Underwater topography survey and precision analysis based on depth sounder and CORS-RTK technology

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Abstract. Underwater topography survey is a basic part of hydrological research, and plays an important role in the development of resources in marine lakes and inland rivers. In this paper, the water depth was measured in some waters of Linyi Beng river by using Real time kinematic (RTK) based Qianxun Continuously Operating Reference System (CORS) services and depth sounder, and the underwater topographic map was obtained. In order to test the accuracy of underwater topographic survey, some of the checkpoints were simultaneously observed by the traditional sounding rope method, and the sounding accuracy of these checkpoints was analyzed. The results show that the average accuracy of the sounding with the CORS-RTK+ sounder is 0.12m, compared with the traditional method, which satisfies the accuracy requirements of underwater topography. On this basis, the items that need attention during the practical sounding are given. The above research results can provide a technical reference for underwater topography survey.

1. Introduction
Underwater topographic survey is the premise and foundation for the development of marine resources. The construction of modern ports and bridges in inland rivers, river dredging, agricultural irrigation. The underwater topographic measurement process has mainly included planar positioning and water depth measurement. The traditional way to obtain the position of the water depth point is to measure with optical instruments, including theodolite intersection method, total station positioning method, and so on. With the development of global navigation satellite systems (GNSS) real-time kinematic (RTK) technology, it provides a new technical means for measuring the position of water depth points\textsuperscript{1,2}. However, the traditional RTK measurement mode requires the base station to be set up and the work efficiency is low. The RTK measurement based on the continuously operating reference system (CORS) does not require the installation of a reference station. And when the corresponding service is connected, the measurement can be directly performed to achieve centimeter-level positioning. The traditional sounding method uses the sounding rod method and the sounding rope (hammer) method to determine the underwater depth. Current sounding techniques include single beam or multibeam sounding systems, laser sounding and remote sensing sounding.

Domestic and foreign scholars have conducted some research on sounding technology. Hao B.Y. et al. analyzed and summarized the error sources and countermeasures in the single-beam water depth measurement process, and compared the data under different conditions of speed, depth of sound probe and RTK precision\textsuperscript{3}. Literature [4] systematically analyzed the measurement error and control method based on the RTK non-tide depth measurement technology. Zhang P.F. et al. pointed out that...
the non-uniform linear measurement of the ship will cause multi-beam sounding error. Zhao J.H. et al. analyzed the relationship between high-resolution side-scan sonar images and seabed topographical factors, and proposed a new method to recover fine seabed topography using high-resolution side-scan sonar images, which improved the sounding data resolution, but building models and data processing is relatively complex. Li W.P. et al. carried out underwater topographic survey based on water-based robots, pointing out that the measurement method basically meets the specification requirements. Single beam or multibeam sounding systems are currently the primary means of performing underwater terrain. Multi-beam sounding system can obtain hundreds of sounding points in one measurement, and the sounding resolution is high, however, which accuracy is susceptible to the sounding depth and beam incident angle. The airborne laser sounding technology can meet the water depth detection requirements of the coastal zone, but there are still more difficulties in data processing problems, and relatively mature and stable practical products are launched less. The above sounding systems can meet the water depth measurement of a large and deeper area, and the efficiency is high, but the complicated data processing process and high cost hinder its wide application. A low-cost single-beam sounder can obtain a sounding point at a time, reflecting the topographic features from the point to the surface, and has a good application in inland river channel measurement.

In this paper, the sounder is combined with CORS-RTK to measure the underwater topography of some waters of Linyi Beng river, draw the bathymetric contour line of the measured waters, and use the sounding rope to measure the partial check points for accuracy comparison analysis. This paper first introduces the principle of underwater topographic survey based on CORS-RTK and depth sounder, and then uses this technique to measure the underwater topography of Beng river waters, and analyzes the sounding accuracy. The end part summarizes the main content of this study and gives some perspectives.

2. Methods
The underwater topographic survey mainly includes the plane position and water depth measurement of the measuring point. Centimeter level CORS-RTK service from Qianxun will be used to obtain three-dimensional position information. The sounding equipment adopts the SDE-28S depth sounder of South Company, and its sounding range is 0.3m~600m, and the sounding accuracy is 0.01m. A transducer mounted on the measuring vessel can transmit vertically an ultrasonic pulse to the bottom of the water, and the time for the ultrasonic from launch to reflection is measured, then the water depth can be obtained.

It should be noted that the deep draft of the transducer needs to be taken into account when calculating the actual water depth. This value can be directly obtained from the scale on the transducer rod. The water depth calculation formula is

\[ h = h_1 + h_2 = \frac{1}{2} vt + h_2 \]  

(1)

Where \( h \) is the depth from the surface of the water to the bottom of the water; \( h_1 \) is the depth from the bottom of the transducer to the bottom of the water, \( h_2 \) is the draft of the transducer; \( v \) is the speed of sound in the water, and \( t \) is the round-trip propagation time of the ultrasonic wave in the water.

In the case of water depth measurement, the position of the RTK measurement is theoretically on the same vertical line as the water depth measured by the sounder, so the RTK head should be mounted directly above the depth sounder probe. The RTK works synchronously with the sounder. The former obtains the plane coordinates and elevation of the water surface point. At the same time, the latter measures the water depth of the point, and the three-dimensional coordinates of the underwater measurement point can be calculated by using the formula 2. The use of CORS-RTK achieves an ellipsoidal height, while the elevation of the bottom is generally referenced to a theoretical depth reference plane, which can be achieved by jointly measuring the level of the known depth reference elevation value. However, the experimental object in this paper is inland shallow waters, and the relative elevation change can only be considered for the accuracy analysis of the sounding depth,
so the conversion relationship between the depth datum and the ellipsoid can be ignored. The sounding principle based on sounder and CORS-RTK technology is shown in Figure 1.

![Figure 1. The sounding principle of sounder combined with CORS-RTK.](image)

In the river survey, in addition to the measured water depth, the elevation of the bottom is required. As can be seen from Figure 1, the elevation $H$ of the water bottom is

$$H = H_0 - h_3 - h_1$$  \hspace{1cm} (2)

Where $H_0$ is the elevation measured by the GNSS receiver and $h_3$ is the height from the bottom of the transducer to the GNSS receiver.

3. Underwater topographic survey

![Figure 2. Experimental area and survey line layout.](image)

This operation area is part of the Beng River from the Yilong Bridge to Mengshan Avenue. The water flow in this area is gentle and the average water depth is about 3 meters. The specific location is shown in Figure 2. According to the experimental scheme of this paper, the required items are: a set of South Galaxy G6 RTK system; a set of South SDE-28S echo sounder); a 12V battery, measuring ropes, life jackets, etc.

3.1 Data collection

Layout survey lines. In order to accurately reflect the underwater topographical features of the measurement area, the layout of the survey line is particularly important. According to the scope and actual conditions of the survey area, this operation uses a sounding line from southeast to northwest and S-type. The spacing of the survey lines is 8-16m, and a water depth point is collected every 3m. The shape of the line layout is shown in Figure 2.

Coordinate transformation. The local coordinate system is used in this experiment, and the data collected by CORS-RTK is WGS-84 coordinates, so coordinate conversion is required. Coordinate
transformation can be achieved by jointly measuring known points. Perform point correction to obtain conversion parameters and achieve coordinate conversion. The process is shown in Figure 3.

![Figure 3](image3.png)

Figure 3. The process of coordinate conversion.

Instrument equipment installation. First connect the three sounding rods. Then install the converter probe at the bottom of the sounding rod and install the GNSS receiver at the top. The installation process is shown in Figure 4. Finally, the above connected device is fixed on the hull, and the transducer and the RTK are respectively connected to the sounder host via communication cables. According to the length of the transducer connecting rod and the water depth of the working area, the draught depth is set to 0.95m.

Software configuration. Open the water measurement navigation software and set the ellipsoid, projection parameters and conversion parameters. Then perform RTK and depth sounder model port configuration, set data acquisition conditions and file storage location. It also needs to set the RTK acquisition condition to a fixed solution and collect the instantaneous water depth every 3 meters. Then carry out the port settings of RTK and sounder. All other parameters take the default value.

Data collection. The vessel sails according to the established survey line until the data acquisition is completed. In the data collection process, the information table on the left side of the software interface can view the coordinates, water depth, navigation speed and point quality in real time, and the collected data can be displayed in real time on the right side of the software.

In order to analyze the sounding accuracy, a number of to-be-checked points are selected on the route to measure the water depth with a measuring rope. And view and record the point numbers collected by the sounder at the moment.

3.2 Results and accuracy analysis
The water depth measurement software is used to check the water depth measurement results reasonably, and eliminate the wrong water depth point, and the rejection rate is less than 10%. The processed measurement data is exported from the sounder, and after preliminary processing, it is imported into the South CASS9.1 software. And the digital ground model triangulation is established by using the CASS9.1 software function, the equal depth is set reasonably, and the isobath is drawn to obtain the underwater topographic map, as shown in Figure 5.
Figure 5. Underwater topographic map.

In order to test the accuracy of the water depth measured by the CORS-RTK combined depth sounder, it is compared with the rope measuring method. The effective data of five corresponding water depth points were randomly selected from the data observed by the two methods, and the two water depth data of the same coordinates were compared, as shown in Table 1.

| Point number | Water depth measured by the sounder (m) | Water depth measured by rope (m) | Difference (m) | Permissible error (m) | Overrun or not |
|--------------|----------------------------------------|-------------------------------|----------------|-----------------------|---------------|
| 1            | 1.92                                   | 1.98                          | -0.06          | 0.40                  | no            |
| 2            | 2.31                                   | 2.13                          | 0.18           | 0.40                  | no            |
| 3            | 2.85                                   | 2.70                          | 0.15           | 0.40                  | no            |
| 4            | 3.18                                   | 3.09                          | 0.09           | 0.40                  | no            |
| 5            | 3.27                                   | 3.39                          | -0.12          | 0.40                  | no            |

The average water depth of this operation water is about 3m. In the case of synchronous measurement, the mean value of the water depth value measured by the sounder is 0.12m relative to the water depth measured by the rope. The mean square error of the underwater sounding of this project is 0.009 m, calculated from the data in Table 1, and the calculation formula is

\[ m = \pm \sqrt{\frac{\sum_{i=1}^{n} v_i^2}{2n}} \] (3)

According to the "Water Transportation Engineering Measurement Specification" (JTS 131-2012), for waters with a water depth of less than 20 m, the measurement limit error should be no more than 0.20 m, and the depth comparison should be no more than 0.40 m. Therefore, this observation data meets the requirements of the specification.

3.3 Discussion of key technical issues

In order to ensure the accuracy of the observation data, some matters should be noted in the implementation of the measurement. The wave causes the vertical and horizontal sway of the ship so that the normal of the radiating surface of the transducer cannot be perpendicular to the depth of the water depth, which has a great influence on the accuracy of the sounding data. Small winds and gentle waters in the waters will help to observe and improve data accuracy, so try to work in good weather conditions. In the operation, the ultrasonic transducer should be fixed on one side of the hull. The CORS-RTK receiver and transducer should be mounted on the hull and perpendicular to the water
surface after installation. If the sounding rod is not mounted vertically, the deflection angle between the sounding rod and the normal of the reference surface will cause the water depth value measured by the transducer not to correspond to the plane position, resulting in systematic errors. In the process of collecting data, in order to prevent deviations in the measured data, the hull balance should be kept as much as possible. When the CORS-RTK solutions are fixed and the bathymetric data is normally displayed on the display, the set of measurement data is stored. If the CORS-RTK is not fixed or has no sounding data, the area should be retested in time to accurately reflect the underwater terrain. In addition, the positioning delay error caused by the out-of-synchronization of the sounder and RTK should also be considered. The larger fluctuation of the underwater terrain will lead to larger errors.

4. Conclusions
In this operation, the average error of the five water depth check data is 0.12m, that is, the accuracy of the sounding data obtained by the sounder combined with the CORS-RTK meets the requirements of the “Water Transport Engineering Measurement Specification”. It can be seen that, under normal circumstances, the underwater topographic measurement method of the CORS-RTK combined with the sounder can meet the requirements of underwater measurement when the water flow is gentle and the measurement synchronization is ensured. Using digital depth sounder combined with CORS-RTK for underwater topographic survey can significantly improve work efficiency and accuracy.

The single beam sounder combined with CORS-RTK can meet the requirements of underwater terrain surveys in small and shallow waters. When measuring underwater terrain in deep water or large areas, the combination of multi-beam sounder and CORS-RTK can further improve work efficiency. The establishment of an accurate error correction model is the key to the widespread application of the above models. In addition, the integration, real-time and intelligentization of underwater measurement systems will be the development trend of underwater measurement in the future.

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