COMBINING HIGH RESOLUTION SATELLITE IMAGERY AND AIRBORNE LASER SCANNING DATA FOR GENERATING BARELAND DEM IN URBAN AREAS

Guo Tao *, Yoshifumi Yasuoka

Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8505, Japan
guotao@iis.u-tokyo.ac.jp

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ABSTRACT:

This paper proposes a framework for generating bare-land Digital Elevation Model (DEM) in urban areas by combining high-resolution satellite imagery and Airborne Laser Scanning (ALS) data. Airborne laser scanners offer an efficient approach for 3D data acquisition. ALS data provides very accurate position and height information, but less direct information on ground objects' geometrical shape, meanwhile high-resolution satellite imagery such as IKONOS offers very detailed information on objects, such as spectral signature, texture, shape etc. Combining these two kinds complementary dataset is quite promising for the research of ground object recognition, e.g. building extraction, 3D city modeling etc. This paper presents the concept and procedures of the approach based on above idea, and also shows some experimental results.

1. INTRODUCTION

In the last few years there is a great increasing interest in 3D city modeling and it has led to intensive research efforts to automatically detect, reconstruct and model 3D buildings, trees and other objects above ground in urban environments. For this purpose, imagery, Digital Surface Models (DSM) and GIS information are primarily used as the most common source of input datasets.

Although some promising results of automatic methods for building extraction have been presented, so far, it still lacks the performance needed for practical application (Forstner 1999). A number of researchers have shown photogrammetric approaches for extracting building models from imagery, mainly aerial images (Lang and Forstner, 1996, Henricsson, 1996, Gruen et al., 1997). Fraser, Baltsavias and Gruen (2001) reconstruct 3D building from high-resolution IKONOS stereo imagery. On the other hand, due to its advantages as an active technique for reliable 3D determination, airborne laser scanning (LIDAR) data has become a rather important information source for generating high quality DSMs. Weidner and Forntner (1995), Maas and Vosselman (1999) develop approaches for extracting building from DSMs or laser altimetry data. Meanwhile, integrating multiple data sources has been approved an efficient approach. Haala (1999) combines DSMs with color aerial images, Vosselman and Suveg (2001) fuse GIS maps with laser data and images show some very good performances.

The aim of our research is to model 3D city using high-resolution IKONOS imagery and airborne laser scanning data. Since the successful launch of IKONOS in September 1999, the high-resolution imagery from this satellite has become widely available. This has broadened the potential significantly for mapping urban areas. However, solely based on 2D images, it is very difficult to reconstruct 3D objects, therefore 3D information such as DSMs should be used whenever available. DSM can be obtained by automatic image matching algorithms applying stereo aerial or high-resolution satellite imagery or can be directly captured by airborne laser scanning system. But in urban areas, stereo matching method has a big problem due to occlusions and height discontinuities. Therefore, the direct height measurement by airborne laser scanners usually provides DSM data of higher and more homogeneous quality especially urban built-up areas (Haala, 1999).

Towards automatic objects extraction in urban environment, the common goal of the first step is the detection of buildings, trees, and streets etc. However, this can be very difficult if only images or DSMs is used because many urban objects appear quite similar in images or DSMs, for example, in some areas roofs and streets are build of very similar material, their reflectance on the images always has very close characteristics. The same problem also exists, if trees close to buildings and we want to discriminate them on DSMs, particularly for ALS data, separation of ground points from points resulting from reflections on buildings, vegetation or other objects above ground is still one of major problems (Vosselman and Maas, 2001).

This paper presents our approach to segment urban objects from coarsely to finely by combining high-resolution IKONOS imagery and airborne laser scanning data, then terrain points are extracted from ALS data to generate urban bare-land DEM. With the difference between DSMs which contain buildings, trees etc. and this bare-land DEM, the so-called normalized DSM can be generated, which represents all objects rising from the terrain. This helps further segmentation on buildings, trees and other urban objects. Therefore the generation of buildings and trees extraction purpose urban bare-land DEM will be described in detail in the following sections.

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* Corresponding author. Tel.: +81-3-5452-6415; Fax: +81-3-5452-6410

2. COMBINATION OF IKONOSN IMAGERY AND AIRBORNE LASEAR SCANNING DATA

2.1 IKONOS Imagery

According to Space Imaging (www.spaceimaging.com), IKONOS imagery basically has five product categories: *Geo, Reference, Pro, Precision and Precision Plus.* Except for the *Geo* product, all are ortho-rectified, with ground control being required for *Precision* ortho-imagery. Their ground positioning accuracies (RMS) are 24, 12, 5, 2, and 1 m respectively. Since our aim is urban objects extraction, we will use *Precision Plus* or *Precision* IKONOS imagery as our input imagery source.

IKONOS image has four 4-meter resolution color channel (Red, Green, Blue and Near Infrared) and a 1-meter resolution panchromatic images. All images are stored in 11-bit format for wider dynamic spectral range. Most objects, like small buildings, even individual trees can be recognized in 1-meter PAN images, but their boundaries are not easily identifiable due to the complex urban scene and traditional edge-based approaches cannot directly achieve good performance. Meanwhile there are big shadow areas in IKONOS images because of the look angle of satellite and solar zenith angle. However Multi-spectral information is a very important merit of IKONOS imagery compared to other high-resolution imagery, such as aerial photography. Normalized Difference Vegetation Index (NDVI) can be derived from its Red and NIR images. NDVI has been widely applied in land cover classification for a long period and it is an efficient way to discriminate crucial information of surface properties. Within this paper, NDVI is used as one of primary keys to segment urban objects.

2.2 Airborne Laser Scanning Data

Airborne laser scanning is an active technique to acquire point clouds describing the earth surface. A typical system can provide 3D points data with 15 cm vertical accuracy and 50 cm horizontal accuracy, and laser points are almost evenly distributed in the covered areas. Therefore high quality and homogenous DSMs can be directly derived from ALS data.

A number of approaches solely based on ALS data for segmenting buildings and trees has been shown. Weidner and Forstner (1995) use morphological opening with thresholding to detect buildings. Mass and Vosselman (1999) show an approach based on the analysis of invariant moments of point clouds. Elberink and Mass (2000) use anisotropic height texture measures to segment ALS data. Vosselman (2000) also describes a slope based filtering method. Most of these approaches can achieve good results applying to dense ALS data, normally point density up to several points per m^2. However the point densities delivered by most systems in standard operation mode are still too small (often in the order of 1 point / $10m^2$) (Mass and Vosselman, 1999). The density of our ALS data in this research is about 1 point / $2.5m^2$, in this case, above approaches don't show great efficiency. And if a laser scanner system is able to register first and last pulse simultaneously, multiple return analysis can be very valuable to detect trees and buildings.

2.3 Digital Surface Models Generation

DSMs can be directly derived from interpolation of ALS data, linear or higher order degree of surface curvature smooth edges of objects and lead to difficulties in discrimination buildings and trees. Therefore Nearest Neighbor (NN) method is used to interpolate ALS data into the same ground sampling distance (GSD) with imagery in order to co-process with images, though it causes shift in objects boundaries, shapes and edges of objects can be preserved, and also when grid size becomes small, this shift will decrease.

2.4 Calculation NDVI

NDVI is defined as (1)

$$NDVI = \frac{IR - R}{IR + R} \qquad (1)$$

IR – Near Infrared reflectance value
R – Visible Red reflectance value

Though NDVI is originally developed for vegetation study, it does contain crucial information for surface properties (Muller, Kim and Tong 2001). Normally in urban environment, vegetation has high NDVI value, bare surface has medium value, and road and buildings' is low. Of course, this is not always correct due to pixels mixture etc., however it is a very helpful and efficient parameter for urban objects classification.

2.5 Processing Scheme

In order to simplify the complexity of processing, our approach generally follows top to down strategy. That is on higher level, emphasis is put on those global and apparent features, and then uses its output combining other information to refine details. We briefly describe our scheme as below two steps

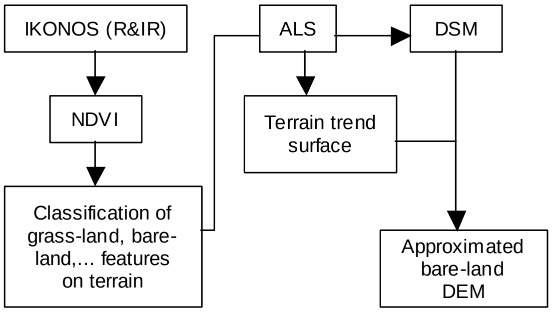

Figure 1. Generation of approximated bare-land DEM

Firstly, resample images and DSMs into the same GSD and co-register them, then using spectral information to coarsely extract those ground objects, such as grassland, bare-land, which have obviously different spectral signature from other objects. Afterwards, retrieve these laser points from ALS data, since they are only a subset of ground points, in most cases, a terrain trend surface can be generated. Through select lower points from this surface and DSM at each pixel position, an approximated bare-land DEM is generated. Smoothing operations such as morphological opening is recommended during processing in order to reduce the influence of misclassification and noise. The purpose of this step is to approximately separate objects above ground and reduce the influence of terrain slope to some certain degree.

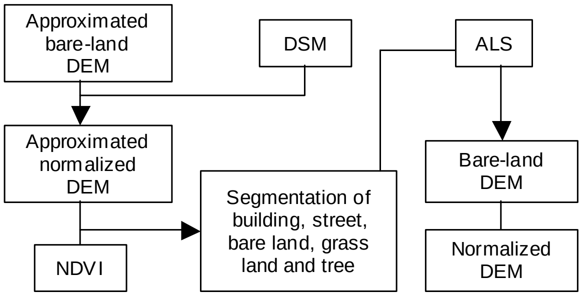

Figure 2. Generation of bare-land DEM

The second step starts with subtracting the approximated bare-land DEM generated in the first step from original DSM to derive an approximated normalized DEM. This results in a representation of most objects rising from the terrain approximately put on a plane. Then combine the approximated normalized DEM with NDVI to segment most urban objects, in our case, buildings, streets, bare lands, grasslands and trees are interests for city modeling. The general rule for this segmentation is quite simple but efficient as shown in Table 1

Objects	NDVI	nDSM
Building	low	high
Street	low	low
Bare land	medium	low
Grassland	high	low
Tree	very high	high

Table 1. Segmentation rule for urban objects

Though this might not always correctly represent urban objects due to the complexity of urban scene and the quality of NDVI or nDSM, in most case it can produce reasonable results. Because at present stage, the goal is detection of ground and non-ground point subset, some certain misclassification doesn't make big difference. As mentioned above, a fine segmentation will conducted based on the coarse output of higher level processing and combining additional information input. However a sequential smoothing or refining operations are employed during processing to reduce errors. Afterwards, retrieve terrain points from original ALS data using ground objects, e.g. streets, bare lands and grasslands, interpolate these points to produce a terrain surface, compared with original DSM, the bare-land DEM can be derived, their difference results in the normalized DSM which will be exported into next stage for segmentation of buildings, trees and ground. Again, refinement operation is necessary for making good outputs.

3. EXPERIMENTS AND RESULTS

3.1 Test Site

Test site covers an area of 1000 x 600m over Komaba campus of University of Tokyo. This area contains most patterns of urban objects. Buildings in this area have various shapes and their sizes rang from very large to big to medium to small. The distribution of buildings ranges from sparse to very close. This area contains a lot of trees as well, from individual trees to tree crowds, some trees very close to buildings. Streets, roads, grasslands, sports fields and bare lands are also contained in this test site.

3.2 IKONOS Imagery and NDVI

IKONOS images are kindly provided by Japan Space Imaging (JSI) Corporation. Acquisition date is on Nov. 4th, 2001. And images have been preprocessed by JSI to *expert* product level (http://www.spaceimaging.co.jp/seihin/seihin1.html) which is close to *Precision* products. All images have been rectified using ground control points (GCPs) and accurate elevation data. The ground positioning accuracy (RSM) is 1.75m. The resolution of multi-spectral (R, G, B, NIR) is 4-meter and Panchromatic image has 1-meter resolution.

Due to the 11-bit color depth, IKONOS images contain rich spectral information. This will be useful for spectral detail analysis, e.g. extraction of spectral signatures within shadow areas. In PAN image, most Objects can be recognized, but their boundaries are not easy to identify. All images are resampled into 0.5-meter GSD in order to co-process with DSMs. Then, NDVI image is calculated using formula (1).

Figure 3. True color (R, G, B) IKONOS image (4m resolution)

Figure 4. Panchromatic IKONOS image (1m resolution)

Figure 5. NDVI image (0.5m GSD)

3.3 ALS Data and DSM

JSI also provides us ALS data, which originally captured using *ALTMS* system (manufacture is TerraPoint, built by HARC with NASA support). The average sampling space of laser points is about 1.5m and the size of footprint of laser beam on the ground is 90 cm, elevation accuracy is 15 cm and horizontal accuracy is about 1m. ALTMS system can record at most 4 multiple returns, but this information is not available in our ALS data. We simply generate a DSM from the ALS point clouds by Nearest Neighbor interpolation with 0.5 GSD the same as resampled IKONOS images.

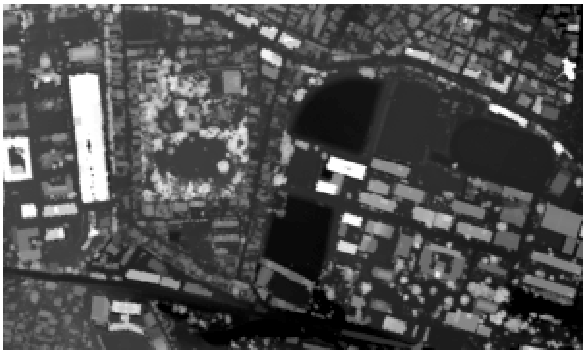

Figure 6. DSM generated by ALS data

3.4 First Classification Based on NDVI

Since our interest is the major objects of urban area, the following 5 classes are picked out:

- Building
- Street
- Bare land
- Grassland
- Tree

For the high level coarsely classification, accurate definitions for each class will not be given for a minimum the number of classes, but for refinement of classification, a further analysis combining texture, geometric characteristics etc. other information will be employed. For this purpose the ISODATA (Iterative Self-Organizing Data Analysis Techniques Algorithm) is applied to NDVI image to derive a 5-class clutter map.

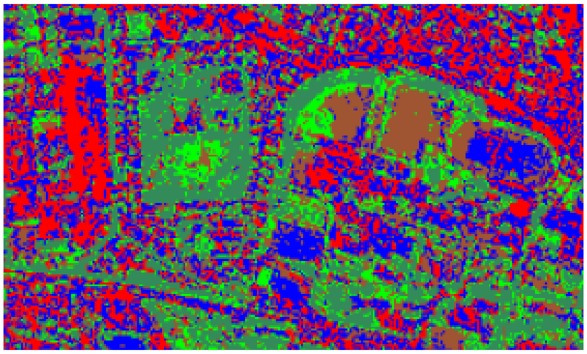

Figure 7. Classification based NDVI

Figure 7 shows the result of classification is very noise, but by comparing with IKONOS PAN image and GIS maps, we found grasslands and bare lands are much close to reality and they represent some areas of ground.

3.5 Classification Based on NDVI and Approximation of Normalized DSM

A subset of ground points are retrieved from ALS data within those grassland and bare-land areas, then generate a ground trend surface and compare it with original DSM to produce an approximated bare-land DEM, Subtraction from original DSM with this approximated bare-land DEM results an approximated normalized DSM (anDSM).

Here classification is conducted based on such a simple fact: the objects, which have the height above a certain value, must be either trees or buildings, meanwhile trees have high NDVI value and NDVI of buildings is low; The same thing, grasslands have low height but high NDVI, bare lands have low height, medium NDVI, and streets have low height and low NDVI. In our case, after comparing with ground truth data, we use following parameters:

Objects	NDVI	Height (m)
Building	< -0.02	> 3.0
Street	< -0.02	< 3.0
Bare land	-0.02 – 0.05	< 3.0
Grassland	0.05 – 0.1	< 3.0
Tree	> 0.1	> 3.0

Table 2. Parameters for classification based on NDVI and anDSM

As mentioned before, this method in most cases can efficiently generate reasonable results. Figure 8 shows classification results are improved considerably.

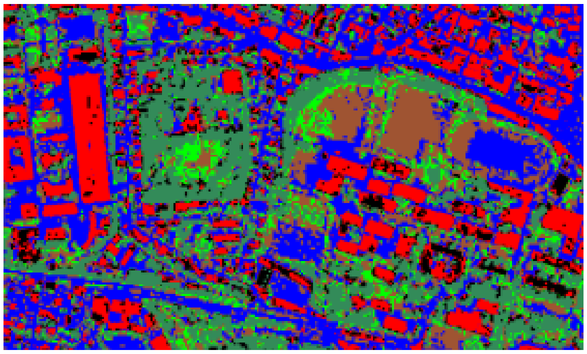

Figure 8. Classification based on NDVI and anDEM

3.6 Generation of Bare-land DEM and Normalized DEM

Up to this stage, since improved classification result is achieved, more ground points with higher accuracy are accessible. Then use these ground points as input, repeat the procedure of generation of approximated bare-land DEM as mentioned above, Bare-land DEM and normalized DEM, which are much close to reality are derived. However, due to existing errors, smoothing operations are employed to improve results.

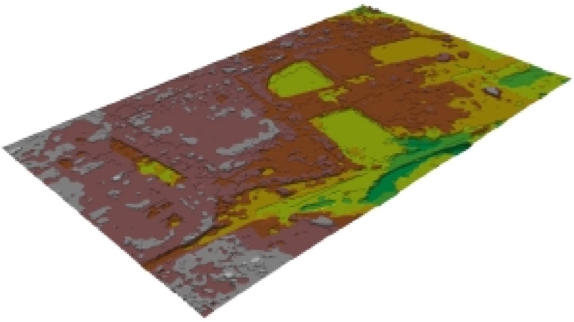

Figure 9. 3D view of bare-land DEM

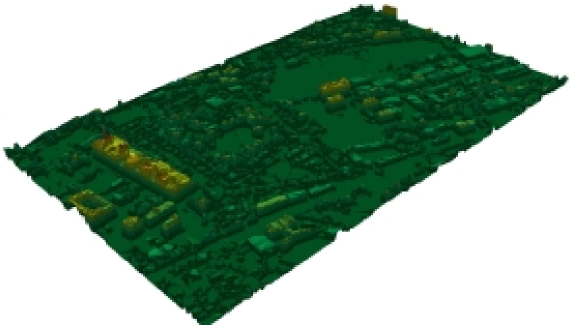

Figure 10. 3D view of normalized DEM

3.7 Shadow Analysis

For further segmentation, besides input normalized DEM, high-resolution PAN image, etc. information, shadow issue must be considered due to its big areas. Shadow can be derived from original DSM through height and light angle. Figure 11 shows derived shadow areas. Further spectral analysis within shadow areas will improve segmentation.

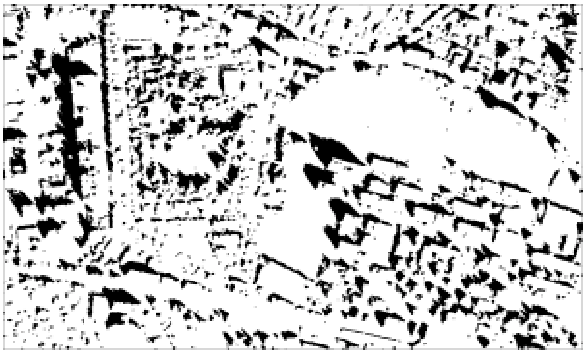

Figure 11. Derived shadow areas

4. DISCUSSION

Within this paper we show our approach of combing IKONOS high-resolution imagery and airborne laser scanning data to generate urban DEM – bare-land and normalized DEM for the purpose of 3D city modeling. Pyramidal top to down strategy efficiently simplifies the complexity. Spectral classification can be considerably improved by combination of elevation information. Though further segmentation will be conducted, separation of urban objects has shown a good result. The generation of urban DEMs, in most case produces reasonable output. Meanwhile the appropriate smoothing operations are important to reduce error and improve quality of the DEMs.

Due to lack of “ground truth DEMs”, validation is difficult to performed, but as an input information of next stage, this result satisfies our requirements.

Generation of terrain trend surface may fail if not enough or not correct ground points have been extracted at the first classification. In this case, other clues such as GIS maps can be used as additional input information. Another issue is propagation of errors among processing steps need more assessments.

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