DESIGNING OF WAVELET-BASED PROCESSING SYSTEM FOR AIRBORNE LASER SCANNER SEGMENTATION

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ABSTRACT:

Recent years, laser scanner has raised the consideration in mapping of the Earth thanks to its fast acquisition and high accuracy. However, in order to utilize this kind of data, a tough task is required to be accomplished. This is segmentation of the laser cloud points and it is also the objective of this paper with the concentration in urban area. Especially, the designed system utilizes the scale property in processing. The core of the processing system is a wavelet-based algorithm, which can detect edge of object depending on scale and as a result, the objects with different sizes are distinguished. Afterwards, perceptual grouping, which is based on proximity, elevation and object boundary, is applied on laser cloud point to finalize the segmentation. This paper concentrates in the designing stage of system development. The work is carrying on with system implementation and evaluation, which will be presented in the later papers.

1. INTRODUCTION

Airborne laser scanner has been introduced and utilized as a high accurate tool for topographic mapping. There have been several attempts in both research and application to utilize this useful tool. However, the algorithm for segmentation of this kind of data, i.e. distinguish between ground surface and objects on the surface, is still on going researched. Due to the complex of Earth surface structure, which affects on acquired laser cloud points, most of proposed algorithms, either geometric or probabilistic, are application oriented and include fusion with other data set. Several developed algorithms can be listed as (Haala et al. 1998) derived parameters for 3-D CAD models of basic building primitives by least-squares adjustment minimizing the distance between a laser scanning digital surface model and corresponding points on a building primitive; (Axelsson, 1999) introduced the classification algorithm based on the Minimum Description Length criterion; (Maas and Vosselman, 1999) proposed two algorithms for extracting building from raw laser data; (Haala et al. 1999) integrated multi-spectral imagery and laser scanner data to extract buildings and trees in urban environment. On the other hand, the developed algorithms can be categorized into two types, i.e. with or without interpolation of the cloud point into regular grid. While the algorithm with interpolation into regular grid can be observed in most developed algorithms, the algorithm applying directly to cloud points has appeared in less number of research such as (Sithole, 2001 and Roggero, 2001). In order to utilize the advantages of both approaches, this research is aim to combine both results from segmentation of grid and cloud points.

Furthermore, in this research, the first time the scale property of object is introduced in airborne laser scanner segmentation. As been known, an important property of any object in the world is that it exists as a meaningful entity in the certain ranges of scale. Therefore, object appears in different ways depending on the scales of observation. Wavelet has been developed by many scientists from different fields in last fifteen years. The fundamental idea of wavelet is to analyze the signal according to scale or resolution. In this paper, before describing of the design system, a brief overview of wavelet and its application in image processing will be given.

This research concentrates in segmentation laser points acquired over urban area, which is a very complicated scene with man-made objects, trees and moving small objects such as cars, van, etc. Furthermore, the segmentation of cloud points mainly depends on the local elevation difference in the neighbor of laser point, which becomes very difficult in modern city. Based on a scale space processing, objects with different sizes can be distinguished and selected so that the man-made objects like building and highway is intended to be detected first by this wavelet-based method. Afterwards, the points belong to trees and others can be detected based on local elevation difference. The remained paragraphs are started with overview of wavelet and then followed by the description of system designing. Several preliminary testing results also presented to illustrate the system. Lastly, some recommendations are pointed out for the further implementation of the system.

2. WAVELET AND ITS APPLICATION IN IMAGE PROCESSING

Originate from the idea in early 20th century, wavelet has been attractive with the solid built mathematical background in 1980's by the researchers and engineers of different fields. Therefore, the description of wavelet is also diverse. Because of the application of wavelet in image processing, this paper only presents a brief overview of wavelet in image processing, especially in feature extraction from image. In image processing, for recent decades, several researches have illustrated the capability of wavelet analysis in de-noising, feature extraction and compression. The common point of these applications is that the implementation is based on multiresolution analysis that was introduced by Mallat, 1989 and is described in the following paragraph.

A multiresolution analysis was defined by a scaling function Φ and a sequence of closed subspaces $\{V_j \mid j \in Z\}$, which approximate the space $L^2(R)$ of R-periodic square-integrable functions, with the following properties:

1) $V_j \subset V_{j+1}$ ($j \in Z$)
2) $\cup_{j \in Z} V_j$ is dense in $L^2(R)$
3) $\cap_{j \in Z} V_j = \{0\}$
4) $f(x) \in V_j \Leftrightarrow f(2^{-j}x) \in V_0$
5) the collection $\{\Phi(x-k) \mid k \in Z\}$ is an orthonormal basis of V_0; an orthonormal basis has the norm normalized to one.

Therefore, an orthonormal basis of V_j is the family obtained by dilations and translations of Φ

$$\Phi_{j,k} = 2^{j/2}\Phi(2^j x - k), \qquad (j, k \in Z) \tag{1}$$

We also have

$$\Phi(x) = \sum_{k \in Z} p_k \Phi(2x - k) \tag{2}$$

Similarly, if we define

$$\Psi(x) = \sum_{k \in Z} q_k \Phi(2x - k) \qquad \text{where } q_k = (-1)^k p_{1-k} \tag{3}$$

the family

$$\Psi_{j,k} = 2^{j/2}\Psi(2^j x - k), \qquad (j, k \in Z) \tag{4}$$

is an orthonormal basis of W_j, which is orthocomplement of V_j in V_{j+1}.

Selecting the appropriate scaling function Φ, with the subspaces V_j, the corresponding orthonormal wavelet Ψ can be constructed. That is multiresolution analysis. It is noted that multiscale and multiresolution terminologies are synonyms with wavelet.

However, in this paper, the redundant *a trous* algorithm, which is carried out without subsampling, is used instead of standard discrete wavelet transform (SDWT). The reason is that the main purpose of feature extraction requires the translation invariant, which cannot be achieved with SDWT. Furthermore, here is not necessary to reconstruct the signal so that the orthogonal transform is not required. The details of this algorithm are referred to (Mallat, 1999) book. Briefly, the algorithm includes the smoothing of image by scaling function. As a result, several smooth versions of image are obtained. Then, the wavelet coefficients are obtained directly from the difference of successive smooth versions. The fast and simple implementation of this algorithm with B3 spline wavelet function was presented in (Starck and Murtagh, 1994). This implementation is used in this research and implemented in IDL. The detail of wavelet implementation is presented in system designing part below.

3. SYSTEM DESIGNING

System designing was started with the study phase about the existence of problem, i.e. segmentation of airborne laser scanner, which needs the development of a new system or an improved system. Several facts, which were found and summarized in the introduction part, concluded that it is necessary to utilize scale property in airborne laser scanner segmentation. The system proposed is illustrated in Figure 1. It is a computer-based system and performs the tasks only after flying survey. The system performs tasks with laser point data set and results a 3D GIS database including database of building, Digital Terrain Model and road network. The system is proposed to develop in IDL and Arcview environment.

There are 3 sub-systems or modules (see Figure 1) in proposed system, i.e. interpolation, parallel processing and 3D GIS generation.

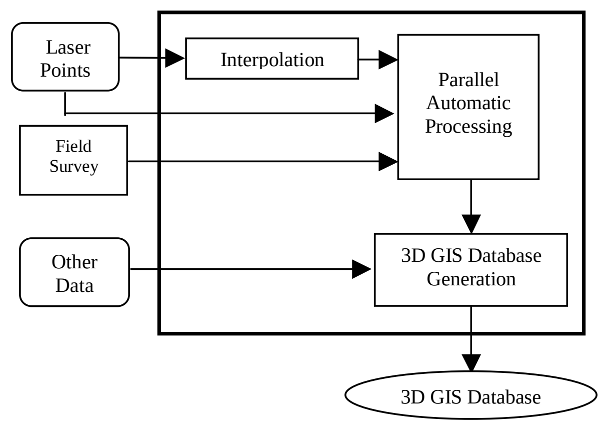

Figure 1. System diagram

3.1. Interpolation

The input of this module is laser point with three coordinates X, Y and Z. The output will be an elevation image. Several methods of interpolation were tested along with searching of references and the method of planar interpolation on TIN was selected due to its higher accuracy (Behan 2000). The details of description of this module is as follow

- Input: text file (X, Y and Z coordination of laser point)
- Output: Elevation image
- Processing: automatically with file name input by operator.

Due to the missed points at the edge, to acquire more accurate scene, some manual editing works should be done after interpolation. The editing is a simple masking of exact boundary of scene. The output of interpolation module also includes the adjacent list of laser points and the image coordination of laser points. Both of these results are stored in text files and will be used in perceptual grouping later. The Figure 2 below illustrates an elevation image obtained by this interpolation method.

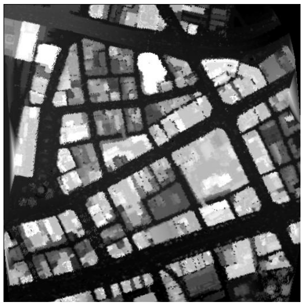

Figure 2 Elevation image of Shinjuku, Tokyo, Japan
Size 512x512 – 1 meter resolution

3.2 Parallel processing

The reason for such a parallel processing is the requirement of $2^n x 2^n$ size of input image in wavelet analysis. Therefore, to adapt this requirement and utilize it for speeding up processing, a parallel processing is proposed. Figure 3 illustrates in details the components including in parallel processing. The description of each component is presented following this figure.

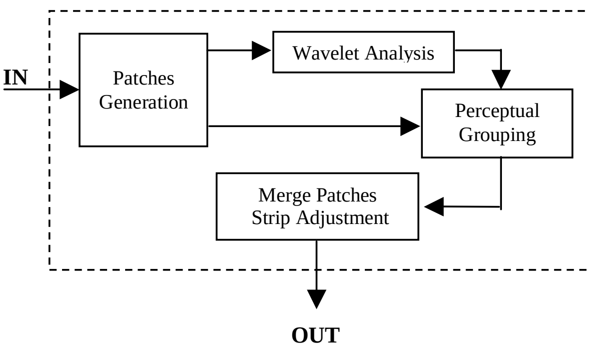

Figure 3. Components of Parallel Processing module

3.2.1 Patches generation

- Input: elevation image
- Output: several elevation images with size 512x512
- Processing: manually

The size of 512x512 was selected based on two factors: time computation and reasonable size of analyzed images. As been known, wavelet analysis is very time consuming and when the size of image analyzed becomes bigger, the computation time will increase dramatically. Therefore, the size of image analyzed should not so big. The size of 256x256 and less than it are too small. Another reason is that not all of laser strip width is greater than 1024. The boundary of elevation image patches are used as mask to divide the point set to the same patches. This processing is also manual. Then, several patches will be sent to different computers in the network to be processed independently.

3.2.2 Wavelet analysis

The analysis is followed the method illustrated in the overview part of wavelet. The implementation of wavelet leads to simple convolution of image with mask 5x5 below iteratively with the number of iteration decided by the users.

$$\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix} \tag{5}$$

While the smooth versions of image show the cluster of points depending on the object distribution, the difference of two successive smooth versions give the information of the edges of objects. Therefore, a detector is developed after wavelet analysis to obtain the edge of objects. Figure 4 below illustrates the testing results of wavelet analysis of a scene 256x256.

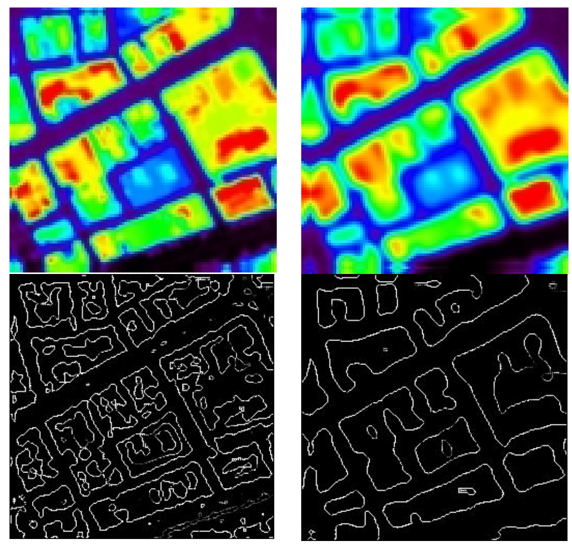

Figure 4 Smooth images (above) and Detected edge images (below) at two successive scales

Figure 4 illustrates clearly the possibility to distinguish objects at different scales. Afterwards, the edge pixels are linked to obtain the closed boundary of objects. Further, the objects are filled depending on their boundary value. Summary, the input and output of this module are as follows.

- Input: elevation image
- Output: edge images and detected object images in different scales.
- Processing: automatically

3.2.3 Perceptual Grouping

There are three criteria that are used in perceptual grouping, i.e. proximity, object boundary location and elevation. Firstly, object boundary detected from above is used to group the points that belong to these objects. This step is mainly used to obtain the building and some structures like highway, which can appear with boundary in wavelet analysis. Secondly, the remained set of point after removing the points of structures mentioned above is classified based on two criteria, i.e. proximity and elevation. Because the trees or other objects might be obtained from laser hit like cars are small generally, their points can be distinguished from the neighbors surrounding at some extent. This method is hardly successful with the object like building and highway. That is the reason why the wavelet-based detection was proposed. The threshold of elevation is provided to classify the points from the neighbors. Therefore, two text files obtained from the first module, i.e. interpolation, are required here. The first one is adjacent list of laser point, which helps the segmentation by investigating the neighbors and the second one is the pixel coordinate of laser points, which is used to group the points belonging to building and highway.

- Input: detected object image from wavelet at different scales, text files contained adjacent list and pixel coordinates of points
- Output: detected objects, classified object points, ground points
- Processing: interactively

3.2.4 Merge Patches and Strip Adjustment

The result of extraction above from different patches is merged together. The task here is performed with the aid of field survey data, i.e. GPS data. Furthermore, the GPS data is also used to evaluate results later. If the study area is large so that it covers not only one strip of flying, the task in this module also concerns with the adjustment of different strips to match each other.

- Input: GPS survey data, elevation images, vector files of extraction results
- Output: Adjusted and merged elevation images and vector files
- Processing: manually

3.3. 3D GIS database generation

After extraction, there are three different layers imported into ArcView, i.e. bald Earth point, building with height information and road network. Other attribute data collected (if possible) such as number of household, road type etc. might be input to database. A details of database designed will be revised again during the time of system implementation due to the lack of information which can be possible at this time. Some editing works might be necessary in this step.

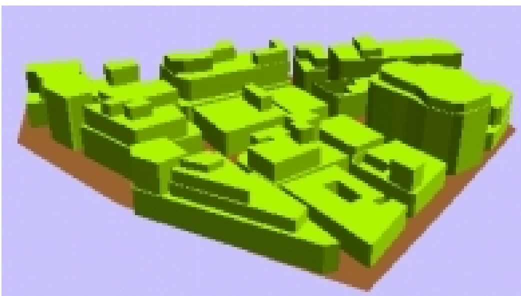

Figure 5 Sample test result of proposed system, Shinjuku, Tokyo, Japan

- Input: vector layers (bald Earth points, building, road)
- Output: 3D GIS database
- Processing: interactively

The digital image taken during flying survey and after being geometric corrected can be imported to this 3D GIS database for visualization purpose. A small sample obtained during the testing stage of this system is illustrated in Figure 5. Much manual work was done in this testing stage due to the unaccomplished implementation of the designed system. However, it shows a promising result of this system processing.

4. CONCLUSION AND RECOMMENDATION

This research is the first time to apply wavelet in segmentation of airborne laser scanner data, which is being continually developed and quite new research. The advantages of wavelet of analysis can be observed from many researches in image processing, pattern recognition and the like. In addition, several testing presented here also proved this point. The proposed algorithm with wavelet, in fact, is shape and size oriented segmentation. Therefore, it works well with man-made object such as in urban area. The application of this algorithm for airborne laser scanner derived from forest area is a challenge. It might work with that kind of region but the frequency of system and then the laser point gap should be good enough to be able to distinguish tree and ground. The disadvantage of wavelet is computation efficiency. Time consuming of wavelet analysis is a point should be considered and need to be improved.

5. REFERENCES

Ackermann, F., 1999. Airborne laser scanning – present status and future expectation. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54,pp 64-67.

Axelsson, P., 1999. Processing of laser scanner data – algorithms and applications. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54, pp 138-147.

Behan, A., 2000. On the matching accuracy rasterised scanning laser altimeter data. *Proceedings of the XIXth congress of ISPRS*, Amsterdam 2000,"International Archives of Photogrammetry and Remote Sensing", XXXIII, part B 2, ISSN 0256-1840, pp 75-82.

Cohen, A., 1990. Wavelets and Multiscale Methods in Image Processing. http://www.ann.jussieu.fr/%7Ecohen/ (accessed February 2001)

Graps, A., 1995. An introduction to Wavelet. Institute of Electrical and Electronics Engineers, Inc. http://www.amara.com/current/wavelet.html (accessed February 2001)

Haala, N. and Brenner, C., 1999. Extraction of buildings and trees in urban environment. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54, pp 130-137.

Maas, H. G. and Vosselman, G., 1999. Two algorithms for extracting building models from raw laser altimetry data. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54, pp 153-163.

Mallat, S., 1999. *A wavelet tour of signal processing*. Academic Press.

Roggero, M., 2001. Airborne Laser Scanning: Clustering in Raw Data. *International Archives of Photogrammetry and*

Remote Sensing, Volume XXXIV-3/W4 Annapolis, MD, 22-24 Oct. 2001, pp 227-232.

Sithole, G., 2001. Filtering of Laser Altimetry Data using a Slope Adaptive Filter. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXIV-3/W4 Annapolis, MD, 22-24 Oct. 2001, pp 203-210.

Starck, J.L., and Murtagh, F., 1994. Image restoration with noise suppression using wavelet transform. *Astronomy and Astrophysics*, 288, pp 342-348.