3-D Spatial Objects Modeling and Visualization Based on Laser Range Data

Jie Du[1], Apisit Eiumnoh[1], Xiaoyong Chen[2], Fumio Yamazaki[2] and Michiro Kusanagi[2]

[1]Natural Resources Management, School of Environment, Resources and Development,
[2]Space Technology Application and Research Program,
Asian Institute of Technology,
P.O. Box 4, Klong Lung, Pathumthani, 12120, Thailand

Abstract

Laser technology has been brought into photogrammetry and cartography fields as a tool for mapping. The main application of laser scanning systems are concerned with large-scale and precise topographic Digital Elevation Models (DEMs). The main research problem are: automatically interpreting range images for extracting geo-spatial features and the reconstruction of geo-objects. The objective of this paper is to develop the algorithms and methods for the modeling and visualization of 3-D spatial data on a large scale, based on processing laser-scanning data. A set of algorithms should be developed for processing airborne laser range data. Those algorithms are mainly include: TIN (Triangulated Irregular Network) based range image interpolation, MM (Mathematical Morphology) based range image filtering, features extraction and range image segmentation, feature generalization and optimization, 3-D objects reconstruction and modeling, CG (Computer Graphic) based visualization and animation of virtual environment.

I. INTRODUCTION

Over the past few years, the need for describing larger-scale 3-D spatial data has continually increased. These data are used for variety of applications such as region planning, architecture, archaeology, disaster prevention, microclimate investigations or transmitter placement in telecommunications. Many kinds of raster and vector based models for describing, modeling, and visualizing 3-D spatial data on a large scale, have been developed. With the development of laser technology and sensor techniques, several types of airborne laser scanners are available for the acquisition of high accuracy 3-D spatial data in real or very fast time. The main application of laser scanning systems concerns large-scale and precise topographic DEMs and DSM, especially in areas that are difficult for conventional photogrammetry. For example, forest areas of total or scattered coverage. Other interesting applications concern coastal areas, wetland, beaches, dunes etc.

The purpose of this research effort is to study and develop algorithms and methods for modeling 3-D spatial objects based on airborne laser range data. For processing airborne laser range data, an appropriate set of algorithms should be developed. These algorithms are mainly include TIN based range image interpolation, MM based range image filtering, features extraction and range image segmentation, feature generalization and optimization, 3-D object reconstruction and modeling, CG based visualization and animation of virtual environment. In this research, laser-scanning data of Kyoto Station area is used to simulate 3-D reconstruction results.

II. METHODOLOGY

Airborne laser scanners are used for area coverage, for instance, by the oscillating deflection of a laser beam perpendicular to the flight direction. The instant angle of deflection has to be known precisely, as a basic geometric principle is used for providing position, direction and length of the vector to the ground point, for each shot. An essential feature of laser scanning is the potential for almost complete automation, the GPS, INS and laser data are digitally recorded. After GPS processing and the necessary system calibration for the computation of the terrain points, the interpolation of a DEM and the block formation of the DEM is quite straightforward, as far as open terrain is concerned. It includes the following main problems:

- Pre-processing for inputting airborne laser range data
- Semi-automated extraction of 3-D spatial features
- Methods for 3-D-visual modeling
- Generation of virtual reality environments
- Editing & checking methods

III. PROCEDURE

In this paper, laser-scanning systems on the ground will be used. In order to map the details of objects, fundamental surveying is brought to data-collected processes in terms of data acquisition. After storage in the proper format, data should be filtered in order to reduce any error accumulated during the collecting processes (Baltsavias, 1999). Scene Modeling is the next step to create 3-D model, after pass filtering.

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Triangulation, segmentation and extraction are also involved in the Scene Modeling process in terms of mathematical algorithms (Ackermann, 1999). Then all data should be combined based on combination modeling established for this purpose. The combination process, consisting of algorithms to be used for merging different kinds of data, is applied to this process. GIS attribute data, aerial photographs, existing maps and laser data are the primary data to be combined. The results of this work can be shown by 3-D modeling as visualization that can let the user to walk through the visual spatial data. Applications for this modeling can be applied to several types of work.

Our goal is to reconstruct large-scale 3-D spatial objects by using the laser range images (airborne or on the ground) and existing maps or image. The Principe is shown in Figure 1 and Figure 2. Laser range images can be considered as a kind of high-resolution digital terrain models (DTMs) or digital surface models (DSMs). The reconstruction of 3-D objects from laser range images can be simply thought as the 3-D raster-vector conversions from a noise DTM to parametric CAD formatted 3-D vector data. Due to the limited resolutions and noise, the existed low lever processing methods for reconstruction of 3-D objects from laser range images generally cannot fit to real application needs. Urban planning maps serve as a set of well-organized high-lever data sources, which can be interpreted and generalized for subsequent 3-D object reconstruction and recognition. The algorithm and the major steps of 3-D reconstruction used in this study are shown below and in Figure 3.

- Pre-Processing
- Laser range image filtering and segmentation;
- Extraction of 3-D spatial objects
- Reconstruction of 3-D objects as a 3-D GIS needed format.
- Visual Texture mapping
- Generation of VR environments

Laser range data imputing and pre-processing

In the first step, the raw data recorded by the laser ranger needs to be translated to a file format that SoftImage|3-D can read. Generally, there are two ways to translate this data. The first way is to generate a SoftImage|3-D graphic file directly. The second way is to translate a DXF file (generated by MicroStation or AUTO-CAD) into a SoftImage|3-D file. Both of these methods for inputting laser range data are useful for different laser range hardware. have tried these two methods for imputing laser range data and it will be useful for different laser range hardware (such as airborne or ground-type machines). Another important issue is the conversion of raw data from their local coordinate systems to global ones. The processing can be realized by making C program for 3-D coordinate transformation based on a set of provided parameters.

MM filtering and 3-D object segmentation

For the purposes of range image filtering and related object segmentation, Mathematical Morphology (MM) based approaches are used (Haralick et.al, 1987; chem., 1991). Generally, MM operators (such as dilation, erosion, opening, closing, hit or miss, thinning...) can be described as a combination of shift and logic operations. Shifting operations are controlled by the given Structuring Elements (SEs) whose size, shape and orientation can be changed by different applications. Different MM operators organize different logic operations for different purposes.

MM filtering is one of the most successful tools used for MM applications. For range image processing, the opening filter was used to remove dirty voxels and small-connected volumes. The closing filter was also used to fill small holes within surfaces and to link short gaps among objects. Here, the key problem is how to select suitable SEs. The spatial features in range images are very dense in most cases, and the direction-oriented SEs are suitable for many applications. How to select the parameters and algorithms for segmentation processing is highly dependent on different applications. Generally, before the real processing of whole large images several, typical, small testing areas can be processed to find the suitable parameters and optimal processing procedures. Also, simple knowledge bases can be generated based on these selected parameters and procedures which can be used for other range image processing.

3-D object segmentation is also based on open processing. In this case, the size of SEs should be a little larger than the segmented objects; the shape of SEs can be a simple convex object, such as a cubic box in 3-D space or a rectangular area

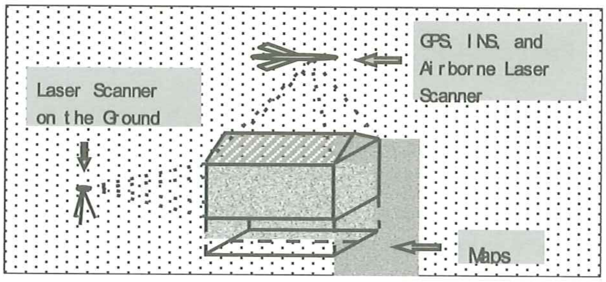

Figure 1. Integration of laser range images and existing maps

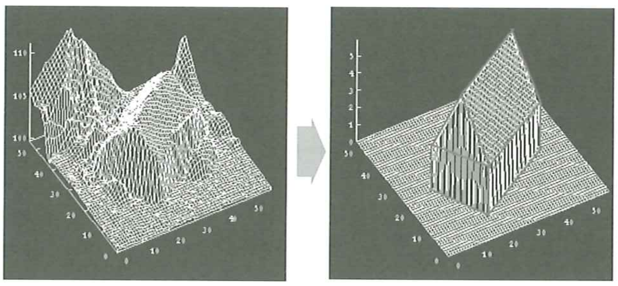

Figure 2. 3-D object reconstruction based on laser range images

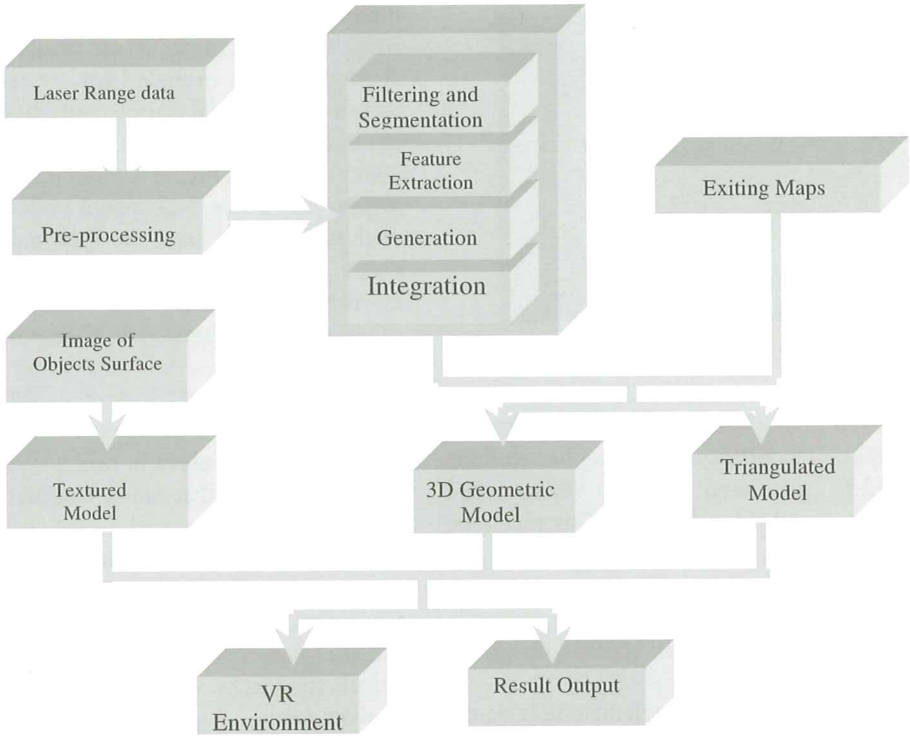

Figure 3. The basic procedure of this research

in a 2-D horizontal plane. The basic idea of MM based object segmentation: firstly, filtering all the parts smaller than the given SEs; then, segmenting the objects by logic difference operations between the original 3-D data set and the filtered 3-D data set. Since MM based filtering with a small SE in the first step of processing will damage the detail object features, a feature recovering step should be added during the object segment procedure. Feature-recovering algorithms are based on conditional dilation operations, in which the segmented object parts serve as the dilation seeds and the original 3-D data set serves as the masking field for limiting dilated ranges. Weidner and Foerstner (1995) have also used similar MM based methods for filtering and the segmentation of 3-D spatial objects from small-scale DSMs.

In large-scale laser range image processing, it is preferred to add the feature recovering procedures during the segmentation of spatial objects for protecting the detail object structures. When using the 2D map data for range image processing, a feature protected filtering based on the conditional masking volumes generated by the 2-D boundary lines of building or roads also can be realized. Figure 4 shows a simple procedure of MM filtering and object segmentation. Figure 5 and Figure 6 are MM Filtering and H result Filtering result of Kyoto elec-rail way station area.

Semi-automated feature extraction

Based on the extracted ground truth data from 2-D existing maps/images, we can Parametric or prismatic building and road models with the unknown heights can be get herated initially. Using this method, small detail object features, such as the roof structures of buildings by using vectored feature lines. Then, next height parameters of generated spatial objects

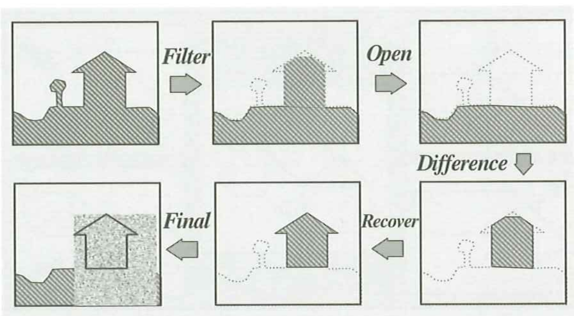

Figure 4. 3-D MM filtering and object segmentation in 3-D space

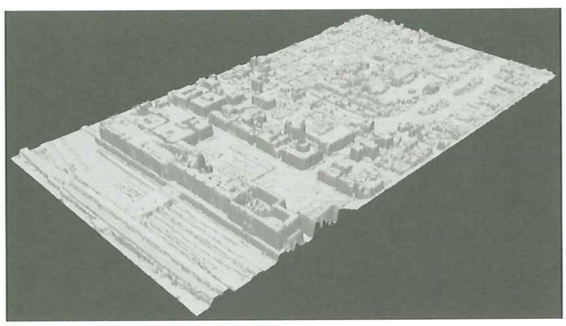

Figure 5. MM Filtering

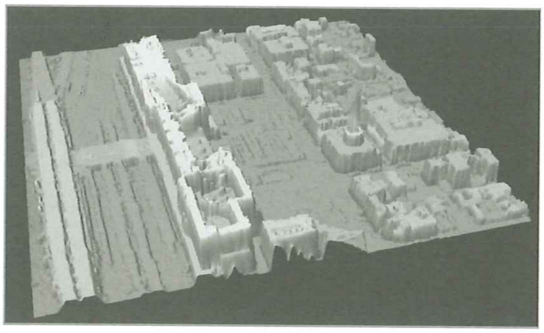

Figure 6. H filtering result

based on the processed laser range images can estimated, which can be vieued as a model based matching between the pre-interpreted models (generated from 2D vectors) and objected data sets (processed range images). This matching operation produces four kinds of results:

(1). A pre-interpreted model matched an object with almost same height;

(2). A pre-interpreted model matched an object with almost different heights;

(3). A pre-interpreted model can not match the object on the given range image;

(4). An object on the given range image cannot match the pre-interpreted object on the map.

In the first case, the matching result means that the object is a prismatic object and we can estimate the object height by using the average or maximum height value within the matching region. In the second case, the match result means the object may have complicated structures. If we know some additional detail object features from vector maps, we can estimate these parameters by using the height values within the matching region. The last two cases of matching results mean that the object changes have been detected, in the first case this means the old object has been deleted, and in the last case this means that a new object has been created. Solving the change detected problems in the system requiressemi-automated editing, i.e. the computer automatically searches for changed places and operators modify these places manually. Figure 7 shows a basic matching procedure between map models and range image objects.

If airborne laser range images and ground laser range images with different view points are available, the above presented methods can be extended for the reconstruction of highly accurate 3-D spatial objects with their detailed features. The basic idea is to extract different DSMs from different view points as show in Figure 8. After that, DSMs can be integrated to generate whole 3-D spatial objects by using data fusion methods. In this case, the information obtained from 2-D vector maps can partially serve as a useful data source for estimating vertical surfaces. Surface interpolation algorithms can be extended and used for generating invisible object parts.

3-D visual modeling

There are several areas in urban systems, relating to design and management, that can be considerably improved with the help of 2-D or 3-D visual modeling. Among these areas are traditional mapping, infrastructure design, urban planning and environment. Since there is no clearly defined terminology for various types of 3-D city models, A 3-D city model can be called a special computer representation of all fixed 3-D spatial objects (buildings, vegetation, traffic- and waterways) within a urban area.

For different purposes and applications, such as GIS related 3-D spatial management and analyzing, simulation and visualization of urban planning, and building design and construction, there are several kinds of 3-D city models existing now. For these models, the 3-D spatial objects in urban areas are described as different detail of structures. Ranzinger and Gleixner (1996) summarized four kinds of 3-D city models for simulation and visualization. 3-D spatial objects are called prismatic models, in which a building is represented as a cubic box with fixed parameters or as an object with a plain polygon adding the same height. The 3-D spatial objects are called the parametric models, in which a building is represented with its roof structures. The other two types of 3-D spatial objects show a complicated 3-D object with an added surface with 2-D or 3-D image textures.

The objective generate a complex 3-D object with added surface 2D image textures from air photos. By using the SoftImage|3-D system, 3-D spatial objects based on extracted

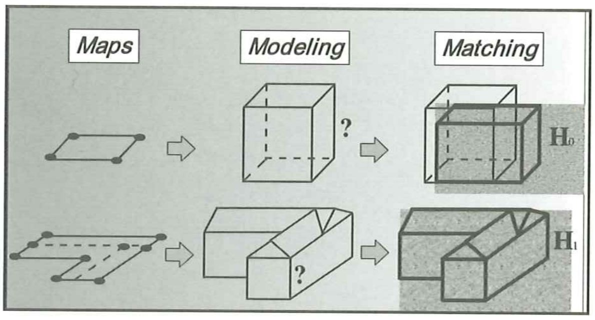

Figure 7. Matching between models and range image objects

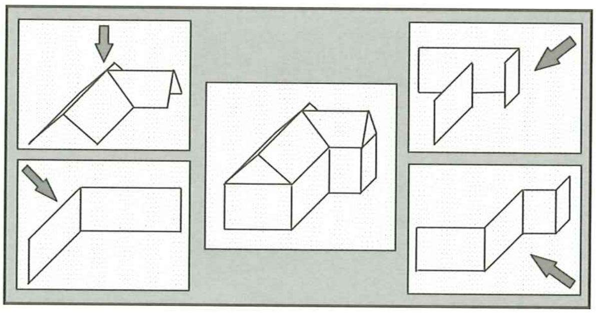

Figure 8. Object reconstruction by using a laser range

spatial lines and surfaces can be generated. The following kinds of 3-D objects have been used for 3-D city modeling for this system:

- Polygon Mesh object: using for modeling grid DTM or surfaces;
- NURBS curves: using for modeling line objects;
- Patch and NURBS surface: using for modeling smoothing un-form surface objects;
- 3-D TIN objects: using for modeling un-form surface objects;
- Boolean object: using for modeling and generating complicated objects.

Generation of virtual reality environments

One of main tasks for generating a Virtual Reality (VR) environment is to put real image textures on generated 3-D spatial objects.

In order to use images as a textures for surfaces, objects can be photographed in several parts and after then be merged on surfaces (Dorffner, L.; Forkert, G., 1998). However, the photographs, 2D texture-map, represented the objects might be mathematically transformed to the orthophoto, differential rectification because the projection of photographs represent in central projection (Zhizhuo, 1990). At the other points within a segment, there are still exist distortions due to relief displacements, and in the case of the indirect projection mode, distortions due to tilt displacements also exist. If these displacements uncorrected, they will give rise to errors and hence affect the quality of the orthophoto (Gruen, 1999).

To generate computer models that are visually realistic, texture is applied to the reconstructed surfaces to make the models appear rich and complex. This is achieved by texturing the 3-D triangulated surfaces from a laser scan with an appearance camera. Segments of 3-D scene structures may appear in several different images. This may be caused, for example, by overlapping an image mosaic generated by a camera, or images taken from radically different views. There is also the case where the camera has zoomed to get very high-resolution data for a particularly important scene feature.

The availability of multiple texture sources for a single triangle necessitates additional consideration. To decide which texture source to use, we make use of the label map, obtained during hidden texture removal to provide the number of pixels in the a corresponding image that can be used to texture a map at any given model triangle. All that is required is to sum the number of instances of the triangles in the label map. This is done for each triangle in every image which and the image contributes the largest number of pixels is used as the texture source, So all triangles sharing a common texture source are grouped together.

This work was performed using a Softimagel3-D system. The summary of the main procedure is shown as follows (The result are shown in Figure9):

- Surface segmentation for 2D texture mapping;
- Generation of texture images by 2D affined transformation;
- Imputing texture images into Softimagel3-D (TIFF to PIC);
- Object oriented texture mapping based on Softimagel3-D;
- Defining parameters for animation (color, camera, light, material and so on);
- Visualization 3-D virtual environments based on Softimagel3-D;
- Output 3-D results from Softimagel3-D to TIFF images;

Spatial object editing

After generation of 3-D visual models or VR environments, the results should be checked using existing air photos and maps. This task was completed using the 3-D editing exiting air photos of maps. The task was finished base on the 3-D editing environment of Softimagel3-D system. A procedure should be developed for sequentially highlighting 3-D objects on a 2-D base map and image environment. The checking is semi automatically done by an operator' s mouse interaction. If a problem is found, the object can be locked and modified using different 3-D editing tools.

Problems and future application plan

According to the research results, The following problems suggest possible research in the future:

1). The accuracy and density of laser range data
- The distance between random points is too far;
- Some sites have no 3-D data;
- The accuracy is lower for extraction buildings with high densities;

2). Improving the accuracy of object structures
- Improving the accuracy of object structures by using 3-D data from multi-sources (mobile mapping, laser range data from ground stations)
- Automated 3-D feature extraction based on knowledge

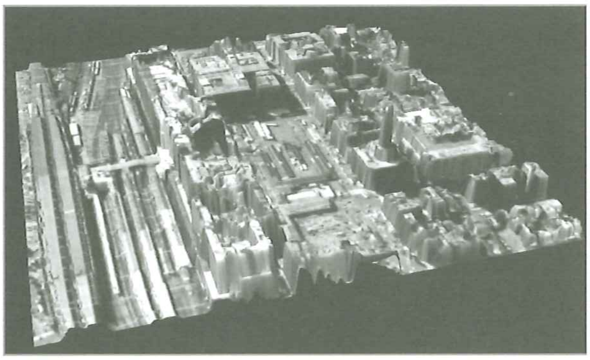

Figure 9. Texture mapping result of Kyoto rail way station area

bases and existing GIS

3). Improving the accuracy of texture images

- Getting the orientation parameters by using digital photogrammetry system
- Generation of ortho-photos for accurately texture mapping

Application plan

Our future works can be summarized as follows:

1) Multi-sensor integration

- Airborne laser range data processing
- Ground laser range data processing
- Mobile mapping data processing
- Integration

2) Improvement of digital photogrammetry system for structure feature extraction

- Automated extraction of roads and buildings based on DSM and laser range data
- Automated extraction of roads and buildings based on existing GIS
- 3-D environment for editing 3-D spatial objects

3). 3-D GIS and virtual environments

- Generation of 3-D spatial information systems
- Generation of virtual environments for visualization and simulation
- Different applications

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