It will be concerned in future works.

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