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# Application of above & below the water 3D measurement technology in reservoir capacity curve calibration*

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**Abstract.** The reservoir capacity curve is a key quantity for the safe operation of reservoirs, and the reservoir capacity may change during the operation of reservoirs due to various factors, so timely calibration is required. The topography of the reservoir area is measured in three dimensions using an unmanned aircraft and an unmanned boat, respectively. The data results establish a digital elevation model (DEM) of the reservoir area, and the DEM square grid method is used to calculate the reservoir capacity, thus realising the calibration of the reservoir capacity curve. The technical method was successfully applied in Lujiayao Reservoir with high accuracy of results.

**Keywords:** Unmanned aircraft; unmanned vessels; three-dimensional measurements; reservoir capacity curves

## 1. Introduction

There are over 98000 reservoirs in China, of which over 95% are small reservoirs (as in [1]), and most were built in the 1950s and 1960s. The basic data of reservoirs are seriously insufficient, especially the key quantity of reservoir capacity curve related to flood control and drought relief safety, which is generally missing, affecting the operation safety of reservoirs (as in [2]). Further, insufficient data or accuracy of the reservoir capacity curve has become a major obstacle in the application of the "four pre" function of intelligent water conservancy (or digital twins). At the same time, influenced by factors such as sediment deposition during the operation of the reservoir, the reservoir capacity curve has also changed, especially in the Yellow River basin (as in [3]). If not calibrated in a timely manner, it will affect the performance of the main functions of the reservoir, reducing the degree of guarantee for power generation, water supply, irrigation, and other functions. Therefore, the research on reservoir capacity curve measurement technology has certain practical significance and practical value.

The key to calibrating the reservoir capacity curve is the acquisition of topographic data in the reservoir area, including underwater topographic data and underwater topographic data (as in [4]). Currently, the measurement method has been transformed from traditional manual methods to remote sensing and unmanned intelligent technology. Unmanned aerial vehicles are widely used in water partial measurement due to their strong applicability and wide mapping range. Unmanned ships carrying scanning equipment operate stably and route intelligently, which effectively solves the problem of wide reservoir water surface range Difficulties such as complex underwater and nearshore environments. The combination of unmanned aerial vehicles and unmanned ships has been widely used in topographic survey of reservoir areas in recent years. This paper takes the Lujiayao Reservoir in Hongsiu, Ningxia as the object, and uses advanced technologies such as unmanned aerial vehicles and unmanned ships to carry out underwater three-dimensional survey to obtain topographic data of the reservoir area. The DEM grid method is used to calculate the reservoir capacity and achieve the calibration of the reservoir capacity curve.

## 2. Project Overview

The Ningxia Hongsibu Lujiayao Water Supply Source Project is a regional key water conservancy construction project aimed at solving the problems of production and living of ecological immigrants in Hongsibu District and industrial water consumption in Hongsibu Entrepreneurship Park, and providing multi-source support for production and living water supply in Hongsibu urban area. The project is a third-class medium-sized project, consisting of three parts: water diversion project, water intake project, and reservoir project. The retaining dam is a roller compacted homogeneous earth dam with a total designed storage capacity of 3.8 million $m^3$, including 512100 $m^3$ of siltation storage capacity,

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3143900 $m^3$ of regulation storage capacity, and 144000 $m^3$ of flood control storage capacity.

The construction process of Lujiayao Reservoir is affected by soil borrowing from the reservoir area, and the reservoir capacity curve has changed compared to the design stage. In addition, the sediment content of the incoming water from the reservoir is large, which may lead to reservoir sedimentation. The two factors have a cross impact, so it is necessary to re calibrate the reservoir capacity curve.

## 3. Research Method

The three-dimensional topographic survey of the reservoir area is divided into two parts: underwater topographic survey and underwater topographic survey. The underwater topographic survey uses a multi rotor unmanned aerial vehicle, equipped with a laser visible light fusion load and a phase free tilt camera to carry out surveying and mapping work in the air. The underwater topographic survey uses a unmanned ship carrying GNSS-RTK and a single beam bathymeter to carry out underwater topographic mapping.

The reservoir capacity is the water storage volume below a certain water level or between two water levels. Using the measured digital elevation model (DEM) of the reservoir area, the water body is divided into several cubes and integrated one by one to calculate the reservoir capacity.

## 4. Three-dimensional Mapping

### 4.1 Fundamental Work

Before the formal field survey, it is necessary to collect and analyze the topographic map, image map, duration storage capacity curve data, and relevant design data of the reservoir within the survey area. The survey control point is the key to the technical preparation stage.

Lujiayao Reservoir lacks preliminary geological exploration data and local elevation control points and coordinate conversion parameters. Therefore, the CGCS 2000 national coordinate system is directly measured using the CORS network RTK (as in [5]). This coordinate system is different from the elevation system used in the design report, and needs to be converted before use. The conversion method is to use local elevation anomalies for correction. Using the EGM2008 model, the elevation anomaly value of the location of the reservoir (37d30'16.55 "N 106d5'11.25.36" E) is -41.0511m. The local normal height $h$ can be calculated based on the geodetic height $H$ and the elevation anomaly value ($\xi$). The relationship line is modified, and the calculation formula is (1).

$$h=H-\xi \tag{1}$$

Therefore, this survey uses the CGCS2000 coordinate system for both water and underwater measurements, with a Gaussian Kruger projection of 3° and a zone of 35. Lujiayao Reservoir is located at 37d30'16.55 "N 106d5'11.25.36" E, with a central longitude of 105° E.

### 4.2 Measurement of the Part above the Water Surface

After determining the control point and coordinate system, conduct a field survey to determine the range of aerial photography and the flight route. The drone flies according to the designated route. The route for this aerial photography is shown in Fig. 1. To ensure flight stability, select a sunny and windless environment for operation, and maintain a stable flight attitude. Due to the scarcity of vegetation in the reservoir area, a dual echo mode is adopted, with a sidewise overlap rate of 60% for lidar and a heading overlap rate of 70% for visible light. This improves the density and measurement accuracy of point clouds in the survey area, with a point cloud density of 200 pieces/$m^2$ and a ground sampling distance (GSD) of 2.73cm/pixel, greatly improving the operational efficiency compared to traditional methods.


Fig.1 Aerial photography route

### 4.3 Measurement of Underwater Part

The unmanned ship carries GNSS-RTK to obtain real-time hull plane position information based on the CORS network. At the same time, a single beam bathymeter is used to conduct underwater topographic survey. The bathymetric line spacing is set to be 10m, and the continuous sampling spacing is less than 2m. To obtain as comprehensive underwater topographic data as possible, synchronization of positioning and bathymetry is achieved, fully meeting the measurement accuracy requirements. In the process of bathymetry, it is also necessary to correct the sound velocity, draft, dynamic draft, time delay, and static bathymetry to ensure the accuracy of the bathymetry. The elevation value of each measuring point is obtained by subtracting the water depth measured by the bathymeter from the real-time water level.

## 5. Reservoir Capacity Calculation and Reservoir Capacity Curve Drawing

### 5.1 DEM

After the completion of aerial photography by unmanned aerial vehicles (UAVs), the data measured on water should be checked first. It mainly checks the flight quality and image quality of aerial photography, such as the actual image overlap, image inclination and rotation angle, route curvature, coverage area, image clarity, image point displacement, etc. Based on the checked data, the beam method and regional network combined adjustment method are used for controlling and encrypting. Using professional software to process the laser point cloud data (Fig. 2), manually delete the reflective noise on the water surface, and remove the noise and vegetation through point cloud filtering, which is used to generate subsequent unit grids.

Fig.2 Digital point cloud 3D model of Lujiayao reservoir

For underwater measurement data, use water depth measurement software to input water level observation data and other correction numbers, and automatically perform various corrections such as water level, dynamic draft, and waves. If conventional mode sounding is used, manual calculation method shall be used for correction. Conduct a rationality check of the bathymetric survey results and eliminate erroneous water depth points, with the eliminated data not exceeding 10%. Determine the choice of sounding line based on the track map and input it into the computer.

The merging and processing of land and water topographies are carried out under the same coordinate system (CGCS2000). The merging principle is that the existing objects at the junction do not change their true shape, and the splicing of landforms does not produce deformation. Figure 5 shows the combined results of above water and underwater data, and generates contour lines (isobaths) based on measured data. As shown in the figure, digital elevation models (DEMs) within the reservoir area can be generated based on the contour lines in Fig. 3.

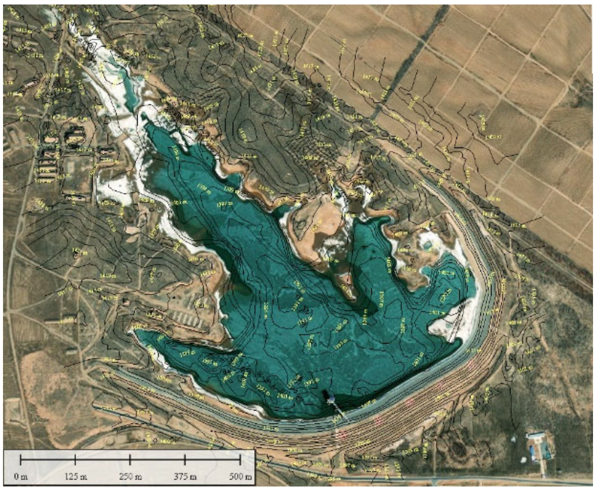


Fig.3 Topographic contour line of Lujiayao reservoir

### 5.2 DEM square grid method for calculating storage capacity

The DEM grid method uses the established digital elevation model (DEM) of the reservoir area to differentiate the water body into several cubes. By integrating the volume space of each cube, the entire reservoir capacity can be obtained. The calculation formula is (2).

$$\boldsymbol{V} = \sum_{i=1}^{n} P_s \left( H - h_i \right) \tag{2}$$

In the formula, $V$ is the storage capacity (m$^3$), $P_s$ is the area value of a single DEM grid (m$^2$), $H$ is the elevation surface of the specified water level (m), $h_i$ is the grid elevation value of the specified water level for the elevation light rain (m), and $n$ is the number of DEM grids with an elevation less than $H$.

There are differences between the above water and underwater topography in this survey and the preliminary design survey, and the comparison between the two is shown in Table 1.

Table 1. Water Level- Area Storage- Capacity Comparison Table

| Elevation (m) | July 2022 | | October 2011 | |
|---|---|---|---|---|
| | *Area*($m^2$) | *Accumulated storage capacity* ($\times 10^4$ $m^3$) | *Area*($m^2$) | *Accumulated storage capacity* ($\times 10^4$ $m^3$) |
| 1389 | 0 | 0.00 | 561.83 | 0 |
| 1390 | 1631 | 0.06 | 3268.08 | 0.17 |
| 1391 | 5314 | 0.40 | 5294.38 | 0.6 |
| 1392 | 9544 | 1.14 | 8600.21 | 1.28 |
| 1393 | 16924 | 2.43 | 14465.49 | 2.43 |
| 1394 | 31408 | 4.78 | 23959.57 | 4.33 |
| 1395 | 53546 | 8.99 | 33460.61 | 7.18 |
| 1396 | 72955 | 15.39 | 44711.34 | 11.08 |
| 1397 | 90275 | 23.49 | 59164.81 | 16.26 |
| 1398 | 108789 | 33.48 | 75252.99 | 22.96 |
| 1399 | 127801 | 45.32 | 90624.87 | 31.24 |
| 1400 | 147797 | 59.08 | 109311.81 | 41.23 |
| 1401 | 168947 | 74.92 | 128232.48 | 53.09 |
| 1402 | 190559 | 92.88 | 151095.41 | 67.04 |
| 1403 | 215575 | 113.14 | 185841.69 | 83.86 |
| 1404 | 245093 | 136.14 | 227083.27 | 104.47 |
| 1405 | 274036 | 162.04 | 267010.64 | 129.15 |
| 1406 | 307770 | 191.09 | 317107.53 | 158.32 |
| 1407 | 340610 | 223.53 | 357005.46 | 192 |
| 1408 | 371615 | 259.15 | 402562.06 | 229.96 |
| 1409 | 418995 | 298.59 | 447761.65 | 272.46 |
| 1410 | 456353 | 342.32 | 499770.54 | 319.81 |
| 1411 | 506971 | 390.62 | 556111.48 | 372.58 |
| 1412 | 566545 | 444.06 | 623008.19 | 431.5 |
| 1413 | 618082 | 503.20 | 678703.34 | 496.57 |
| 1414 | 687943 | 568.33 | 741260.13 | 567.54 |
| 1415 | 745153 | 640.10 | 819625.14 | 645.55 |
| 1416 | 793384 | 717.10 | 894116.47 | 731.21 |
| 1417 | 836963 | 798.50 | | |
| 1418 | 874310 | 884.22 | | |

### 5.3 Reservoir capacity curve

The storage capacity curve can be drawn based on the calculated storage capacity curve data.

According to Table 1, in areas with elevations below 1397m and above 1412m, the measured storage capacity is close to the original storage capacity results (2011), and within the elevation range of 1397m to 1412m, the measured storage capacity is greater than the original storage capacity results. According to the construction and operation of the reservoir, the factors that cause topographic changes in the reservoir area include the impact of the dam construction period on the surrounding terrain, bank collapse and settlement in some areas after the reservoir impoundment, and sedimentation due to high sediment content in the incoming water. According to the measured terrain this time, there is no obvious siltation bar near the reservoir intake, indicating that the reservoir has had a relatively light siltation situation since its completion, and sediment deposition is not the biggest factor in topographic changes since the reservoir was built and operated. In addition, different measurement methods and methods may also be the reasons for differences in reservoir capacity curves, including elevation point measurement methods, contour generation processes, and reservoir capacity calculation methods.

## 6. Conclusion

In this paper, unmanned aerial vehicles and unmanned ships are used to conduct three-dimensional measurements on the water and underwater, and the measurement results are spliced and applied to achieve calibration of the reservoir capacity curve. This has been successfully applied to the Lujiayao Reservoir in Hongsibu, Ningxia. The main conclusions reached are as follows:

The survey data are processed through inspection, correction, noise removal, and encryption to form a digital elevation model for the reservoir area. The reservoir capacity is calculated based on the DEM grid method to ensure the quality and accuracy of the results.

There are three factors affecting the reservoir capacity, namely, construction soil borrowing, water storage, bank collapse, and sediment deposition. The first two factors dominate the change in the reservoir capacity of Lujiayao Reservoir. In addition, different measurement techniques and methods also have a certain impact on reservoir capacity results.

This survey adopts advanced airborne laser radar system and unmanned vessel bathymetric measurement system, with small measurement point spacing, high accuracy, and high reliability of measurement results.

## References

1. S. Zhengang, Z. Lan, and D. Zhongde, “Quantity and distribution of reservoir projects in China,” China water resources, vol. 2, pp. 10-11, July 2013.
2. L. Gang, “Research on Management and Maintenance of Water Conservancy Projects,” China Water Transport, vol. 11, pp. 125-126, July 2011.
3. D. Anjun, C. Jianguo, and H. Haihua, “Analysis of reservoir siltation in China,” Shuili Xuebao, vol. 53, pp. 325-332, June 2022.
4. Z. Chen, M. Naixia, and Z. Xia, “Application of Unmanned Intelligent Technology in Topographic Surveying and Capacity Calculation of Reservoir,” Bulletin of surveying and mapping, vol. 2, pp. 72-76, November 2017.
5. S. Jianguo, Z. Xinghua, and D. Wenyi, “The Measurement Method of Reservoir Capacity Based on the Underwater Terrain Survey and UAV Aerial Photography Technology,” Zhejiang Hydrotechnics, vol. 6, pp. 90-93, June 2015.