# Application research of multi-beam bathymetric and UAV aerial technology on mountain reservoir capacity measurement

NAN Sheng[1,a], YE Sui Gao[2,b *], ZHONG Wei Fan[3,c]

[1,3]Zhejiang surveying institute of estuary and coast, Hangzhou 310008, China

[2]Zhejiang Institute of estuary and hydraulics, Hangzhou 310020, China

[a]nans365@163.com

[b]yesuigao@aliyun.com

[c]zhongwf59@126.com

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**Abstract:** The reservoir capacity curve is important to maximize the utilization of water resources and effective reservoir management. The reservoirs in Zhejiang Province generally locate in mountainous area, and it is difficult to obtain DEM of area above water level by conventional measurement method. UAV technology was applied to obtain DEM of area above the water surface, and multi-beam bathymetric technology was used to obtain high-density and more precision DEM of area underwater. The reservoir capacity curve was obtained by using the underwater DEM combined with the land terrain data above water. The case study in Tongjiqiao reservoir of Pujiang County, Zhejiang Province, proved that the method could be a reliable solution for mountainous reservoir capacity measurement, characterized in high efficiency and guaranteed surveying accuracy, meanwhile, overcome the difficulty of manual surveying on the steep banks.

## Introduction

From the capacity curve, one may obtain the reservoir capacity and calculate the water balance to facilitate the optimized reservoir operation, and thus the reservoir capacity is the important parameter to optimize the reservoir operation and its precision directly influences the flood control safety and economic benefits on power generation and irrigation of the reservoir [1]. Generally, the capacity is calculated by DEM established with the topographic data of the reservoir area [2,3], and the influencing factors in calculation of the reservoir capacity with this method mainly include ① the selection of math model in capacity calculation and its differential order, and ② the precision of the topographic data. The math model is correlated with the morphologic conditions, size and complexity of the reservoir. The topographic data mainly include the data of the contours or elevational points. Insufficient precision or concentration of the contours or elevational points will impair the precision of DEM model and thus worsens the precision of the capacity calculation.

Establishment of DEM data for the reservoir area requires underwater and land topographic data. In the traditional underwater topographic data, the survey point is positioned with net RTK technique and the water depth is surveyed with bathometer, i.e. with single beam bathymetric method, but the underwater elevational points obtained with this method have a small concentration. The land topographic data are obtained through manual survey, however, for the mountainous reservoir the topography and geomorphy of the reservoir boundaries is very complex, its manual survey is impossible or much difficult, and the traditional survey method requires much time and labors, and involves high cost. In the last years, the underwater bathymetric technique was developed rapidly, and the multi-beam bathymetric technique was widely used in underwater topographic survey, which, compared with the single-beam bathymetric technique, is characterized by multiple bathymetric points, high survey precision, fast and simple survey, and full-coverage of the survey area [4]. With constant development of 3S technique, acquisitioning the high-precision land DEM with UAV aerial technology becomes a new technique in calculation of reservoir capacity. This method is characterized by the high precision, short engineering period, small-required human resources, high automatic degree, and fast calculation. Here, the survey on reservoir capacity is approached with the multi-beam bathymetric technique in combination with UAV aerial technology. This method was used in a project production, the high-precise capacity of mountainous reservoir was obtained, and the capacity curve is plotted, which improves the capacity calculation precision, solves the difficulty in manual survey, and provides a reliable solution for survey of capacity of the mountainous reservoir.

## Multi-beam underwater topographic survey

Compared with the traditional single-beam bathymetric system, by which one time of survey merely obtains one value of the surveyed depth of the sea bed vertically under the survey boat, the multi-beam bathymetric system obtains the values of sea bed depth of several survey points in the area covered by a belt, transforms the “point-line” survey to the “line-face” survey, has the advantages of wide survey range, fast survey, closed collection points, and high precision and efficiency, expands the bathymetric survey from point and line to face, is developed to the stereo bathymetric survey and automatic imaging, and is especially suitable for massive underwater topographic survey.

### Work principle

The multi-beam bathymetric system surveys the water depth on basis of the characteristics of underwater transmission of the sound velocity. It with the transducer array transmits wide sectional-area covered sound waves to the sea bed, starts the counter, and receives the narrow beam of the reflected sound wave with the transducer array. The return time of the echo is different for different refection points from the transducer. The echo reaching the transducer includes the information on the underwater relief, and the processing of the echo on formation of multi-beam at fixed direction, the energy accumulation, and the amplitude detection. When the echo signal at a given angle is detected, its counter is recorded, and one cycle of survey is completed when all echoes at all to-measure angles are reached. On basis of the calculated value of the corresponding angle and the sound velocity at which the survey is made, the distance between the reflection point and the transducer may be calculated, and through trigonometric transformation the depth of several points may be measured. When the survey boat moves forwards and makes survey continuously, it may complete the underwater topographic scanning [5,6] in the water area by its both sides.

### Positioning of survey point and control of water level

The survey point is positioned and the water level is controlled with net RTK 3D bathymetric technique, and during the survey process, CGCS2000 geodetic coordinates and temporary geodetic elevation of the survey points are directly collected. In order to ensure synchronous positioning of survey point and bathymetric survey, the time of the computer, the time of bathymetric equipment, and the time of GPS positioning shall be unified. The receiving antenna of GPS shall be vertically fixed above the bathometer transducer, and the installation height of antenna shall be above the haul height and insulated from the metallic parts. Before survey, the distance from the GPS antenna to the water surface is precisely surveyed, and then input to the navigation software for automatic correction so as to ensure correct and reliable temporary water surface geodetic elevation surveyed by net RTK.

**Layout of survey line**

In underwater multi-beam topographic survey, the main survey lines are vertical to the thalweg of the reservoir, and their interval shall be designed as per the requirements on survey scale. The single-beam inspection lines shall be evenly arranged in the relatively flat area, and are basically vertical to the main survey lines, and as per the specification, their length shall not be below 5% of total length of the main survey line.

**Data processing**

The multi-beam bathymetric data are processed in Caris Hips & Sips as follows: At first, calibrate the surveyed data, find out the roll, pitch and yaw of the system, establish the boat model on basis of these parameters, input information on relative positions between the auxiliary devices of Sonic 2024 system, newly establish engineering document with the said document of boat form, load-in the original-observed data into the creation document, after edition of the navigation data, attitude data, course data and water depth correct the profile of sound velocity and the wave level, on this base conduct the transformation calculation of the water depth of the belt, after defining the geographic parameters of the survey area conduct gridding of the water depth, on basis of the grid model edit the water depth data in sub-areas, finish the grid model of the bed surface, and derive the elevation data. The elevation of each survey point in the underwater topographic survey is obtained through deduction of the temporary water level by the water depth at the survey point. The data processing is shown in Fig. 1.

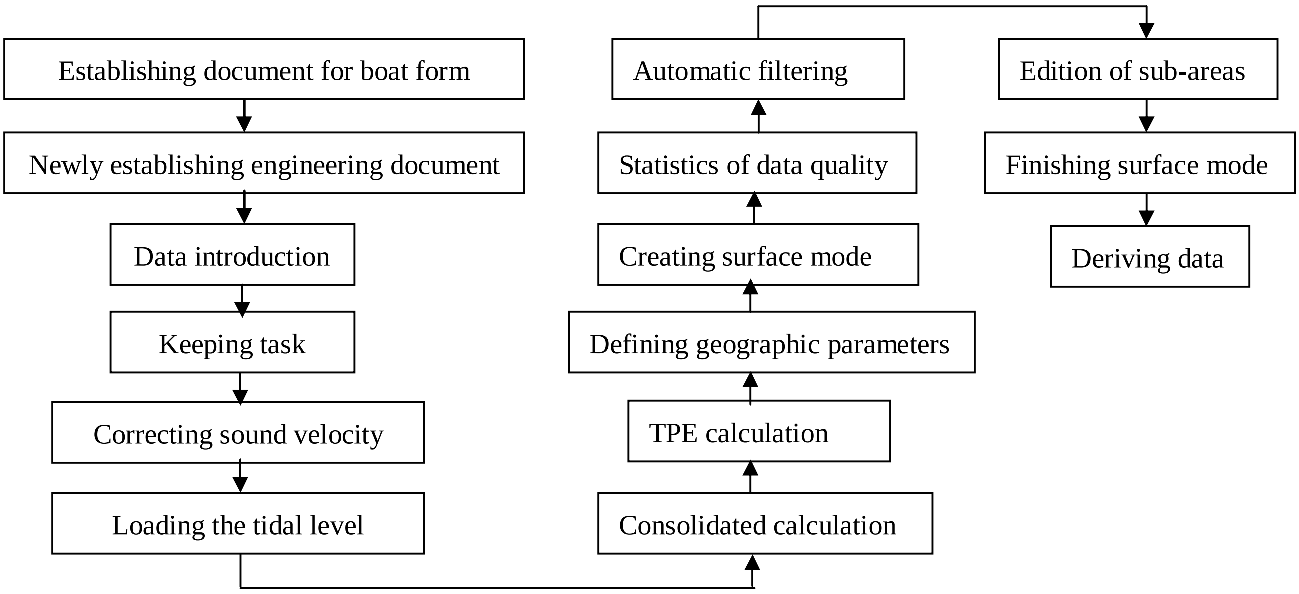



Fig. 1 Caris Hips & Sips multi-beam data processing chart

**UAV aerial technology**

UAV aerial technology is characterized by the long cruise duration, real-time image transmission, possible sounding in highly dangerous area, low cost, high resolution, and good flexibility, and is widely used in ecological protection, monitoring of ocean environment, investigation of land utilization, investigation of hazards in highly dangerous area, survey, plotting, and upgrade of topographic map, and urgent rescue [7,8,9,10]. Due to the wide coverage, flexible attitude, and strong wind resistance, in combination with auxiliary devices such as carried GPS and POS, the fixed-wing UAV is widely used to obtain high definition image data and survey and plot the large-scale topographic map and it can meet the requirements on precision for topographic maps at 1: 2000 or higher scale.

**UAV platform**

UAV denotes the non-manned aircraft manipulated and controlled by radio remote controller or automatic driving and automatic controlling unit to implement the flight or other tasks, and it mainly includes the fixed-wing UAV, unmanned helicopter and unmanned airship [11]. Due to easy remote control or programmed control, and high wind resistance, the fixed-wing UAV is the UAV in China which is currently most widely used and has the most species. The unmanned helicopter is flexible in takeoff and landing, and has low requirements on ground, but it is liable to affect by weather, is difficult in manipulation and control, and low in speed, and is usually used in urgent survey and mapping. The unmanned airship is characterized by the high load, easy manipulation and control, and low speed, can ensure sufficiently high safety, and is usually used for operation in high-popularized area.

**UAV aerial technology process**

UAV aerial technology process includes four steps (route design, digital air-photo, arrangement and survey of photo-control point, and data processing), as shown in Fig. 2. Depending on the geographic conditions of the survey area, the used digital camera and the requirement on scale, in the design and planning of route in the photo-area, the forward overlap and the lateral overlap shall not be below 70% and 50% respectively. On the ground station, the designed route is loaded into the flight control system, UAV ground station system controls the flight of UAV as per the designed route, and the flight control system governs the camera to take photos as per the preset route and photo mode. The camera stores the taken pictures, and renders them high definition, rich stratification, adequate contrast, and freedom of defects such as cloud and shade. On basis of the original images and the image POS data, the data is fast montaged, and on the fast-montage map the adequate photo-control points are selected. The photo-control points shall be evenly distributed over the entire survey area and easily identified. Usually, the image-controlled survey is made with net RTK, and for the difficult areas, GPS fast static survey is made. The aerial triangulation process includes the distortion correction, image matching, free network adjustment, image puncturing point, control network adjustment, and outputting of the aerial triangulation achievements.

DLG data at scale of 1:2000 is formed with the job method “outside after inside”. As per the aerial triangulation achievements and image data, the stereo model is established in full-digital photo survey system Virtuo Zo NT, in the stereo model the visible ground objects and landform are collected, through field operation the properties, structure and attribute of the ground objects are checked, annotated, and additionally surveyed, and the indoor operation corrects the survey on basis of the additional annotation achievements.

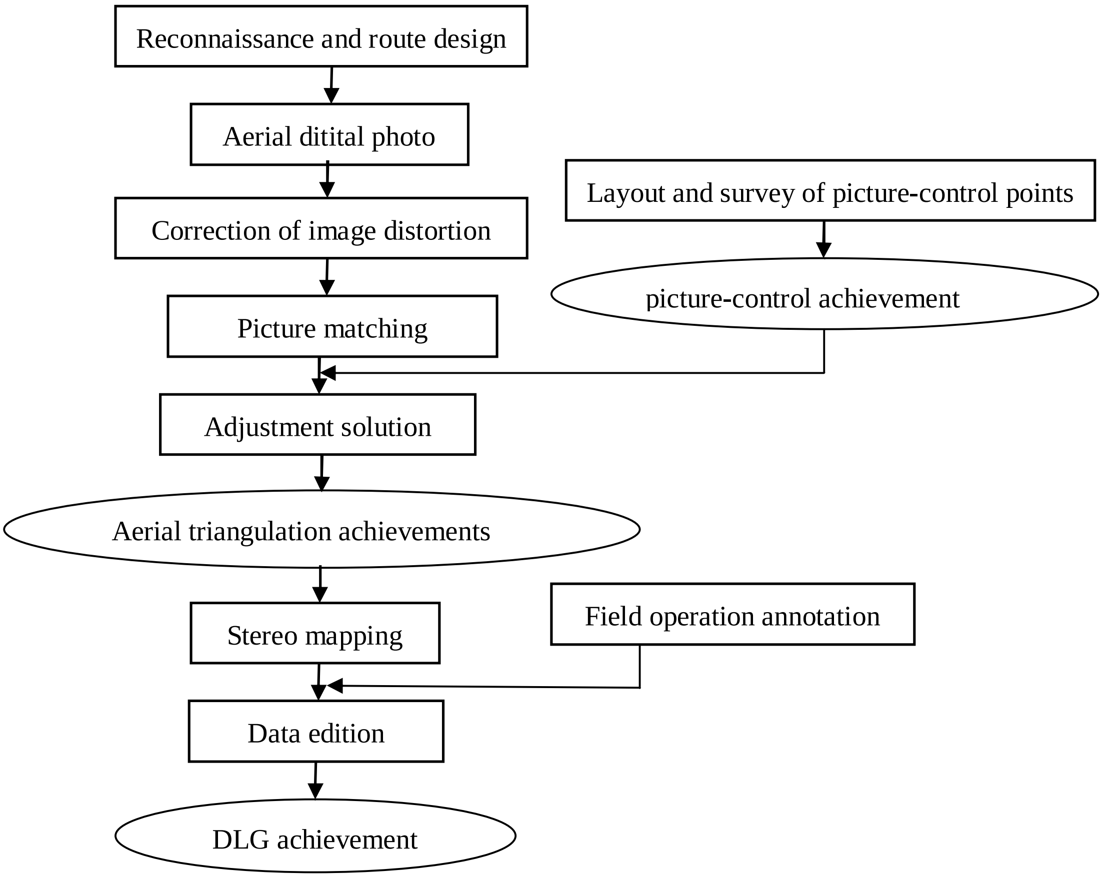



Fig. 2 UAV aerial technology process

## Capacity calculation method

Generally, the structure of DEM data includes TIN (triangulated irregular network) and grid (regular grid). By establishing DEM data (including the underwater and land topographic data), it integrates the underwater and land topographic data, extracts the data of contour and elevational point, checks for point-line contraction and data mission existing in the data, loads the data, transfers the data to GIS software, and forms DEN with the said software, as shown in Fig. 3.

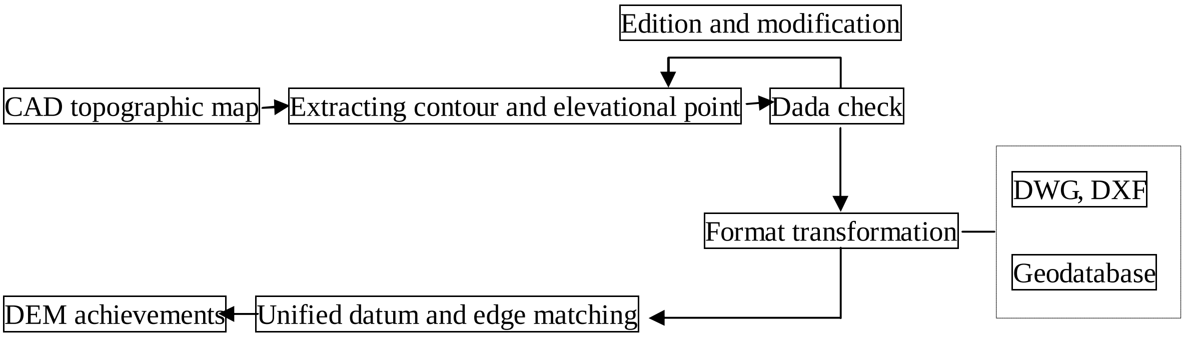



Fig. 3 Flow chart of fabrication of DEM

## Square grid model

By square grid method, it with the established regular grid DEM data of reservoir area differentiates the reservoir water body into several cubes, and the capacity of the entire reservoir may be obtained through summing the volume integration of the formed cubes. Its math model is:

$$V = \sum_{i=1}^{n} p_i (H - h_i) \tag{1}$$

Where, V is the capacity, $p_i$ the area of each grid, H the elevation value of the designed water level, $h_i$ the elevation value of grid below the designed water level, and n the number of DEM grids whose elevation value is below H.

**Triangular grid model**

By triangular grid method, it with the established irregular grid model TIN of reservoir area and as per the actual bottom morphologic features differentiates the reservoir water body into several triangular prisms and the capacity of the entire reservoir may be obtained through summing the volume integration of the formed prisms. Its math model is:

$$V = \sum_{i=1}^{n} p_i (H - (h_i + h_{i+1} + h_{i+2})/3) \tag{2}$$

Where, V is the capacity, $p_i$ the area of each grid, H the elevation value of the designed water level, $h_i$, $h_{i+1}$ and $h_{i+2}$ the elevation value of three angular points of the triangular grid, and n the number of triangular grids.

## Case study

Tongjiqiao Reservoir is a middle-scaled reservoir integrating with the flood control, irrigation, culture and power generation. In order to provide basic data to the reservoir comprehensive regulation project, the topographic data of reservoir are obtained with 3D bathymetric survey method in combination with the UAV aerial technology and the multi-beam bathymetric system.

In the underwater multi-beam topographic survey, the multi-beam bathymetric system manufactured by USA R2 Soinc Corporation is used, the designed interval of survey lines is 40m, and the total length of the survey lines is 95.1km, with the survey lines and inspection lines shown in Fig. 3. The survey method and survey precision for the single-beam inspection line are same to that for the main survey line, and, after the survey, the comparison between the elevations of the survey point of the main survey lines and inspection lines within 1mm range of the map shows that the bathymetric survey precision meets the requirements. The elevation at each point is found through subtracting the temporary water level by the water depth of survey point and thus the underwater topographic map at scale 1:1000 is obtained.

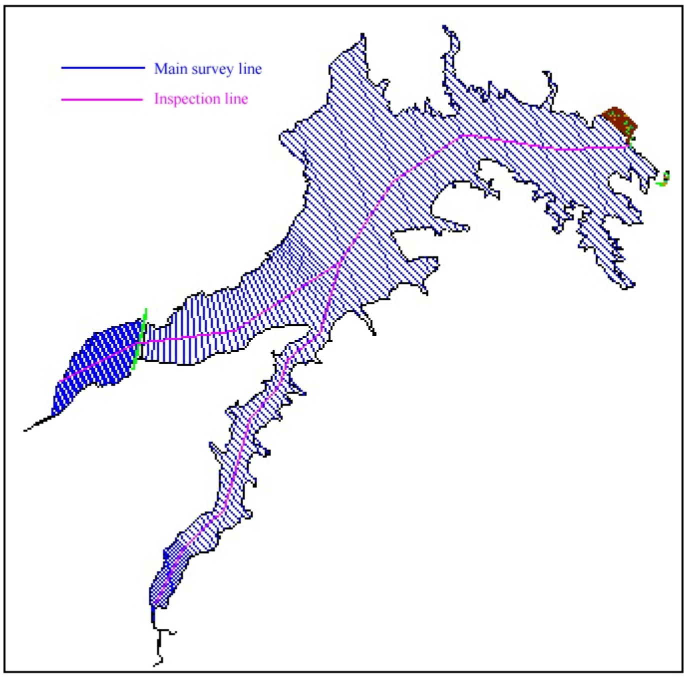


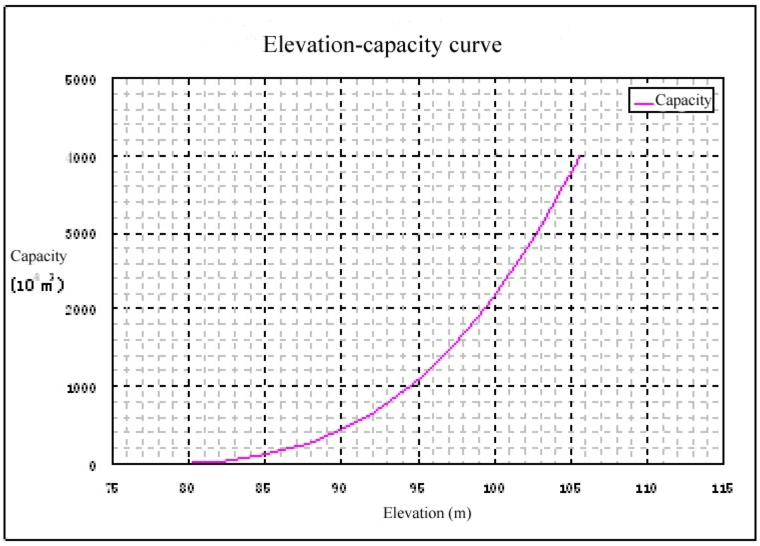
Fig. 4 Schematic diagram of layout of survey lines in underwater topographic survey area

Model DM-150 fixed-wing UAV-carried Canon EOS 5D MARKIII camera takes aerial photos and collects data, and the focus of camera mirror is 34.37mm. Within the survey area, the highest and the lowest absolute elevation is about 441m and 75m respectively, the designed resolution is 8cm, aerial photo scale is 1: 12480, the designed relative flight height is 436m, the forward overlap is 75%, the lateral overlap is 50%, the flight coverage is 30km$^2$, totally 20 strips are covered and 2152 pieces of original pictures are taken. At encryption of the aerial triangulation, the relative orientation points are evenly distributed, the standard error and the maximum error in relative orientation is 8μm and 16μm respectively. After absolute orientation, the residual of basic orientation points, the inconformity of surplus control points and the deviation between common points conform to the specification, and Table 1 is the statistic report of control points. The plane standard error and the elevation standard error of DLG conform to the DLG production specification at scale 1:2000.

Table 1 Precision of aerial triangulation Unit: m

| Statistic content | | Standard error | The maximum | The minimum |
|---|---|---|---|---|
| Control point | X | 0.21 | -0.46 | 0.11 |
| | Y | 0.15 | 0.44 | 0.12 |
| | Z | 0.13 | 0.31 | 0.11 |
| Check point | X | 0.28 | -0.61 | 0.15 |
| | Y | 0.29 | 0.52 | 0.14 |
| | Z | 0.58 | -0.93 | 0.19 |

Integrate the underwater topographic data with the topographic data, abstract the contour and elevational point data, with ArcGIS software form reservoir topographic DEM data, on basis of the designed elevation (assumed water level) calculate the corresponding capacity, and plot the elevation-capacity curve of the reservoir area (shown in Fig, 5).




Fig, 5 Elevation-capacity curve of reservoir area

## Conclusions

In Zhejiang, the reservoirs are usually built in geomorphic-complex mountainous areas, manual survey of the topographic data of the reservoir bank is very difficult and highly dangerous, and the work efficiency is rather low. With fast development of UAV aerial technology, this technology is widely used in large-scale topographic survey mapping fields, especially in operation in difficult areas and for urgent response, which eliminates the insufficiency of the traditional survey method. With constant maturating and perfection, the multi-beam bathymetric technique is widely used in underwater topographic survey. Here, a method combining multi-beam bathymetric technique with UAV aerial technology is proposed to acquisition the reservoir underwater and land topographic data. This method can fast, correctly and easily acquisition the reservoir underwater and land topographic data and is successfully applied in the capacity survey project of Pujiang Tongjiqiao Reservoir, which eliminates the trouble of impossible survey for difficult area usually encountered by the traditional survey method, improves the work efficiency, saves the cost, and provides a solution for survey of reservoir capacity.

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