Mapping of the 3D River Boundary Line Using LiDAR Data and Aerial Photograph

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ABSTRACT

Prevention of flood and protection of properties in river zones are the important national issues in Korea. Utilization of remote sensing data is recently famous for national river mapping in Korea due to its ability for acquisition of spatial information data without ground surveying. 3D river boundary line mapping is critical and one of the initial steps for the national river mapping plan. Use of the remote sensing data such as LiDAR and the high resolution aerial photograph is efficient for river mapping due to its accessibility and high accuracy in horizontal and vertical direction. Airborne laser scanning (LiDAR) has been used for river zone mapping due to its ability to penetrate shallow water and its high vertical accuracy. Use of image source is also efficient for extraction of features of river zones by using image processing technique. Therefore, aerial photograph also have been used for river zone mapping tasks due to its image source and its higher accuracy in horizontal direction. Due to these advantages, in this paper, research on the three dimensional river boundary mapping is implemented using LiDAR data and aerial photographs. Using image processing techniques such as mean shift segmentation and edge detection algorithm, the 2D river boundary mapping is implemented from the high resolution aerial photograph, and LiDAR data is integrated for construction of the 3D river boundary line. This research sugeests an semi-automatic method for mapping of the 3D river boundary line using the LiDAR data and the aerial photograph.

1. Introduction

A river is defined as a natural stream of water of great volume flowing in a bed or a channel between defined banks or walls, and it sometimes forms the dividing line between two political jurisdictions, two nations, two states, two cities and etc (Shalowitz, 1964). There are three principles for defining river boundaries (Shalowitz, 1964): (1) The geographic middle of the river; (2) The middle of the channel; and (3) the shore or bank. In this research, we define a river boundary as the shore; hence, a river boundary line is defined as the shoreline, the line of contact between the water body and the land. Mapping the river boundary line is critical for monitoring and management of the river zones, prevention of flood, estimation of erosion in river zones and protection of properties of river zones. Due to irregular surface of river zones and dynamic water level changes in shores, ground surveying method has a limitation for mapping of the 3D river boundary. Recently, utilization of remote sensing data such as LiDAR and aerial photographs has widely used for the national river mapping in South Korea due to its easy accessibility to river zones and its high vertical and horizontal accuracy. We used image processing techniques to map the 3D river boundary line using the LiDAR data and aerial photographs.

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2. Methodology

In this section, we introduce multiple methods for mapping of the 3D river boundary line using the aerial photographs and the LiDAR data. First of all, mean shift segmentation, one of image processing techniques, is applied for extraction of the 2D river boundary line in the aerial photographs. Then, we apply the Canny operator, one of the multi-stage algorithms for edge detection in the digital image, to the segmented image to detect the linear features in the image. The linear features are manually connected to form the final 2D river boundary line. The grid format of the LiDAR data is generated using the LiDAR points, and the generated 2D river boundary line is integrated to the grid format of the LiDAR data to construct the 3D river boundary line.

Mean Shift Segmentation

An image processing technique is the essential skills for extraction of the important features such as points, lines and polygons in the digital images. Mean shift segmentation, one of the segmentation methods in image processing techniuqes, is applied to for classification of pixels which have similar values each other into several clusters. Mean shift segmentation algorithm has been widely used for feature mapping in coastal zone. Lee et al. (2009) and Lee et al. (2010) used mean shift algorithm for shoreline mapping using LiDAR data and image sources. Di et al. (2003) also used mean shift segmentation to extract shorelines from IKONOS images. The basic procedure of the mean shift algorithm is given below and the procedure consists of the five steps (Lee et al., 2009):

1) Step 1: Create a window (kernel) with a predefined radius.
2) Step 2: Calculate the center of mass for the points in this window.
3) Step 3: Move the window center to this center of mass. Repeat from step 1 to until the center of mass converges.
4) Step 4: The converging coordinate of the window center defines a segment. Each point within the radius of the trajectories that converges to the same location in the dataset belongs to the same segment.
5) Step 5: Repeat from step 1 to step 4 until every point in the dataset belongs to a segment.

Using the given n data points x_i, i=1, …… , n in the d - dimensional space, the mean shift vector at location x is computed using the below equation 1 (Comaniciu and Meer, 1999, 2002).

$$M_h(x) = \frac{\sum_{i=1}^{n} x K\left(\frac{x-x_i}{H}\right)}{\sum_{i=1}^{n} K\left(\frac{x-x_i}{H}\right)} - x \qquad (1)$$

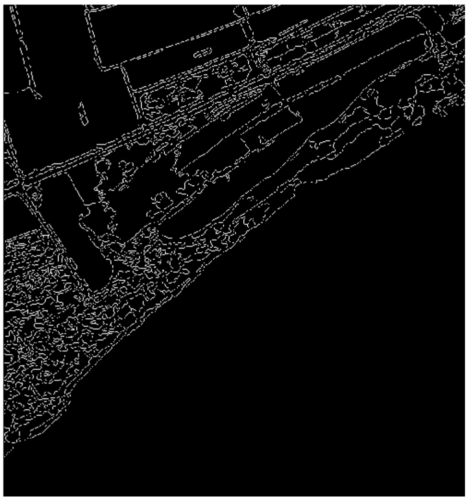
where ***K*** is a kernel with a monotonically decreasing profile and ***H*** is the bandwidth of the kernel. In general, a uniform kernel or a normal kernel is used in the above equation. Mean shift is a repetitive procedure that shifts each data point to the sample or weighted mean in its neighborhood (Di et al., 2003). This method was initially introduced by Fukunaga and Hostetler (1975) as a non-parametric clustering method. It has been proven that mean shift is guaranteed to converge at the modes of the density (Comaniciu and Meer, 1999, 2002). Using the mean shift algorithm, the delineation of the clusters is the natural outcome of the mode-seeking process. Using this algorithm, after convergence, the basin of attraction of a mode, i.e., the points, in the data set, that are visited by all the mean shift procedures converging to the mode, automatically delineates a cluster of arbitrary shape (Comaniciu and Meer, 2002). Comaniciu and Meer (2002) introduced one of image segmentation methods based on mean shift analysis in a joint spatial range domain. The spatial domain represents the two-dimensional image with column and row. For application of the mean shift segmentation, the user only needs to set the bandwidth ***Hs*** in the spatial domain and ***Hr*** in the range domain. In the above equation 1, the bandwidth parameters actually determine the scale and resolution of the analysis and an optional parameter ***M*** can be set to remove the spatial regions that contain less than M pixels. Using these three parameters, mean shift segmentation considers not only pixel information but also spatial relation information during its procedure. In this research, we applied mean shift segmentation on the aerial photographs of 50cm-resolution to segment the images into the multiple pixel clusters which represent homogeneous regions, and the segmentation parameters are set as (***Hs, Hr, M***) = (6, 5, 20). One segment of the aerial photograph of the study area is illustrated in left column of Figure 1 and the segmented image of the original aerial photograph is illustrated in right column of Figure 2. In the right column of Figure 1, using the mean shift segmentation method, the region of water body of the river was well segmented from the region of lands.

Original image Segmented image

Figure 1. Original image (left column) and Segmented image (right column)

Generation of the 3D river boundary lines

The Canny operator was applied to the segmented image for extraction of the linear features in the segmented image. The Canny operator is a useful and multi-stage algorithm to detect the edges in the digital image. The extracted linear features using the Canny operator has the raster format (left column, Figure 2). For generation of the final 2D river boundary line, we applied a raster-to-vector conversion using the spatial analysis tools in Arc GIS. After application of a raster-to-vector conversion, we could obtain the linear features with a vector format. We manually picked the linear features which are the candidates of the river boundary lines. The selected linear features were manually connected to form the final 2D river boundary line. The linear features with a raster format are illustrated in left column of Figure 2 and the linear features with a vector format are illustrated in right column of Figure 2.



Linear features with a raster format Linear features with a vector format

Figure 2. Linear features with a raster format (left column) and a vector format (right column)

LiDAR is an active sensor which transmits the laser pulses to a target and records the time it takes for the pulse to return to the sensor receiver (NOAA, 2009). The results of LiDAR technology are the 3D coordinates of the measured points on the object surface. Figure 3 shows the LiDAR data taken in the study area.

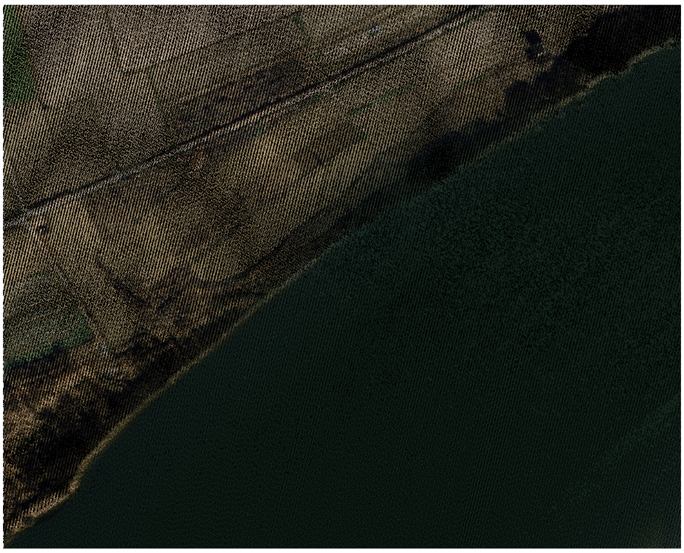
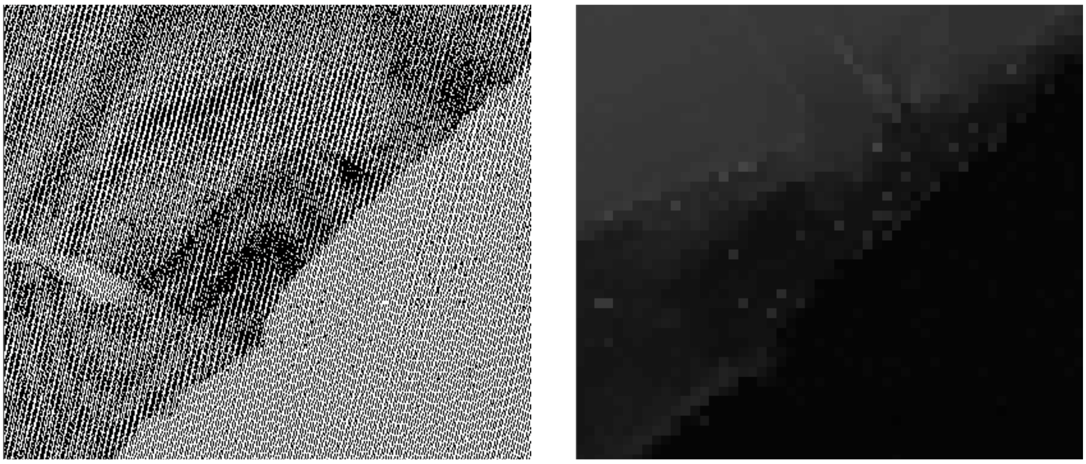


Figure 3. LiDAR data taken in the study area

Since the LiDAR data can offer the elevation information of the extracted linear feature, we used the z coordinate of the LiDAR data. First of all, using the spatial analysis tools in Arc GIS, we applied the point-to-raster conversion to generate the grid format of the LiDAR data. Then, we overlapped the final 2D river boundary line on the grid format of the LiDAR data. Figure 4 shows the original LiDAR data and the grid format of the LiDAR data.



Original LiDAR data　　　　Grid format of the LiDAR data

Figure 4. Original LiDAR data and grid format of the LiDAR data

After the elevation information of the LiDAR data is added into the 2D river boundary line, the 3D river boundary line is generated using the LiDAR data and the aerial photograph.

3. Study area and data sets

The study area for this research is located along the shore of Nakdong River of South Korea. We choose the 1km shore in the study area. The area of this study is the one where Jeungsanje is located near Hamanbo along the Nakdong River. The establishment date of the collected data is December, 2010. The collected data includes the LiDAR data and aerial images. The tools of this study include the aerial DMC photographic tool, whose specifications are shown in Table 1, and the LiDAR tool of ALTM Gemini 167, whose specifications are shown in Table 2.

Table 1. DMC

Manufacturing company	Z/I Imaging (Germany)	RGB&CIR Sensor(pixel)	3,072×2,048
Image sensing Technology	Frame	No. of CCD	8
focal Length of Panchromatic Sensor	120(㎜)	Image Interval Rate	21 sec/frame
Panchromatic Image Size(Pixel)	13,820×7,680	Analog-to-Digital Conversion	12 bits
Pixel size(㎛)	12	Radiometric Resolution	12 bits
Field of view(cross/along)	69.3° / 42°	Panchromatic Sensor	4
Gorund Sample Distance	7.5 ㎝ at 750m	Stroage in Flight	1.2TB >3,3000 images

Table 2. ALTM Gemini 167

Manufacturing company	Optech
Model name	ALTM Gemini 167
Laser repetition rate	33 ~ 167 kHz
Operating Altitude	80 to 4,000m
Horizontal accuracy	1/11,000m × altitude, ±1-sigma
Elevation accuracy	5 ~ 10cm typical, ±1-sigma
Range capture	Up to 4 range - each pulse
Intensity capture	4 intensity reading with 12bit
Scan frequency	Variable to 70 Hz
Scan Angle	Variable from 0 to 25
Spot distribution	Sawtooth, uniform spot spacing across 96% of scan
Scanner product	Scan angle × scan fre. <1,000
Roll Compensation	± 5degree Updat
Swath width	Variable from 0 to 0.93×altitude
Beam divergency	Dual divergence 0.15/0.25 mrad or 0.80 mrad

4. Conclusions

Mapping of a river boundary line is necessary for prevention of flood and protection of river properties. In this research, we introduce a semi-automatic method for extraction of the 3D river boundary line using the LiDAR data and the aerial photograph. The proposed method is based on mean shift segmentation for identification of the region of the water body of the river, the Canny operator for edge detection, data conversion from the raster format to the vector format for generation of the 2D river boundary line and data conversion from the point format to the raster format for adding the elevation information of the LiDAR data into the 2D river boundary line. Due to the irregular surface of coastal zones and dynamically change of the coastal surfaces, development of fully automated method for extraction of the river boundary line at high accuracy in vertical and horizontal direction is very difficult. In addition, use of the multiple remote sensing data sets from the different sensors can provide additional information for extraction of the complicated features in the coastal zones. Thus, further research is needed to develop the fully automatic method for extraction of the 3D river boundary line using the multiple remote sensing data sets.

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