# URBAN LAND-USE CLASSIFICATION USING INTEGRATED AIRBORNE LASER SCANNING DATA AND HIGH RESOLUTION MULTI-SPECTRAL SATELLITE IMAGERY

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**ABSTRACT:**

One of the most promising approaches to solve the challenging task of urban land-use classification is integration of multi-spectral satellite image data and range data. In this paper, height data acquired by airborne laser scanning is not only applied for geometric correction of the multi-spectral satellite image data by the generation of ortho-images, but also integrated in urban environment classification. Laser scanning data acquired by *Airborne 3D Imager* is used to obtain information on the location height above the terrain surface for each pixel. This information can be applied in order to separate urban objects higher than the ground level from objects that are at ground level, e.g., buildings, trees, streets, grass-covered areas, water bodies and bare land etc. It is demonstrated that the classification of urban scenes is significantly improved by integrating multi-spectral and geometric datasets.

## 1. INTRODUCTION

City is not only a very important place for a human living, but is also the center of economy and social development. The land-use classification of urban environments plays a key role in Urban Area Land-use Mapping, Urban Planning & Management, Establishment & Revision of GIS Database, Environment & Disaster Monitoring and Establishment of Telecommunication Network Station etc. Remote Sensing is the important technique to quickly obtain information of earth resource and environment, and it has got a very big development during the recent 30 years.

Spectral information is the foundation of Remote Sensing image classification and the image spatial resolution is the main factor that influences the recognition accuracy of the ground objects. The successful launch of high resolution multi-spectral satellite spread the application of Remote Sensing, and made it possible to carry on the thematic information investigation of large mapping scales in urban areas by satellite images. But, there is not any essential change in the course of Remote Sensing data processing. Ground control points are still needed in image rectification, stereo-observation or image matching are still used in three-dimensional information acquisition, and it takes comparatively long time from data acquisition to product delivery to end users etc., all these can not meet the fast reaction requirements to Remote Sensing.

In 1980s, with the development of the quality of GPS positioning and the improvement of the ability to measure position and attitudes of inertial measurement units (IMU), the study and application of airborne laser scanning technology have been put forward further. During the corresponding period, the airborne laser scanning mapping systems integrated by GPS, INS and laser scanner, used for DSM/DEM/DTM fast acquisition, are being developed worldwide. Until 1999, there are about 40 similar airborne laser scanning mapping systems in the world. (Baltsavias E P. (1999)). In the middle of 1990s, Professor LI Shukai of China present the idea that integrates GPS, INS, laser scanner together with the spectral imaging scanner to form the *Airborne 3D Imager*. The distinctive advantage of *Airborne 3D Imager* is that it can produce geo-referenced spectral image and DEM data without any ground control points. Work efficiency can be greatly increased 10 to 100 times compared with the traditional remote sensing processing methods. People can easily come to know the current status of the cities by the data quickly acquired by this technology.

Even though objects rising from the terrain can be detected quite well from the height data, the discrimination between buildings and trees can be difficult, if only simple criteria like region size or shape are considered. (N.Haala, V.Walter.( 1999)). Due to the restriction of surface geometry, the number of object types which can be discriminated within a DSM is very limited. It is also difficult to classify the urban area if only spectral information is used, since, for some areas, roofs and streets are built of very similar material. Their similar reflectance complicates the classification and lowers down the classification accuracy. In order to mutually complement the different remote sensing data captured by different sensors, a classification method is present in this paper by simultaneously using the geometric and multi-spectral information. It is demonstrated that the classification accuracy is improved significantly.

## 2. SYNOPSIS OF AIRBORNE LASER RANGING / MULTISPECTRAL – IMAGING MAPPING SYSTEM

*Airborne 3D Imager* is a type of Airborne Laser Ranging/Multi-spectral Imaging Mapping System assisted by State 863 Plan, developed by Chinese Academy of Sciences. It is composed of GPS receivers, an Inertial Navigation System (INS) unit, laser scanner and spectral imaging scanner. GPS is used to obtain the accurate positional coordinates of the *Airborne 3D Imager* (WGS-84,$X_0$,$Y_0$,$Z_0$). INS is the device that determine the aircraft attitudes (roll, pitch and yaw) with the high accuracy over the short period of time. Laser scanner can accurately measure the distance between the ground object and *Airborne 3D Imager* (slant range $l$). Laser scan angle is $\theta$. The three dimensional coordinates of the laser point (X,Y,Z) can be computed as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{\sqrt{1+tg^2 p + tg^2(r+\theta)}} \times \begin{bmatrix} tgp\cos y - tg(r+\theta)\sin y \\ tgp\sin y + tg(r+\theta)\cos y \\ -1 \end{bmatrix} [l] + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \quad (1)$$

While DSM is acquired, the spectral image of the ground objects can be obtained synchronously by the spectral imaging scanner. Presently, the wavelength used in object detection is between visible light and infrared ray. The spectral imaging scanner and laser range finder (LRF) use the same optical system that form AL-Hi, which ensures the laser point to match the spectral image pixel. This is the main difference between Airborne 3D Imager and any other overseas similar systems. Because of the limited energy and repeated frequency of the laser scanner, ringed scan pattern is adopted in order to get denser laser sample points, averagely, one laser point per square meter. In the post-process, these laser points with three dimensional coordinates are used as control points to precisely rectify the simultaneously acquired spectral image by the spectral imaging scanner by generating ortho-images. DEM and DTM can also be derived from these acquired laser points. Principle of Airborne 3D Imager is depicted in figure 1.

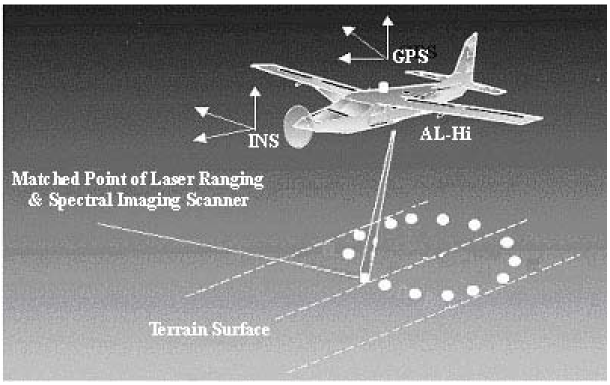


Figure 1. Principle of *Airborne 3D Imager*

Unlike the traditional remote sensing methods that obtain two-dimensional remote sensing information, *Airborne 3D Imager* obtains three-dimensional information, that is, it can simultaneously acquire the three-dimensional position information together with the spectral information of the ground objects, and it can realize the integrative acquisition of positioning and qualitative data.

Compared with other airborne laser scanning systems, *Airborne 3D Imager* has the following characteristics: (1) By using the same optical system on the hardwares, DSM data and spectral image data can be synchronously acquired and co-registered. (2) Geo-referenced spectral image and DSM data are produced without any ground control points. (3) It is the quasi-real-time system. After the flight, DEM and ortho-spectral-images can be acquired in several hours. The efficiency is 10 to 100 times higher than the traditional approaches. (LI Shu-kai, XUE

Yong-qi. (2000)) (4) It is not only a positioning measurement system, but also is a spectral information recording system. DSM data and the spectral images can be obtained at the same time.

Data of north Beijing acquired by *Airborne 3D Imager* on December 2000 is adopted in this paper. Figure 2 is the DSM data presented in a color image. Figure 3 is the simultaneously acquired spectral image. The space between the laser sample points and the spatial resolution of the spectral image is 2m respectively.

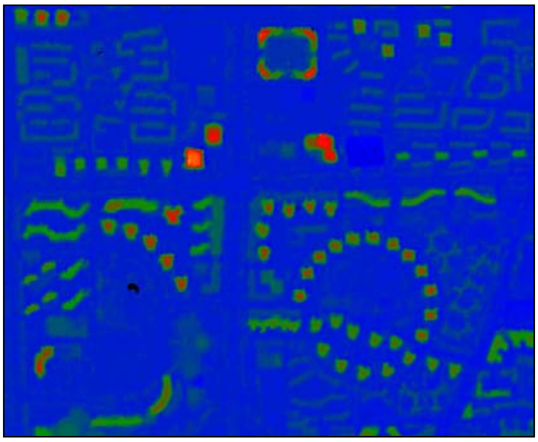

Figure 2. DSM Data Acquired by *Airborne 3D Imager*

Figure 3. Remotely Sensed Image Acquired by Airborne 3D Imager

## 3. HIGH RESOLUTION MULT-SPECTRAL SATELLITE IMAGERY

High resolution multi-spectral satellite imagery includes IKONOS data (launched by USA, 1999, has 1m resolution panchromatic band and 4m resolution multi-spectral bands including blue, green, red and near infrared bands), QuickBird data (launched by USA, 2001, has 61 cm resolution panchromatic band and 2.44m resolution multi-spectral bands including blue, green, red and near infrared bands) and OrbView-3 data (to be launched by USA, has 1m resolution panchromatic band and 4m resolution multi-spectral bands including blue, green, red and near infrared bands) etc. Adopted data of the test area is the IKONOS imagery acquired on April, 2002.

## 4. LAND-USE CLASSIFICATION IN URBAN ENVIRONMENTS

### 4.1 Registration of the Datasets

In order to integrate the different data types, the first problem to be resolved is the registration of the datasets. In IKONOS imagery ortho-rectification, control points used are the laser imaging points acquired by *Airborne 3D Imager*, and DEM used is derived from DSM data acquired by *Airborne 3D Imager* and processed by the self-developed software package. Figure 4 shows the IKONOS ortho-image of the small test area.

Figure 4. IKONOS Ortho-image

### 4.2 Layered or Hierarchical Classification Approach

Layered or hierarchical classification approach is employed in this paper. The main interested land-use classes are buildings, streets, bare land, trees, grass-covered areas and water bodies. Firstly, segmenting the urban area into three parts. Then using the maximum-likelihood classification method to classify the segmented image parts separately. Multi-spectral information and vegetable index image are taken into account in this stage. Finally, combining the classification result of each part to form the integrated one. DSM data and shadow information are used in separating the urban area into three parts. The main purpose of the procedure is to control the classification accuracy in the next sub-classification.

**4.2.1 Segmentation of Urban Areas Using DSM Data:** DSM data is used to separate the urban area into two parts: above the terrain surface and at the terrain level. Water bodies, streets, bare land and grass-covered areas have the local height that are at terrain level, while buildings and trees have the local height that are above the terrain surface.

**4.2.2 Segmentation of Shadow Areas:** In order to eliminate the misclassification in shadow areas and increase the overall classification accuracy, shadows must be pre-processed separately. Because the pixels in shadow areas have completely different spectral reflecting characteristics than the ones in non-shadow areas, shadow areas should be extracted and classified separately. Each of the land-use classes for non-shadow areas has the corresponding class for shadow areas. After the classification, pixels for shadow and non-shadow areas of each land-use class can be combined again to obtain one unique class for each land-use type.

Shadow areas on an image can be segmented out by the selected threshold value from a panchromatic image band (Shettigara V K, Sumerling G M. (1998)), or acquired by classifying the fusion image of panchromatic band and multi-spectral image band (HE Guo-jin, CHEN Gang, HE Xiao-yun, et al. (2001)). Shadow areas can also be derived automatically based on the given DSM data as well as the elevation and azimuth of the sun at the time of image acquisition (N.Haala, V.Walter. (1999)).

**4.2.3 Maximum Likelihood Classification:** After the segmentation of the image to be classified, maximum likelihood classification method is applied in each part of the image segmentation. The blue, green, red and near infrared bands of IKONOS imagery are selected into the classification. The first principle component of the PCA process with the IKONOS four multi-spectral bands is selected into the classification as the feature image. Normalized vegetation index, computed by IKONOS red band and near infrared band also is imported into the classification in order to separate the vegetation objects from the non-vegetation objects.

$$NDVI = \left( \frac{4-3}{4+3} + 1 \right) \times 127 \tag{2}$$

Training areas are required in order to obtain the spectral characteristics of the different land-use classes. Training areas should be representative and avoided being digitized on the border of the different land-use types. Based on this information, the pixels are assigned to one of the predefined classes in the classification stage. After the classification of the three segmented parts, three classified results are integrated into one, which is the final classification result of the whole tested urban area.

**4.3 Analysis and Comparison of the Classified Results**

The basic idea of this classification method is to combine three-dimensional information together with multi-spectral information. In urban environments, streets, grass-covered areas, water bodies and bare land are objects with the height at the ground level and buildings and trees are the objects with the height over the ground level. With the integrated information provided by DSM acquired by Airborne 3D Imager and IKONOS multi-spectral imagery, the easily misclassified land-use types when only one data type is applied can now be discriminated. Figure 5 is the maximum likelihood classification result based on IKONOS imagery. Figure 6 is the maximum likelihood classification result based on IKONOS imagery and Airborne 3D Imager data. Figure 5 and Figure 6 demonstrate very well that in an urban environment the classification results has been considerably improved.


Figure 5. Classification Result Based on IKONOS Imagery


Figure 6. Classification Result Based on IKONOS Imagery and DSM Data

## 5. CONCLUSIONS

The direct applications of the urban area land-use classification is Urban Area Land Use Mapping and Urban Area Land Use Database Revision, it also has the diversified applications in urban planning & administration and disaster monitoring etc.

In this paper, height data acquired by Airborne 3D Imager is not only applied for geometric correction of the multi-spectral satellite image data by the generation of ortho-images, but also integrated in urban environment classification.

It is demonstrated that combining laser scanning data and high resolution multi-spectral satellite imagery data for automatic land-use classification in urban environments can fully complement the characteristics and fortes of different sensor data, and considerably enhance the classification accuracy compared with the one where only one type of data is applied.

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