The research of artificial shoreline extraction based on airborne LIDAR data

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Abstract: Shoreline is closely related to the management and development of the ocean, people’s life, and national economic construction. Therefore, it is particularly important to accurately obtain the location of the shoreline. The existing Shoreline Extraction methods are based on image data, lidar data, or the integration of the two kinds of data. However, due to the characteristics of image data, the extracted shoreline is often fragmentary or there are areas where shoreline cannot be extracted, and the type of shoreline is more, there is no unified, uniform algorithm. Therefore, this paper attempts to extract shoreline of man-made construction areas from airborne lidar data, and the algorithm is implemented with C++ and PCL. The experimental results show that the method can extract shorelines completely with high precision. Compared with the contour tracing method, the shoreline extracted by this method is smoother, and there is no local regional jump.

1. Introduction
The shoreline is an important concept in the description of marine attributes, which is closely related to people's life and national economic construction. Therefore, efficient and accurate measurement of coastline has become an inevitable demand of social development. The traditional methods have made an important contribution to the coastline measurement, but they can no longer meet the needs of coastline measurement with a large range, long line, and high accuracy. The development of new measurement methods has become the need of the times. At present, the coastline measurement methods are mainly based on InSAR images, aerial images, and lidar methods. Researchers have made great contributions to each kind of technical method. Josep E. Pardo Pascual et al. [1] automatically extracted the coastline at the micro-tidal flat from the infrared bands of Landsat 7, Landsat 8, and sentinel-2 images, and evaluated the accuracy of Coastline Extraction. It was verified that the average horizontal error of coastline was about 3M and 6m at high and low gain images. Yun Jae CHOUNG et al. [2] used high-resolution satellite images, machine learning, and the index of water methods to extract coastline. They can extract coastline by using these two methods respectively. When the coastline is regular, they can extract results with higher accuracy, but when the coastline is irregular, they can't extract coastline. Ivan sekovski et al. [3] used the image classification method to extract coastline from very high-resolution multispectral images. AMR Yousef et al. [4] used lidar data DEM combined with aerial images to extract coastline, LIDAR is an emerging technology, and some researchers have used LIDAR data to extract coastline. Shen Xu, Ning ye, Shanshan Xu [5] proposed a method to extract coastline...
from airborne LIDAR point cloud data, which uses flatness to search and remove water points, then uses minimum cost boundary model to extract land boundary, and then removes the false boundary caused by human objects and vegetation to get the real boundary. Ismael Ferna’ndez Luque et al. [6] proposed a method to extract coastline by using digital elevation model (DEM) extrapolation of lidar data. It uses the local elevation gradient in the data to estimate the location of the coastline and then extrapolates the slope to achieve zero elevation contour. Hilary f. stock don [7] proposed a shoreline position estimation method based on lidar data. Shoreline position refers to the cross-shore position perpendicular to the shoreline datum. Lidar altimetry data in a vertical range near the shoreline datum are fitted into a function, and then the function is evaluated to estimate the shoreline position. InSu Lee et al. [8] discussed the application of cadastral coastline extraction using Lidar data for the first time, indicating that lidar technology has a good application prospect under the new criteria of data and tidal reference reconstruction. William Robertson V et al. [9] updated the historical coastline data set through lidar technology and verified that this method is feasible to estimate the accuracy of coastline. Literature [10-21] also used lidar data to do related research on coastline extraction, which promoted the development of this technology. The above research has promoted the progress of lidar technology in coastline extraction, but there are many kinds of coastline, which can be divided into the natural coastline and artificial coastline, natural coastline can be divided into bed rock coastline, sandy coastline, gravel coastline, muddy coastline, and artificial coastline can be divided into the port coastline and construction coastline. The data gotten is different for different shorelines and there is no unified shoreline extraction algorithm which can adapt to all kinds of shoreline types. Extracting coastline from airborne lidar data has the characteristics of being affected by climate, only working in the daytime, no high precision coordinate data, fragmented coastline, and unable to extract coastline when there is shadow. Therefore, this paper will use airborne lidar data to study the construction shoreline extraction in artificial shoreline, and propose an extraction algorithm suitable for this type of shoreline.

2. Methods

A lidar data file contains a large area, and the resulting data file is also large. Therefore, the processing speed will be slow, the coastline and its adjacent area is only a small part of the file, so we need to segment the point cloud of the coastline and its adjacent area from the file first. Therefore, before processing, we use other point cloud software to display and analyze lidar files, mainly get the x, y coordinate range of the file, the range of the coastline area, the flight direction, and the coastline on the left or right side of the flight direction. With this information, the point cloud of the coastline and its adjacent area can be segmented by setting x, y coordinate thresholds. If the file is still large, it can be further segmented by setting the z coordinate threshold, and finally, the point cloud of the coastline area to be processed is obtained. The approximate flow chart of Coastline Extraction is shown in Figure 1.

![Figure 1. Coastline Extraction Flow Chart](image-url)

2.1. Remove the point cloud in the water direction area along the coastline

If the coastline is in the north direction, it needs to remove the point cloud in the north of the coastline. If the coastline is in the south direction, it needs to remove the point cloud in the south of the coastline.
If the coastline is in the east or west position, it needs to remove the point cloud in the corresponding direction, which is conducive to the subsequent algorithm for Coastline Extraction. As shown in (a) and (c) in Figure 2, it is necessary to construct an algorithm to remove the point cloud outside the coastline. The algorithm can be constructed by the information of low reflection intensity, low elevation, remote location, and so on.

2.2. Coastline point cloud extraction
According to the flight direction and the scanning direction of lidar, the data value changes regularly. Taking the coastline in the northerly direction as an example, through the data before and after displayed by other point cloud software, and the combination of the data x and y value, we can judge that the flight direction is from east to west, x value increases from east to west, y value increases from north to south. Therefore, we can construct the algorithm to extract the point at the northernmost edge. Assuming that the point cloud outside the coastline is \( P \), the northernmost point has the following characteristics:
\( p_i \cdot y < p_{i+1} \cdot y \)  
\( p_i \cdot y < p_{i+1} \cdot y \)  
\( p_i \cdot y < p_{i+6} \cdot y \)  
\[ \Delta y = p_{i+1} \cdot y - p_i \cdot y > y_{\text{threshold}} \]  

Where, \( p_i \cdot y \) is the y coordinate of a point, and \( y_{\text{threshold}} \) is the threshold value of coordinate difference. This threshold value can be set to a larger value because the y coordinates from north to south in a file differ greatly. The formula \( p_i \cdot y < p_{i+6} \cdot y \) is to increase the stability of the algorithm, and it is not necessary to add 6, as long as it is a point with a larger span.

2.3. Coastline point cloud completion
The extracted coastline point cloud is not too dense generally, and the distance between points is large. To make the point spacing smaller, appropriate points should be inserted between the points. To make the point smooth after connecting, the coordinate value of the insertion point should not be in a straight line as far as possible, so the points will be completed according to the following method.

When \( d_{p_i \cdot n} > 1 \), three points are added, with the proportion of \( 1 / 4 \), \( 2 / 5 \), and \( 3 / 4 \), then the coordinates of new points are added. Take \( 1 / 4 \) as an example

\[ x_{p_{i+1}} = 1 / 4 \Delta x_{p_i \cdot p_{i+1}} + x_{p_i} \]  
\[ y_{p_{i+1}} = 1 / 4 \Delta y_{p_i \cdot p_{i+1}} + y_{p_i} \]  
\[ z_{p_{i+1}} = 1 / 4 \Delta z_{p_i \cdot p_{i+1}} + z_{p_i} \]  

When \( 1 < d_{p_i \cdot p_{i+1}} < 2 \), five points are added, with the proportion of \( 1 / 6 \), \( 1 / 4 \), \( 3 / 5 \), \( 2 / 3 \), \( 3 / 4 \), then the coordinates of the new points are calculated as formula (2);

When \( d_{p_i \cdot p_{i+1}} > 2 \), eight points are added, and the proportions were \( 1 / 8 \), \( 1 / 7 \), \( 1 / 5 \), \( 2 / 5 \), \( 1 / 2 \), \( 3 / 5 \), \( 3 / 4 \), \( 4 / 5 \). Then the coordinates of the new points are calculated as formula (2).

2.4. Determination of pre-extracted coastline elevation
As shown in Figure 2, the artificial coastline may be in a shallow water area or deep water area. In shallow water areas, there is a lidar echo signal, but the echo intensity is weak. In a deep water area, the light beam will be absorbed without an echo signal. Therefore, the method of determining the coastline elevation is different. As shown in Figure 2 (a), the point cloud with high water content in shallow water area is \( A = \{ A_1, A_2, A_3, \ldots, A_n \} \), before the coordinate transformation of coastline is

\[ B = \{ B_1, B_2, B_3, \ldots, B_j \} \], there are:

\[ H_A = \sum_{i=1}^{n} H_{A_i}, H_B = \sum_{j=1}^{j} H_{B_i} \]  

\[ \Delta H = H_B - H_A \]  

The coastline elevation after correction is:

\[ H'_{B_i} = \begin{cases} H_{B_i} - \Delta H, & H_{B_i} - H_B \leq H \ 
\text{remove}(B_i), & H_{B_i} - H_B > H \end{cases} \]  

\( H \) is a threshold, setting the allowable change range of coastline elevation before correction.

As shown in Fig. 2 (b) and (c), the coastline in deep water area is under the condition that the light beams on the side of the artificial construction boundary near the water body are all absorbed, and the construction boundary can not reflect the elevation of the water body. At this time, the elevation of the
water body can only be measured by the tide gauge station, and then the coastline elevation can be corrected.

2.5. Point cloud translation and coastline generation

The actual location of the coastline should be a certain distance away from the construction boundary, because the density of the points acquired by airborne lidar is sparse and the distance between the points is slightly large, the average distance of the data points acquired should also be calculated, marked as \( \sigma \). Let the point cloud after completion be \( P_{\text{buquan}} = \{ P_1, P_2, P_3, \ldots, P_n \} \), Taking the coastline in the north direction as an example, the y coordinate of each point shifts \( \frac{1}{2} \sigma \). After translation, the point clouds are clustered as \( P'_{\text{buquan}} = \{ P'_1, P'_2, P'_3, \ldots, P'_n \} \), which satisfies the following relationship:

\[
\begin{align*}
    P'_1.x &= P_1.x \\
    P'_1.y &= P_1.y - \frac{1}{2} \sigma \\
    P'_1.z &= P_1.z
\end{align*}
\]

If the coastline is in the south direction, it will shift to the south. If the coastline is in the east or west, it will also shift to the east or west. Combined with the elevation correction method of 2.4, the coastline point cloud can be obtained, and then the coastline shape can be obtained by connecting them into a line in turn.

3. Experiment and analysis

In this paper, we use C++ and PCL to implement the above algorithm and select the airborne lidar data in the Longkou coastal area of Shandong Province as the experimental data. The data size is 867.494M, with a total of 17079691 points. Some of the captured images are shown in Figure 3 (a), and the segmented artificial construction area is shown in Figure 3 (b).

![Figure 3. (a) part of the original lidar data, and (b) the segmented artificial construction area](image)

Figure 3. (a) part of the original lidar data, and (b) the segmented artificial construction area

Figure 3(b) is further segmented based on the elevation parameters, as shown in Figure 4 (a), and according to the echo times and echo intensity information of each point, the points are shown in Figure 4 (b). The red point is the point where the echo intensity is less than 8, the blue point is the point where the echo number is greater than 1, and the black point is the point except for both. It can be seen from the figure that there are points with lower reflection intensity on the left and right sides above the coastline, which are the surface feature points immersed in or exposed to the water, that is, the points with higher water content.
Figure 4. (a) the point cloud obtained by re-segmentation, (b) displayed according to the echo number and intensity

Removing the point cloud outside the coastline, and according to the Coastline Extraction Method in 2.2, the artificial construction boundary is shown in Figure 5 (a), the point cloud after completion is shown in Figure 5 (b), and the generated coastline is shown in Figure 5 (c).

Figure 5. (a) original coastline point cloud (b) point cloud after completion (c) coastline generation

After elevation correction and translation, the generated coastline is superimposed with the origin cloud data map, as shown in Figure 6 (a). The superimposed display of the coastline and origin cloud data map generated by the proposed method and contour tracking method is shown in Figure 6 (b). Red
represents the contour racking method, and cyan represents this method.

Figure 6. (a) superposition of the proposed method and origin cloud (b) superposition of two methods and origin cloud

The superimposed display of the coastline generated by the two methods is shown in Figure 7. It can be seen that the contour tracking method will occasionally jump in the local area, and it is not smooth enough, which also shows that the method in this paper can achieve good results in extracting coastline.

Figure 7. Effect of superposition comparison of two methods

4. Conclusion
Compared with the isoline tracing method, this method can extract the coastline of artificial construction areas. Through coordinate translation and elevation correction, the coordinates of each coastline point can be as close to the actual value as possible. In this method, the previous point cloud segmentation in the coastline region and the algorithm of removing the point cloud in the water body outside the coastline need to be verified in a variety of data cases. If the algorithm has unsuitable data, the algorithm should be improved to achieve the stability of the two algorithms, so that the whole coastline extraction algorithm is more stable, and the coastline extraction algorithm is automated as much as possible.

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