2021 20th International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES)

*Research on Model and Method of Inland River Ship Overload Measurement**

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Abstract—The problem of detecting overloading of inland vessels is an important topic on water traffic safety. But the workload is too large to rely solely on traditional manual enforcement. This paper studies model and method for automatically calculating the distance between the trunk of an inland watercraft and the water surface by utilization of LIDAR(LIght/LAser Detect And Ranging) data and modern technologies such as AIS(Automatic identification System) and network transmission. Related models are established which calculate the real-time water surface height, preprocess the LIDAR data and measure the distance between the trunk and the water surface by a dual-fitting model. The model and method have their important theoretic meaning and can be applied to practice for the detection of overloaded inland watercraft.

Keywords- ship overload; laser radar; regression analysis; ship's actual freeboard value

I. INTRODUCTION

In recent years, the overloading of ships in the inland water network area has become more and more serious[1,2]. At the same time, accidents such as ship sinking, casualties, and channel obstruction have occurred from time to time. This affects not only the safety of water transportation, but also restricts the development of water transportation economy. The phenomenon of ship overloading has been repeatedly banned due to that it is a hidden danger to the safety of water traffic. As an important business task of maritime management agencies, the prevention and control of overloading has always been highly valued by maritime departments[12]. In the practice of preventing overloading, the detection of ship overloading was mainly carried out manually. With the increase of ship flow and the continuous improvement of modern management level, it is necessary to study the automatic measurement method of ship overloading. This problem involves the comprehensive integration of multiple equipment and technologies[13]. The key issue is the model and calculation method for measuring the height of the edge points on the deck surface and the water surface.

Some scholars have researched into the issue already. There are many methods such as sonar technique[6], video graphic[4], pressure sensor[9], electronic water gauge[10], DSP etc. These methods have a common shortcomes in which some sensors are required to be installed into ships[10,11]. The laser scanners are also used to check the height betheew the free board and the water surface. But the models are complicate in which the video graphic are needed also[7,8,14].

If this problem can be solved, the static and dynamic information of the ship can be automatically obtained through the relevant position information of the AIS[15] equipment, and the ship database of the maritime department can be accessed to obtain its registered dry height[3,5]. By comparing the two heights, It can be judged whether the ship is overloaded or not.

Fig. 1 shows the main equipment of the proposed ship overload detection system. The LIDAR continuously scans the ships passing through the detection area to obtain the cross-sectional data of the ship, and through the analysis and calculation of the obtained cross-sectional data of the ship, the actual height from the edge point of the upper surface of the freeboard deck to the water surface is obtained to judge whether the ship is overloaded.

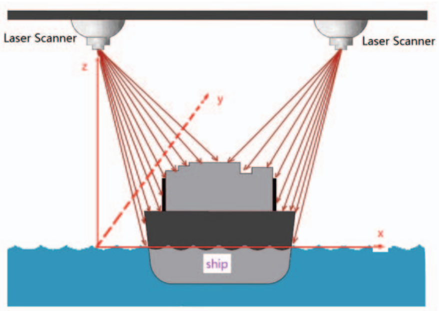

Figure 1. Ship overload detection system.

II. LIDAR EQUIPMENT SELECTION AND REAL-TIME CALCULATION OF WATER SURFACE HEIGHT

A. LIDAR related terms

LIDAR is a way to obtain directly three-dimensional coordinates of object surface points through observation data such as position, distance, and angle. It can be applied to a series of application scenarios such as ship surface information extraction and three-dimensional scene reconstruction technology. The LIDAR data involved in this article is two-dimensional cross-sectional data, which is to obtain the angle and distance information of the ship's surface under a certain angular resolution.

1) Resolution: The minimum change value of the detection distance that can be output. To change the default, adjust the template as follows.

*It is Supported by: Technological innovation team work on ship's new energy and power equipment application, No.2019td01

2) Angle resolution: The minimum change value of the detection angle that can be output, in radians.

3) Horizontal resolution and vertical resolution: The minimum change value of the distance in the horizontal direction and the vertical direction. To change the default, adjust the template as follows.

4) Systematic error: A series of observations are made under the same observation conditions, and the magnitude and sign of the error show a fixed pattern or change according to a certain law.

5) Random error: Refers to the deviation between the measured value and the true value random.

6) Free board (sometimes referred to as standard free board): Refers to the vertical distance measured from the upper surface of the free board deck to the relevant full-load waterline in the middle of the ship. The calculation formula is

$$F = D + \delta - d(m).$$

In this formula: F is free board(m), D is moulded depth(m), δ is the thickness of freeboard deck side plate(m), and d is ship's full draught(m).

7) The distance between the free board deck and the surface of the water: Refers to the average distance from the upper surface of the free board deck to the surface of the water in the middle of the ship(m).

B. Real-time calculation of water surface height

The height of the water surface of the inland river is changing continuously due to the influence factors such as tides, rain, fluctuations, wind and waves, so it is necessary to calculate the height of the water surface in real time.

As shown in Fig. 2, a dedicated LIDAR is used to measure the real-time height of the water surface.

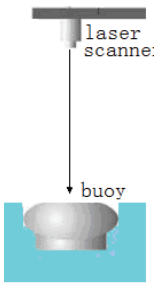

Figure 2. LIDAR measures the height of the water surface in real time.

h_0 is the previously calculated height of the water surface from the radar before calculating the altitude, and the value of h_0 for the first time can be determined by actual measurement.

Suppose there are a total of several cross-section data $\{(\rho_i, \theta_i) | i = 1,2,3\}$, we select three points in the k-th cross-section data, where θ_i is the angle between the reflection line and the straight downward line. They meet the following conditions: the value of $|\theta_i|$ is the smallest 3 of the cross-section points; $\theta_1 < \theta_2 < \theta_3$. Let $z_i = \rho_i \cos\theta_i, i = 1,2,3$, under ideal conditions, the average height of the water surface from the radar calculated from this cross-section is $h_k = \frac{1}{3}\sum_{i=1}^{3} z_i$.

The $k-th$ section data should be eliminated if

a) $\max\{|z_1 - z_2|, |z_2 - z_3|, |z_1 - z_3|\}$ is obviously too big.

b) The h_k calculated by the (1) such that $|h_k - h_0|$ obviously too large.

c) $z_1 + z_3 = 2z_2$ is obviously not true.

Suppose there are m remaining sections after the elimination. Then the height h_0 of the water surface from the radar is updated to the real-time height.

$$h_0 = \frac{1}{m}\sum_{k=1}^{m} h_k \tag{1}$$

The h_0 calculated by (1) is saved as a system parameter and recorded as the initial value for the next real-time calculation of altitude.

III. Theoretical Model and Calculation Method

For the convenience of discussion, we first establish a right-handed spatial coordinate system, as shown in Fig. 1. The line connecting the two LIDARs installed under the bridge deck is the x-axis direction, the upward direction perpendicular to the water surface is the z-axis, and the lower displacement h_0 of the LIDAR is the coordinate origin. It is the vertical height between the LIDAR and the horizontal water surface, and its value is obtained by the LIDAR from a buoy placed on the water. The coordinate plane xoz is the plane where the laser radar scans to obtain the ship's cross-sectional data. The angle of the laser radar scan is based on the negative direction of the z-axis, which is adjusted when the laser radar is installed. The y-axis direction is the direction the ship travels. In other situations, such as the other direction of the ship, the LIDAR on the other side, etc., the modeling conditions can be transformed into this situation by simply rotating and translating the coordinate axis. In order to facilitate data exchange with AIS and GPS, the longitude and latitude of the LIDAR and the direction of the y-axis in the GPS coordinate system should also be determined.

A. Data conversion and preprocessing of LIDAR

At a certain moment when the LIDAR scans the ship, it scans the outer surface of a certain section of the ship, and obtains the reflection data of a series of points, namely a series of distances and angles $P_i(\rho_i, \theta_i), i = 1,2,\cdots,n$, which is shown in Fig. 3. $OR = h_0$ is the height of the LIDAR from the water surface, $\angle ORP_i = \theta_i$ is the angle, and the angle direction is defined as the positive direction starting from RO and counterclockwise with R as the center. The rectangular coordinates of P_i are:

$$x_i = \rho_i \sin\theta_i, z_i = h_0 - \rho_i \cos\theta_i \tag{2}$$

Because the data is noisy, the data points after (2) conversion need to be preprocessed, which is described as following 3 steps.

Step1. Floating objects on the water, sand and waves in the river water are in the rectangular coordinate system xoz, and the z coordinate must be near 0, so the point $z_i < \Delta_1$ in $P_i(x_i, z_i), n = 1, 2, \cdots, n$ is first eliminated. Where Δ_1 is a certain given threshold.

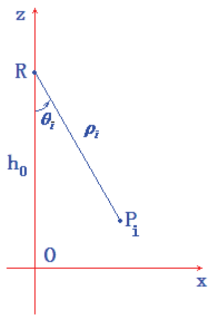

Figure 3. rectangular coordinate system for the cross section.

Step2. The possible reflection points of floating objects in the air, rain, snow, fog, etc. are in the rectangular coordinate system xoz , and the coordinate must be very large, so the point $z_i > \Delta_2$ in $P_i(x_i, z_i), n = 1, 2, \cdots, n$ is eliminated. Where Δ_2 is a threshold setted manually.

Step3. After the above two steps, the remaining data are arranged in ascending coordinates according to the x coordinates, and the one that $\frac{1}{3}$ is ranked first is a cross-sectional data point to be further processed.

B. *Calculation model and method*

1) *Data refinement of cross-sectional feature points*

Let $(x_i, y_i, z_i), i = 1, 2, \cdots, n$ be the n points extracted preliminarily by the cross-section feature point extraction model based on the adaptive threshold. The specific steps are as follows:

a) Calculate the sample mean and sample standard deviation of height $z_i\left(i = 1, 2, \cdots, n\right)$:

$$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i, s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(z_i - \bar{z})^2} \tag{3}$$

If $|z_i - \bar{z}| > 3s$, then delete the i -th point (x_i, y_i, z_i).

b) If the i-th point is deleted, go back to the i-th section data and try to find a point that is close to the ($i-1$)-th feature point $(x_{i-1}, y_{i-1}, z_{i-1})$ and the ($i+1$)-th feature point $(x_{i+1}, y_{i+1}, z_{i+1})$. The similar criterion is

$$\left|x_{ij} - \frac{x_{i-1} + x_{i+1}}{2}\right| < \delta, \left|z_{ij} - \frac{z_{i-1} + z_{i+1}}{2}\right| < 3s \cdot$$

Where (x_{ij}, z_{ij}) is a certain point in the i -th cross-sectional data, threshold δ is the horizontal resolution corresponding to point $\left(\frac{x_{i-1} + x_{i+1}}{2}, \frac{z_{i-1} + z_{i+1}}{2}\right)$, and s is the sample standard deviation calculated by (3).

c) Repeat a) and b) several times until s is relatively small.

2) *"Double fitting-removal" model of free board height*

The y coordinate of the i-th cross-section feature point is represented by y_i, which is obtained by the speed v of the ship and the interval t_0 between the two scanning sections of the LIDAR:

$$y_i = v(n-i)t_0$$

Where n is the total number of all initial cross-sections of the LIDAR, and the y coordinate of the n -th cross-section is 0. The influence of the direction change of the speed v on the y coordinate and the influence on the feature point extraction algorithm can be ignored.

The ship's driving direction and its changes can be obtained through the ship's AIS real-time dynamic data. The calculation method is as follows: (1)Linearly interpolate the heading angle of the AIS ship every 1 second; (2)Numerical difference of direction angle; (3) Take the average of the calculated rate of turn at intervals (such as 10 seconds).

If the absolute value of the steering angle exceeds a certain range, the feature point of the corresponding cross-section is selected as a segment point during curve fitting. Each segment is fitted with a parabola of x and y.

If the absolute value of the steering angle does not exceed a certain range, use a straight line parallel to the y axis to fit.

The specific steps of the regression analysis from the cross-section feature point to the upper-surface feature points of the deck are composed of two repeated "fitting-removing":

Let $(x_i, y_i, z_i)(i = 1, 2, \cdots, m_1)$ be the sequence obtained by preprocessing the cross-section feature point data, generally $m_1 < n$.

- *Fitting-elimination process of x with respect to y*

a) Fitting m_1 points (x_i, y_i) , and the fitted equation is recorded as

$$x = f(y) \tag{4}$$

If $|x_i - f(y_i)| > \delta$, delete the i -th point (x_i, y_i, z_i) in the m_1 data sequences. Where δ can be taken as $\frac{4}{3}$ times the horizontal resolution at (x_i, z_i).

b) When deleting data using (4) for the first time, if there are a large number of points to be deleted in the first small part or the last small part of data points, we need to delete the entire section to eliminate the influence of the irregular curve formed by the edge points on the upper surface of the bow or stern deck.

c) Repeat *a),b)* several times for the remaining data points

- *Fitting-elimination process of* z *with respect to* y

Suppose that after the fitting-elimination process of x with respect to y , the remaining data point sequence is $(x_i, y_i, z_i)(i = 1, 2, \cdots, m_2)$. Note that m_2 here is the new number of data points after the abnormal points have been eliminated.

a) Perform straight line fitting on m_2 points (x_i, z_i) , and the fitted equation is recorded as $z = cy + d$. If $|z_i - cy_i - d| > \delta$, delete the i-th point (x_i, y_i, z_i) in the m_2 data sequence. Here δ can be taken as 3 times the mean square error of the sample points about z .

b) After two repeated "double fitting-removal" processes, m data points $(x_i, y_i, z_i)(i = 1, 2, \cdots, m)$ are finally obtained. Pay attention to keep the correspondence between these m data points and the original original cross-section labels of the LIDAR relationship. Through the final fitting equation $z = cy + d$, the final estimated value $\overline{z}$ of the distance between the ship's deck surface and the water surface can be obtained:

$$\overline{y} = \frac{1}{m}\sum_{i=1}^{m} y_i, \overline{z} = c\overline{y} + d$$

IV. CONCLUSIONS AND SUGGESTIONS

This article mainly studies the selection of LIDAR and equipment installation, real-time calculation of water surface height, adaptive cross-section feature point extraction, cross-sectional feature point data preprocessing, cross-sectional feature point extraction to the upper surface feature point of the deck edge, deck on both sides of the shape and verification of the projection curve of the feature points on the edge of the upper surface, and the final method of determining the free board height, etc.

The data processing and modeling method of the single LIDAR above will be further extended to the comprehensive processing of two LIDAR, and the analysis and calculation on each side of xoz plane, xoy plane and yoz plane will finally get the height required to measure.

Specific engineering applications also involve the selection and installation of laser radar equipment, especially the alignment of the scanning plane, the alignment of the scanning angle, and the determination of the position and direction of the laser radar equipment in the GPS coordinate system. At the same time, the comprehensive integration of related equipment such as LIDAR, AIS, and cameras, its time synchronization, and the acquisition and utilization of static and dynamic data of ships, are also tasks that need to be further clarified.

In addition, the successful application of the entire system will also involve network transmission, database technology and computer software and hardware platform selection and other related issues. According to the model and method in this article and various hardware integration methods, implementation development and engineering applications can be carried out smoothly.

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