

# AN INTERACTIVE TOOL FOR 3D OBJECT EXTRACTION USING AIRBORNE LASERSCANNING DATA AND ORTHOIMAGES

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## ABSTRACT:

Light Detection And Ranging (LiDAR) provides reliable and detailed 3D data of the earth surface. This data combined with digital Orthoimages can be used to create detailed 3D object models that are essential for a variety of applications such as city planning, disaster management, tourism or transmitter placement in telecommunications. Even though first software products for city modelling are available, the number of published procedures for automated or semi-automated object extraction is still quite low. This paper describes the development of a MATLAB tool for 3D object extraction, which uses LiDAR and Orthoimages simultaneously. Focussed on buildings 3D digitization of the object outlines and ridges is carried out manually. Orthogonality checks serve for better geometric quality. Part of the digitization process is the interactive selection of the roof type. By using topological and geometric conditions the roof models are reconstructed. In addition to buildings, other objects like roads can be taken into account by using or extending the MATLAB tool. For the experiments and for testing of the routines LiDAR and Orthoimages from a Stuttgart Center test data set are used.

## 1. INTRODUCTION

### 1.1 Motivations and Goals

The spectrum of application areas dealing with 3D city models such as urban planning, telecommunication, city planning, location based services, noise simulation, disaster management, tourism, security services, architecture and entertainment is increasing over the past few years so that the efficient generation of 3D models is an important task, both from a practical and from a scientific point of view. 3D city models have become an attractive product of Photogrammetry and Remote Sensing with the consequence that research and development for 3D object extraction is further stimulated.

Airborne LiDAR is currently the most prominent technology to collect reliable and detailed 3D data of the earth surface. Several studies have shown that laserscanning data has the potential to support 3D feature extraction, especially if combined with other types of data such as 2D GIS ground plans (Brenner and Haala, 1999; Weidner and Förstner, 1995).

Due to the rich information provided by an Orthoimage this data source is a preferred source, in particular, in 2D digitizing projects. An Orthoimage provides a good geometrical precision and is easy to use. Among users it is even a more popular data set than stereo images which allow capturing 3D models. In combination with LiDAR data Orthoimages can be used to extract 3D objects from LiDAR data.

Due to the complexity of natural scenes and the lack of performance of image understanding algorithms, there are only a few practically successful systems on the market that are dealing with automated object extraction (Mayer, 2004). A crucial point is that automated algorithms cannot guarantee stable results that are reliable enough for practical use (A. Gruen and X. Wang, 1999).

Therefore, in interactive approach that provides computational support for the user in order to generate 3D models using

LiDAR data and Orthoimages simultaneously is a quite attractive alternative. As a matter of course, such a tool for object extraction should be easy to use and modest regarding the required hardware. For this reason, a 3D object extraction tool called OET has been developed and implemented under MATLAB 7.1 with a Graphical User Interface (GUI) and visualization of the output in VRML. Focussed on buildings the object outlines are manually digitized by using the Orthoimage. In combination with height information from LiDAR the roof structure of selected roof types is semi automatically reconstructed. A 3D model of buildings and other objects like roads is created and visualized using VRML.

### 1.2 Related Works

Grün and Wang (1999) developed a semi-automatic tool called CC-Modeler (CyberCity Modeler) for building extraction. The concept for 3D modelling is based on 3D point clouds that have been measured manually using analytical plotters or photogrammetric stations with stereo viewing. Another successful semi-automatic system for building extraction is inJECT (Gülch et al., 1999). The system offers a set of building primitives covering the most frequent house and roof shapes. Multiple overlapping aerial images are analysed to generate the building models in a semi-automatic way. Elaksher, A.F. and Bethel J.S. (2002) and Tarsha-Kurdi F., et al., (2006) have investigated 3D building models using LiDAR data only. The use of additional data source can improve the extraction process. Several papers describe the advantages of using both laser data and other data source (Brenner, 2000), (Haala et al., 1998). Elberink, S.O. and Vosselman, G. (2006) have described the reconstruction of 3D topographic objects by fusing medium scale map data (2D) with the height data from LiDAR. This method was applied for the 3D reconstruction of a complex motorway.

### 1.3 Overview

The paper is organized as follows. The first section introduces the rationale of the project. Section outlines the data set used for the investigations. Section three presents the overall approach to extract 3D objects and gives details on the develop algorithm. Evaluation of the methods and results obtained with of the developed tool are shown and discussed in section four. The final section draws some conclusions and gives an outlook on future work.

## 2. DATA PROPERTIES

The primary two data sets used in this research are LiDAR data and color Orthoimages from Stuttgart center area. Two types of laser scanner data are available: Range based first and last pulses. The LiDAR data and images have been recorded by the TopScan GmbH as a contribution to the research project on "Automated Extraction of 3D Objects from Airborne LiDAR data". The recording has taken place on April 2006 by ALTM 2050 laser scanner with a measurement density of 4.8 per m<sup>2</sup> on the average. The images have been recorded simultaneously using the Rollei AIC-modular-LS digital metric camera with a 20cm ground resolution.

The LiDAR data is provided as a 3D dense point cloud data. In the context of this research application, LiDAR data are rasterized using elevation data as intensity value called LiDAR image or ALS image. By using the aerial colour photos and the LiDAR data the Orthoimage is generated which together with the LiDAR image are the main input sources for our object extraction tool (OET).

## 3. OBJECT EXTRACTION

To generate 3D objects from LiDAR data and Orthoimage involves three major components: manual data acquisition, roof reconstruction and model creation and visualization. Each of three processes is embedded in the same Graphical programming User Interface (GUI) with the different functionality. When collecting LiDAR point cloud data from the earth surface three dimensional data are record. In case of snow, some water area, the LiDAR systems do not guaranty to record elevation data for the area including with this problem. Therefore, LiDAR system records those areas with no elevation values. The original LiDAR data is normalized by removing the non height value from the data set before start object extraction. This is done by filling the area with elevation values using nearest neighbor interpolation in order to preserve sharp features by defining area around the non value area.

### 3.1 Data Acquisition

In OET, the object identification and measurement is implemented in manual mode, by screen digitizing on Orthoimage. During the data acquisition, two dimensional points belonging to a single object should be coded into two different types according to their functionality and structure: boundary points and interior points. Boundary points must be measured in a particular order, either clockwise or anticlockwise direction. Interior points can be measured in an arbitrary sequence. The measurement process begins using the Orthoimage. The digitization is activated subsequently to the operator by selection object type such as road or building with different roof type, in the menu or by the icon in the toolbar.

For that, OET offers a catalogue of object types, distinguished from each other through their geometry and shape. Currently this catalogue contains six categories of building types, and roads. This catalogue has been set up considering common roof types. The object is extracted by digitizing vertex points of selected object type. When the user accepts the digitize process, the coordinates referring to the current coordinates system of Orthoimage are calculated. Immediately after the coordinate calculation, coordinates are transformed to the LiDAR image to take the elevation data using transformation parameters and affine transformation.

The standard procedure to measure the object height is digitizing a ground point by moving the mouse cursor to a ground point in the vicinity.

### 3.2 Roof Reconstruction

The next step is to build the structure of the roof, i.e. to determine how many faces the roof has, which points define an exact face and the spatial relations of the faces. The concept of this process is based on a functionality related view of a roof. The points of the object are measured in an ordered fashion and separated into two groups called outline points (B) and interior points (I). The points of the object are considered as the nodes and each line of the object is considered as an edge between two nodes. The combination of the boundary points and interior points leads to the generation of roof faces. With a help of general geometric point of view of modeling a building, the following assumptions are considered in such a way that 3D building models are obtained:

1. All groups of eaves and ridges of a building have a same height.
2. Parallelism of straight edges of building.
3. Right angle of intersecting roof points.
4. If the line that connects two interior points (nodes) is perpendicular to the line connecting two adjacent boundary points, the roof patches should be defined by three points (triangle). If it is parallel, it should contain more than three points.
5. Every two adjacent B points are always part of the face.
6. Minimum distance: Each interior node should be assigned to the outer boundary node with a minimum distance.
7. Every interior (I) points are belongs to more than one face.

Due to the manual data acquisition, irregularities on the objects may occur. A geometric regularization is used to model the objects as close to their existing size and shape as possible. Under these constraints, it was considered to make straight lines parallel and perpendicular where they are actually not, or to have all points of a group: eaves and ridge points, at a same height.

After the geometric corrections, the construction of roof faces based on the B and I points is investigated. From basic constraint based reasoning techniques: every two adjacent boundary points are considered as a basic edge of the face and every two adjacent boundary points are always part of the face. Every two adjacent boundary points together with an interior point constructed a face. In addition, shorter distance between boundary point and interior point, are examined to define roof faces of building. Therefore, the distance between boundary

points and each ridge point is calculated that expresses the probability which interior point belongs to the outer boundary point (B). So the initial probability of  $B_i$  belongs to  $I_j$ , is determined according to the spatial distance from  $B_i$  to  $I_j$ . Finally, each element for each face set is determined.

### 3.3 Model Creation and Visualization

After having generated the roof faces, the three dimensional building models are created. The completed faces have to be combined to form a model. A vertical face corresponding to a wall is inserted for each edge (eaves) and defined a step edge

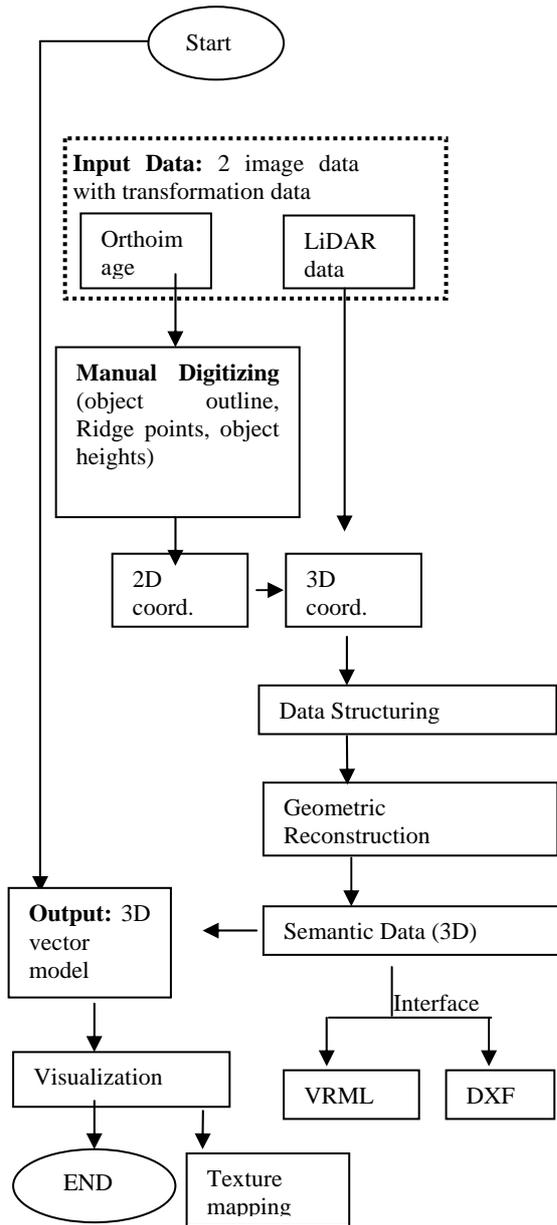


Figure 1. Main Program Flowchart

using the ground height which was unique value for each wall and extracted from the image digitizing. The vertical building walls extrude from the intersection of the roof polygons with the ground. All face sets/topology are grouped together to form

a building wire frame that is used to visualize a 3D model in VRML and MATLAB VRML viewer.

The appearance of the powerful tools for interactive visualization is one of the driving forces motivating the great efforts for 3D model. A proper representation of geometry and texture has to be provided for each building. Therefore, the texture mapping was integrated to make the virtual appearance more attractive. As Orthoimages are used for object extraction with the develop application, the texture for each building surface is already available as a by-product. In OET roofs are textured automatically using the Orthoimage.

The general methodology flow chart of all processing steps is shown in figure 1.

### 4. SOFTWARE DEVELOPMENT (OET)

Each process is embedded in the same graphical programming interface (GUI) with the different functionality. The general conceptual program structure (Figure 2) consists of six modules.

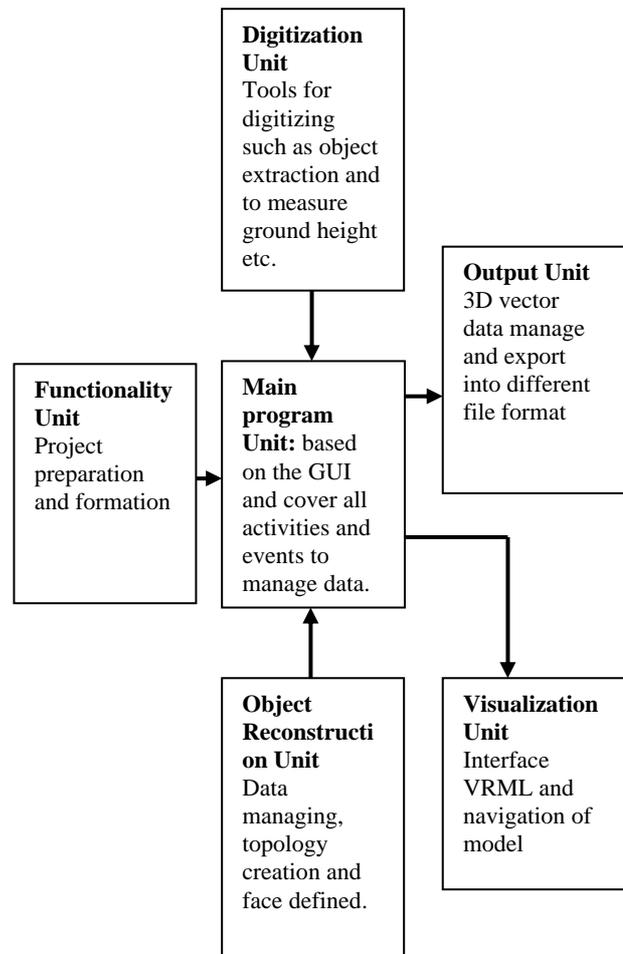


Figure 2. Program Structure

The main part of the program structure is the main program unit which used to manage all important program activities by exchanging of messages and data between all other units. It is also known as control unit of the program structure. It is

therefore control the communication between operator and the application. Further, it determines and examines the calculations part of the application and a series of working functionalities.

All dialogs essential for the project preparation and formations such as create new project, open existing project and save current project belong to the second unit of program structure, called functionality unit. The third unit called digitizing unit offers all functionalities required to digitization Orthoimage and LiDAR image simultaneously and cover different dialogs, measurement tools, different icon to manage digitizing, and functions for calculation. All functionalities demanded for data structuring, topology creation and face definition are accomplished in the fourth unit called object reconstruction unit. It generally comprises all calculation to realize the three dimensional models. Finally, visualization and output units offer capabilities to save and export data in different file formats and visualize generated 3D model in MATLAB VRML viewer.

The application is controlled by a main Graphical User Interface which is linked with other GUI to manage and share data. The main program unit is based on the GUI. The main user interface of OET consists of five windows (Figure 3). The two main windows display an Orthoimage and LiDAR image, the window in lower left is an overview window which includes Orthoimage and first and last pulse LiDAR images.

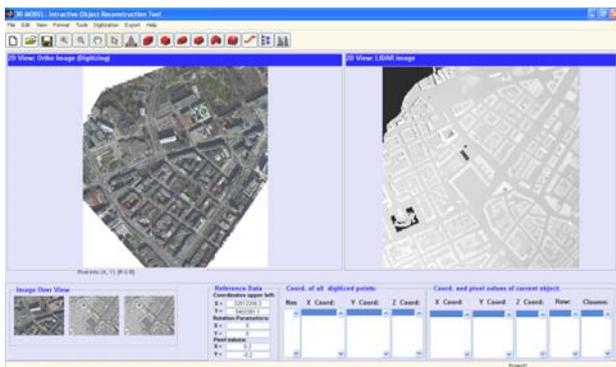


Figure 3. Graphical User Interface of OET

Beneath two data windows give details about transformation data of Orthoimage and, if objects are digitized, also the current object coordinates. The main menu and toolbars are located in the upper part of the GUI.

## 5. RESULTS

OET has been tested with the data of the Stuttgart center area. The whole area of available information covers about ten square km. However, the area around the Stuttgart University of Applied sciences has been used to test the developed tool. The pixel size of the LiDAR image and Orthoimage are 50cm and 20cm respectively, which is used only for the evaluation of the results.

Objects are manually digitized by operator with an experience of screen digitizing. This data forms the input for the object reconstruction with the methods that have been discussed in the previous section. The final extracted model is shown in Figure 4, with VRML including buildings and roads. For the enhanced visualization, the texture from the Orthoimage is draped over each object (Figure 5). Figure 6 shows a result that is

superimposed with the Orthoimage and DTM. Obviously, visual results are rather good. The main factor determining the performance is the degree of familiarity of the operator with the OET and user experience with screen digitizing. With an experienced operator, objects can ultimately be generated at an average rate of one minute per object.

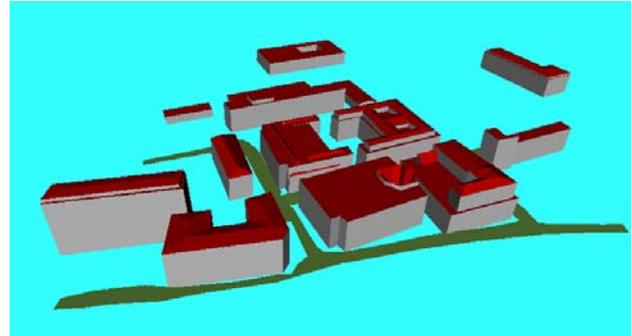


Figure 4. Stuttgart city around Applied Sciences University in VRML without roof textures

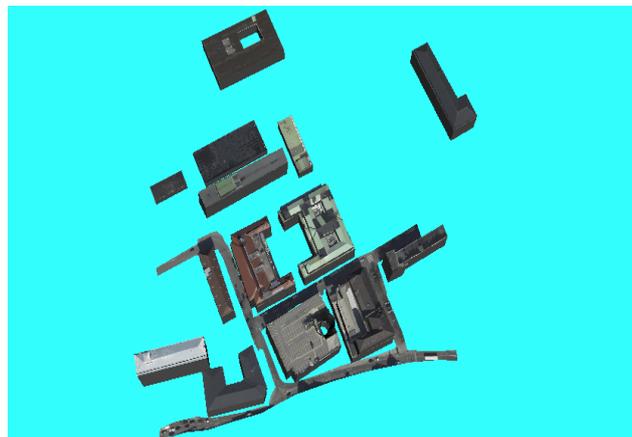


Figure 5. Stuttgart city around Applied Sciences University with roof texture



Figure 6. Stuttgart city around Applied Sciences University with roof texture is superimposed with Orthoimage and DTM

Our experience with the OET is overall positive, however, limitations do occur. These limitations are related to situations in which the roof is not included in the developed tool. In this experiment, trees and other objects are not considered due to the limited time available. This simple model also missed out

some details, such as chimney on the roof. In addition, the building has multiple heights although this can not be seen from the OET. As an example, shed type roof buildings failed with geometric shape of view as OET assumed that each eaves has same height. In some case, the digitized object in Orthoimage does not perfectly coincide with the LiDAR data due the quality of Orthoimages such as unclear borders in Orthoimage. The quality of delineating the building height can be enhanced by improving the quality of Orthoimage.

## 6. CONCLUSION AND OUTLOOK

We have presented an interactive tool that extract 3D objects form LiDAR data and Orthoimage. Interactive digitization uses LIDAR and Orthoimages simultaneously, the object outlines and ridges are extracted. The roof types are classified by the user during digitization. Several conditions related to the topology and geometry of the object model has been applied to reconstruct roof regions and a 3D model. The output is in VRML, DXF and ASCII format. The VRML output is directly supports the visualization of the extracted objects. The tool is fast and flexible. The approach requires accurate outlines and inside points (example ridge points) of the object which are digitized manually on Orthoimage, a building model catalogue, and the ability and experience of the user with OET and screen digitizing. With this tool, operator can extract up to two hundred objects per day, or even more, depending on the ability and experience of the user. The geometric accuracy in horizontal and vertical are generally positive. However, the geometric accuracy in elevation can be increased by improving quality of the Orthoimages.

In near future, it will focus to extend the model catalogue for other objects. To determine the appropriate height of the objects especially for building height, DTM can be taken into account so that will give the heights for each bottom points of eaves correctly. Also, to investigate the possibility for the use of existing data such as ground plan in an objective way needs to be studied in the future. This gives the opportunity in future to extract 3D objects automatically from LiDAR data.

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