# Reconstruction of Buildings from Satellite Image and LIDAR Data

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**Abstract:** Within the paper an approach for the automatic extraction and reconstruction of buildings in urban built-up areas base on fusion of high-resolution satellite image and LIDAR data is presented. The presented data fusion scheme is essentially motivated by the fact that image and range data are quite complementary. Raised urban objects are first segmented from the terrain surface in the LIDAR data by making use of the spectral signature derived from satellite image, afterwards building potential regions are initially detected in a hierarchical scheme. A novel 3D building reconstruction model is also presented based on the assumption that most buildings can be approximately decomposed into polyhedral patches. With the constraints of presented building model, 3D edges are used to generate the hypothesis and follow the verification processes and a subsequent logical processing of the primitive geometric patches leads to 3D reconstruction of buildings with good details of shape. The approach is applied on the test sites and shows a good performance, an evaluation is described as well in the paper.
**Keywords:** Buildings reconstruction, high-resolution satellite image, LIDAR, DSM, urban

## 1. Introduction

Modeling urban entities in geometric forms provides a fundamental platform for urban related studies. Traditional 2D map has been long one of popular and valuable urban models, but there are several inherent constraints which limit itself from widely using in this field, among them: it takes much resources and a long cycle for updating, field survey and aerial photography measurement are quite expensive and time consuming, meanwhile, the change in urban areas normally occurs very fast and frequently, for some near real time applications, updating changes in short cycle is normally required; Moreover 3D information can be not properly presented, even though the information of the third dimension could annotated on 2D maps, the truly and fully 3D representations of real-world objects are still not available. Moreover 3D information is quite significant for many applications such as urban safety analysis, urban microclimate and pollution control analysis, transportation navigation, landscape planning and visualization, telecommunication industry etc.

In comparison with field survey, deriving 2D or even 3D information from the photography is quite economic and fast way. Meanwhile remote sensing generally is the science of acquiring and analyzing information about objects or phenomena from a distance. From the early use of aerial photography, up to the later use of satellite imagery, remote sensing has been recognized as a quite valuable technology for environment study.

In last decade, the resolution of satellite imagery has reached from several kilometers to several dozen meters, and shown a really good performance in the study of large homogeneous area, i.e. land use classification, and geological structure derivation etc. Still with this level resolution, it is not sufficient yet for the local scale studies, which require relatively detailed information. However recently when more and more high-resolution satellite imageries have become widely available, the application of remote sensing technology for the acquisition of the details of urban, not only land use classification, is currently becoming an issue of increasing interest and high importance to both researchers and users from remote sensing, geo-information, urban planning, government administration, commercial companies, etc. This field is often referred as urban remote sensing as well.

Despite the optimistic potentiality it is a challenging yet extremely difficult task to automatically even semi-automatically extract objects in urban densely built-up environment solely based on image, this is not only because of the attributes of image, but also because of the high object density, occlusions and scene complexity in urban environment. In this research, we combine the high-resolution IKONOS satellite images and LIDAR data to extract buildings for the purpose of 3D city modeling based on such a fact that the characteristics of these two kinds of data source are quite complementary for 3D features extraction.

## 2. Reconstruction of Buildings

Generally, there are three steps in our scheme. They are urban objects segmentation, buildings detection and buildings reconstruction. The brief descriptions are given as below sections.

### 1) Urban Objects Segmentation

In our scheme, because the building is the focus of interests, the purpose of the first step is trying to separate raised objects from terrain, and to make a rough classification on raised objects. The task sounds simple, but is actually really tough and the results have significant influence on late processing. So far accurate urban terrain automatic detection still remains as a challenging topic. Our scheme starts with a rough classification by using spectral signature such as well-known NDVI derived from IKONOS multiple-spectral image to exclude most trees, and then height information taken from Digital Surface Model (DSM), which is directly generated from LIDAR data, is adopted to help for finding pixels on the ground. A ground trend surface can be constructed if sufficient ground pixels are found. By comparing with the ground trend surface, tall and raised objects which violate the ground trend very much are therefore excluded. Up to this stage, the objects with the high possibility of being non-terrain features have been "picked out", and then terrain surface can be detected with better accuracy by using well-recognized morphological operations, which is suffering with the difficulty of elimination of big size objects. Subtracting the terrain surface from the original DSM results in a representation of most objects rising from the terrain approximately put on a plane, and the slope influence of terrain has been removed, that is so-called normalized DSM (nDSM).

### 2) Buildings Detection

In order to combine IKONOS image and nDSM, they have to be co-registered. Because the ortho-image is rectified by using ground control points, this means objects have been ortho-rectified only at their footprint parts, tall objects appear still lean on the image, here is referred as "building lean" problem. The co-registration of image and nDSM becomes an issue of "restore lean buildings to straight". Based on the attributes and geometric relations of both IKONOS image and LIDAR data, buildings are then ortho-rectified using nDSM. After solving the building lean problem, the IKONOS image and normalized DSM have been actually co-registered.

Multiple clues are therefore derived from co-registered IKONOS and nDSM for building detection. A hierarchical scheme for detection of building potential regions from above coarse classification is presented as illustrated in Fig.1. The essential idea is to utilize complementary attributes of multiple clues for separating objects by emphasizing various characteristics at different stages. In our schemes, clues of height, size, spectral signature, and texture are hierarchically used as discrimination factors.

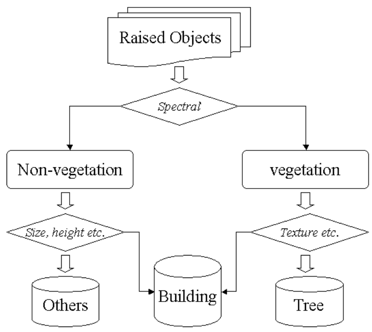


**Fig. 1. General scheme for building detection**

At this stage, buildings are detected as 2D regions, but no precise descriptions of 2D buildings are given, conversely, a "region relaxation" is made, this because detailed construction of 3D buildings will be conducted in the next step, description of 2D buildings naturally becomes available once 3D buildings geometric model are reconstructed. Fusion of image and height data plays a very important role in this processing.

### 3) Buildings Reconstruction

Building detection has given an explicit representation for buildings in terms of region and location. However, it is necessary to give an explicit semantic description on buildings, which is so called "building semantic model" in this paper. Our building semantic model considers several factors of buildings: size, shape, planes of surface, and structure. Therefore, for IKONOS image and ALS data, the building semantic descriptions is given as:

- With sufficient size for reliable recognition.
  Small size buildings could be missed or merged to big ones with neighbors.
- Rectilinear outline.
  Neighboring edges of buildings are straight lines and form orthogonal polygons, which could be concave and have holes.
- With multiple layers of roof patches structure. Information about walls is unable to be directly extracted. Complex structure of buildings is represented as composition of roof layers.

Correspondingly, "buildings parameterized model" as (equation 1) is defined according to building semantic model, and it is specially the geometric description about building. According to the buildings parameterized model, 3D roof patches reconstruction becomes the key for 3D building reconstruction.

$$3DBuilding = f_{model}(Location(Center(x,y), Size), Orientation,$$
$$\bigcup f_{layer}(Height, f_{roof\_patch}((x,y)_n))) \quad (1)$$

The presented 3D building model as illustrated in Fig. 2, can be considered as a constructive solid geometry (CSG) model, where the primitive actually is the rectilinear polyhedron.

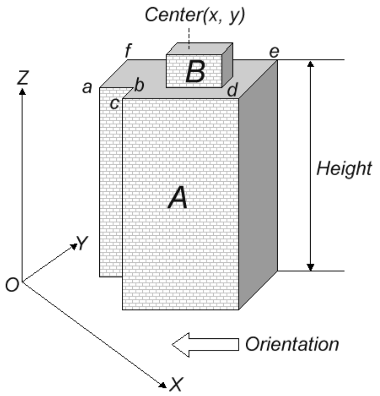


**Fig.2. Building parameterized model**

After clarify the building model based on the input data, our scheme starts with feature extraction, here interest is linear feature of lines. Edge detectors are used to detect edges from both image and nDSM in the detected building potential regions, and then straight lines are extracted by using Douglas straight-line fitting algorithm (Douglas and Peucker, 1973).

A method based on statistic analysis of straight lines direction histogram to determine building orientation is presented. And then straight lines are grouped into primary and secondary clusters according to their directions.

The scheme of 3D roof patches reconstruction as illustrated is typically formulated as a process of hypotheses generation and verification. On each layer, the hypotheses are initialized as rectangles covering the building potential region. Then the rectangle is further decomposed into small rectangles using the clues of primary and secondary straight lines. Verification is performed to each rectangle, and finally 3D roof patches are reconstructed by merging valid rectangles. 3D roof patches and their height form actually orthogonal polyhedrons, with these polyhedrons, the 3D building reconstruction becomes a simple issue of logical union operation applying to 3D building primitives.

# 3. Evaluation

Presented schemes have been conducted in several test sites. Meanwhile a qualitative and quantitative assessment about the presented 3D building extraction model is briefly conducted based on these experiments. For 2D assessment, by comparing with digital maps with our model, it shows that most buildings (about 85-87%) in urban densely built-up areas can be approximately reconstructed by applying our 3D rectilinear building model from IKONOS image and LIDAR data. Fig.3 shows an example of visualization of presented 3D buildings models

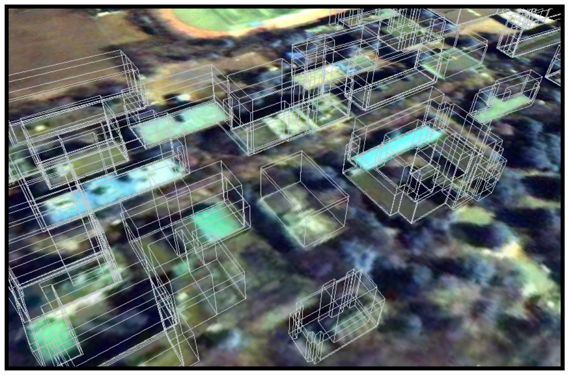

**Fig. 3. Simple visualization of 3D building models**

# 4. Conclusions

A novel 3D building extraction scheme has been presented in this paper. The scheme starts with the low-level pixel processing for feature segmentation and detection, and then exploits available knowledge about building appearances in the data sources to group detected features into organized primitive elements, finally extract 3D geometric description of building by using a recursive process of hypotheses generation and verification. And also conducted experiments demonstrate a promising performance for presented schemes.


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# References


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