Experimental study of three-dimensional photogrammetry technique in the observation of qiantang tidal bore’s height

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Abstract. In this paper, the three-dimensional photogrammetry is introduced in the tidal bore height observation of Yanguan station for the thread-shape bore near the Qiantang River estuary. The three-dimensional scene of the tidal bore is restored by remote control and post-solution. The measurement of tidal bore’s height in three-dimensional environment is realized, and the auxiliary measurement of tidal bore’s upper bound, the foot line, the tidal curve and other vector data are extracted. The accuracy of the measurement is compared with the result of the tidal bore height measured by the Water gauge observations on the same station. The results show that not only the tidal bore’s shape can be captured but also the tidal bore’s height can be quantitatively calculated by three-dimensional photogrammetry. The three-dimensional photogrammetry can be used to quantitatively observe the tidal bore’s height in Qiantang River Estuary and the measurement accuracy is reliable.

1. Introduction
The tidal bore in the Qiantang River estuary is a very special kind of water movement, with high flow velocity, strong destructive power, and complex flow characteristics. It can bring landscape entertainment to the public and cause erosion and siltation of the river bed and erosion of the foundations of buildings along the river. Destabilize the embankment and destroy the building. To maintain the unique natural landscape resource of tidal bore, and to alleviate or even eliminate its harm, it is necessary to objectively understand the tidal bore, master the hydraulic characteristics of the tidal bore and the law of tidal wave motion.

A direct indicator to measure the magnitude of tidal bore is the height of tidal bore. According to Lin Bingyao's definition, it is the water level difference corresponding to the pre- and post-tide water flow at the tidal bore relative to the tidal bore that meets the water volume and momentum continuous conditions[^1]. Another element is the tide pattern, including the shape of the tide line and the flat line pattern. The tide head pattern refers to the shape of the different tide surge stages. As the tide strength increases, the tide head shape will develop from a wave train to a rolling state. The plane line shape refers to the flat line shape of the tide line on the river surface. For example, the Cross Tide formed by the Qiantang River tide in Haining Babao, the Line Tide of Yanguan, etc[^2].

The traditional method of tidal bore observation is manual visual observation, and then began to use video surveillance system (global eye) to assist manual observation. Manual observation relies too much on the experience of the observers, and the observation results are relatively rough and random,
and it is impossible to measure the irregularity of the tide cycle and the height of the tide. Among the hydrological observations, there are methods to observe the height of tidal bores or waves by means of shore wave meters, such as float gauges. Using a fixed platform, radar or laser can also be used to track the surface motion of water bodies, and other water remote sensing measurement systems are also used in nearshore monitoring[3]. These methods are able to determine the tide height to a certain extent, but the Qiantang River is a strong tidal bore estuary, and the tidal level changes greatly within a short duration when the tide head comes. The above-mentioned observation methods are relatively lagging in judgment and have a greater impact on accuracy. Large, it has a greater impact on the determination of the tide height. Moreover, since the average tide level for a period of time (usually 30s) after the tide head minus the low water level before the tide is used as the observed tidal bore height[2], it is the water level difference at a fixed point at different times and cannot truly reflect the space process of tidal bores.

Three-dimensional photogrammetry provides a new idea for tidal bore observation. Close-range photogrammetry can form a measurable three-dimensional image on a professional instrument from the three-dimensional image captured by a close-up target, so as to obtain the plan view, three-dimensional view, and cross-section of the target object. Figures, perspective diagrams, contour maps, digital models and physical parameters such as the coordinates or length and area of specific points on the surface[4]. In order to improve the completeness and accuracy of tidal bore observations, this experiment was carried out in the Qiantang River Estuary. The officer conducted three-dimensional photographic observations to determine the height and shape of the tide.

2. Experimental design

The main principle of 3D photogrammetry to generate a 3D model is to restore the relative positional relationship of the two images by determining the sparse points of the same name on the image taken by the stereo camera, and at the same time perform dense matching to obtain the dense points of the same name on the stereo image, using the front intersection, The object point coordinates corresponding to the points with the same name are calculated to obtain the three-dimensional point cloud of the measured target, which is then constructed by a triangulation network to generate the TIN model of the measured target, or the Triangulated Irregular Network, which is mapped by texture Method, the texture is mapped to the model to generate a three-dimensional model of the measured target with texture information[5].

The site of this observation and experiment was set up at the Yanguan Tidal Bore Observation Station about 90km away from Hangzhou Bay. The test time was from 11:00 to 13:00 on April 8, 2016, and lasted 2 hours. The test is mainly based on the technical means of close-range photogrammetry. A three-dimensional close-range photogrammetry platform is built at the test site. Later, the wave analysis software is used to solve and analyze the tide surge observation image, restore the three-dimensional scene of the target area of the tide surge, and extract the feature vector data of the tide surge. Measurement and calculation of tidal bore wave height and tidal bore shape in a three-dimensional environment.

2.1. Photogrammetry system

The three-dimensional photogrammetric test system is mainly composed of a three-dimensional photogrammetric device, an observation tower, and a measurement calibration field. The entire system can meet the control requirements of the three-dimensional camera for millisecond-level synchronous shooting. The three-dimensional camera can obtain three-dimensional images within a range of at least 60 meters; the modeling accuracy of the experimental river 3D model meets: within 20 meters from the stereo camera baseline in the experimental river morphology 3D model The error is less than 2cm; the error in the shape of the river within 40 meters from the baseline of the stereo camera is less than 10cm.
2.2. Station calibration

The large air currents along the Qiantang River will cause the observation tower to shake, which will make it impossible for the stereo camera to accurately determine the geodetic coordinates of the tide. In order to eliminate this effect, this experimental design uses the photo control measurement to inversely calculate the geodetic coordinates of the camera position at the time of photography. Add ship-mounted floating landmark GPS surveys on the river surface as the field station calibration field, and set up points near the standard photo control points to achieve the calibration of the absolute position and attitude of the stereo camera for the three-dimensional photogrammetry of the river morphology. At the same time, a high-precision and stable three-dimensional control field was established at the observation station, and the spatial rear intersection solution method of a single photo in photogrammetry was used to calculate the orientation elements inside the camera to calculate the relative position relationship between the two stereo cameras.

2.3. Distortion parameter processing of 3D photogrammetry

In the close-range photogrammetry system, the geometric distortion of the image needs to be corrected. Generally speaking, the geometric distortion of an image is divided into radial distortion and tangential distortion. Radial distortion is the change of the vector end point along the length direction, which is the change of the vector diameter; Tangential distortion is the change of the vector end point along the tangent direction, that is, the angle change dt. The calculation formula of the distortion parameter is as follows:

\[ \Delta x = (x - x_0)(k_1r^2 + k_2r^4 + \cdots) + P_1[r^2 + 2(x - x_0)^2] + 2P_2(x - x_0)(y - y_0) \]  
\[ \Delta y = (y - y_0)(k_1r^2 + k_2r^4 + \cdots) + P_2[r^2 + 2(y - y_0)^2] + 2P_1(x - x_0)(y - y_0) \]

\[ r = \sqrt{(x - x_0)^2 - (y - y_0)^2} \]

In the formula, \((x, y)\) are the coordinates of the pixel point, \((x_0, y_0)\) are the coordinates of the principal point of the image, \(\Delta x, \Delta y\) are the correction values of the image point, and the distortion parameters \(k_1, k_2, p_1\) are calculated according to the above formula, \(p_2\), so as to establish the relationship between the camera calibration field and the feature points on the target image and the distorted image obtained by the camera calibration.

2.4. Image data processing and analysis

The tidal wave stereo shot by the stereo camera synchronously uses the FugroViewer open source graphics processing software to obtain a dense 3D point cloud through image preprocessing, feature extraction, image matching, and forward intersection. Before generating the point cloud, perform photogrammetric correction on the matching points to eliminate or reduce the influence of the camera lens distortion on the point cloud coordinate accuracy.

The three-dimensional point cloud surface conforms to the geometric image representation method, and the spherical polar coordinate system is used to transform the geometric information in the point cloud surface to generate the corresponding geometric image. The point cloud data processing steps are: (a) Point cloud data preprocessing, including denoising, sampling, etc.; (b) Automatically convert point cloud data into polygons (Polygons); (c) Polygon stage processing, mainly removing spikes (d) Convert polygons to NURBS surfaces; (e) Texture mapping; (f) Output file formats that match CAD/CAM/CAE. Through the processing of the above steps, the wave model software is used to model the surge, and the profile surge height value is read through the data analysis tool.

3. Measured results of tide height at Yanguan Station

3.1. Three-dimensional photogrammetric results of tidal bore at Yanguan Station

After Wave Analysis software image preprocessing, feature extraction, image matching, forward intersection and other steps, a dense 3D point cloud is obtained as shown in Figure 1.
Figure 1. The test results of point cloud computing

Before generating the point cloud, the matching points were photogrammetrically corrected to eliminate the influence of the poor camera lens distortion on the point cloud coordinate accuracy. After processing, the three-dimensional picture of the tide surge is generated as shown in Figure 2.

Figure 2. The restored three-dimensional images of tidal bore (Yanguan station on April 8, 2016)

3.2. Calculation result of tide height

Figure 3 Three-dimensional photographic point cloud data of tidal bore obtained from this experimental observation (the white area on the right is the embankment). The red area in the figure is the high water surface elevation. From the point cloud image, it can be clearly distinguished that there are three wave crests and three wave troughs in the tidal bore image (outside the shooting range, the third wave trough is incomplete).
In this point cloud, select the cut planes parallel to the embankment at 10m, 20m, 30m, 40m, and 50m from the embankment. The location of the cut plane is shown in Figure 4. The tidal bore shape of each section is shown in Figure 5.

According to the measurement and calculation, the tide height of each section is shown in Table 1. It can be seen from the table that the pre-tide and post-tide water levels are generally higher near the shore and lower at the far shore, which is consistent with the side wall effect theory. At the same time, what is different from our subjective impression that the tide head at the near shore is larger is that the height of the tidal bore is higher at the far shore. The calculation results show that on April 8, 2016, the maximum tidal height at the near shore of the daily tide at Yanguan Station was 0.9m, and that at the far shore was about 1.3m, with an average of 1.09m.
Table 1. The calculation results of tidal bore’s height using three-dimensional photogrammetry.

| Distance from shore (m) | Water level after tide (m) | Water level before tide (m) | Bore height (m) |
|-------------------------|---------------------------|-----------------------------|-----------------|
| 10                      | 1.77                      | 0.90                        | 0.87            |
| 20                      | 1.73                      | 0.82                        | 0.91            |
| 30                      | 1.69                      | 0.70                        | 0.99            |
| 40                      | 1.53                      | 0.23                        | 1.30            |
| 50                      | 1.53                      | 0.15                        | 1.38            |
| Average                 | 1.65                      | 0.56                        | 1.09            |

3.3. Results of water level observation tide bore height

The time course data of the water level station is used to calculate the tide height by subtracting the water level 30s after the onset of the tide and the water level before the tide[6]. Figure 5 shows the process of the ebb and flow of the daily tide on April 8, 2016, measured by the pressure water level gauge installed at the test station. It can be seen from Figure 6 that the average low water level before the tide is 2.13m, and the tide level instantly rises to 3.21m in the 30s after the arrival of the tide. The height of this daily tide is calculated to be 1.08m, and the three-dimensional tide photography obtained 1.09m value is very close, and the relative error is only 0.93%.

Figure 5. Water level process when fromming the tide for April 8, 2016 Yanguan Station

4. Conclusion

In this paper, a three-dimensional photogrammetric system was set up near Yanguan at the mouth of the Qiantang River to quantitatively observe the tidal bore intensity, and a tidal bore observation test was carried out during the high tide level to accurately observe the shape and height of the tidal bore. The main conclusions are as follows:

(a) Three-dimensional photogrammetry can capture the shape of the tide head, the process of tide level and the height change within a short duration when the tide head comes, and can accurately observe the vector data of the tide top line, the tide foot line, and the tide curve.

(b) Test results showed that in three-dimensional photography applications Xinanjiang observed tidal bore bore accurate height, the height of the measured tidal bore bore height gauge and consistent observation, only relative error between them is 0.93%. Three-dimensional photogrammetry can be used to quantitatively observe the tide height of the Qiantang River estuary.
Three-dimensional photogrammetry observes the difference between the pre-tidal and post-tidal water levels at the time of the tidal surge on the plane. The water level is calculated as the difference between the post-tidal water level and the pre-tidal water level at the same location. Photogrammetry can dynamically capture the tide surge pattern and calculate the full and accurate tide surge intensity in conjunction with the tide surge height. It has a wider range of applications than the traditional water gauge for single observation surge height, such as forecasting tide surge viewing grades and tide erosion on both sides of the seawall. Prediction of the impact of strength, analysis of the impact of tides on buildings in the river, and tide avoidance forecasts for navigable ships in the river provide accurate data support.

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