Relic exploration of Huanghuacheng Great Wall based on underwater surveying technology

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ABSTRACT: Located in Huairou District of Beijing, the Huanghuacheng Underwater Great Wall was constructed in the Ming dynasty, dating back over 600 years of history. Due to the construction of the reservoirs and dam in 1970s, the bottom part of the wall submerged under water and flood, thus a strange section of underwater Great Wall relic formed. After immersion in water for nearly 50 years, the status of the underwater section has not been investigated in detail due to technical limitations. Fortunately, with the use of RC-S2 Survey Remote Controlled Boat, current topography status of the underwater wall was obtained by sonar. After comparison with the spatial location of the Great Wall ruins on the shore, current height and orientation of underwater Great Wall relic were obtained. The 3D model of the underwater Great Wall was established based on these parameters, laying technical foundation for the following archaeological discoveries of underwater ruins. The results showed that: (1) The RC-S2 survey boat is able to collect bathymetric data at a 500ms sampling interval, and the sounding resolution can be up to the centimeter level. (2) The specific location of the underwater Great Wall can be clearly distinguished from the high-precision DEM produced by depth data, and it was consistent with the result of field verification, proving the reliability of the data collected by RC-S2. (3) The real underwater Great Wall scene can be represented by DEM and remote sensing images, combing with 3D model techniques. The successful application of RC-S2 in the underwater Great Wall area opened up new prospects for wide range investigations of underwater ruins with high precision.

Key Words: relic exploration, underwater Great Wall, RC-S2 Survey Remote Controlled Boat

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1 INTRODUCTION

China is the only ancient civilization which has 5,000 years of continuous development, with a vast territory and a long history. And cultural heritage sites are all over the country(Nie, et al., 2009). In history, due to natural catastrophes, such as earthquake, volcanic eruption and tsunami, combined with human factors, some waterside buildings and tombs have been sunk in water (Smith. et al., 2003). The underwater millennium city in Qiandao Lake, Zhejiang Province and the palace ruins of Ptolemy Dynasty under Alexandria port in Egypt are in this case. As important parts of cultureheritage, these underwater cultural heritage sites are in characteristics of historic, irrefragable and non-substitutability. Meanwhile, as a result of less human intervention, they could

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provide a great deal of reliable information on archaeology, culture and technology, which could not only make a supplement in information got from land, but test its validity (Zhao, 2008). With the progress of science and technology, human began to discover, explore and salvage the underwater cultural heritage (Li, 2008). But restricted in professional equipment, technology, staff, investigation cycle, and underwater environment, it is notapplicable to large numbers of small areas. This is a kind of regret to perfect, protect and tourismdevelopment for those non-key regional historical data. As the symbol of the Chinese nation and one of the world's largest historical cultural heritage, the Great Wall has not been known scientifically and uniformly for its reality and current preservation situation for a long time(Chen, et al., 2010), which seriously restricts on effective protection and scientific research on the Great Wall. As a indispensable part of the Great Wall, the Huanghuacheng Great Wall which located in Huairou District of Beijing hasn't been investigated in detail due to instruction in technology and its current situation as a tourist attraction. In this paper, using RC-S2 Remote Controlled Boat, targeting on Huanghuacheng Underwater Great Wall as underwater ruins, through measuring Xishuiyu Reservoir to obtain detail information on position and pattern, which could provide scientific evidence for underwater cultural heritage protection.

2 STUDY AREA AND RESEARCH DATA

2.1 Study area

The Huanghuacheng Underwater Great Wall located in Xishuiyu Reservoir, Huairou District of Beijing, within the range from 40 ° 24'33 "N to 40 ° 24'53" N, 116 ° 17'41 "E to 116 ° 18'28"E , which area of water is 0.15km^2. It was built in Yongle Period of Ming Dynasty, with history of over 600 years, which is the essence of the Ming Great Wall, and the structure of layer block. In the 1970s, owing to the construction of reservoir and dam intercepting, the Great Wall in bottom part had been submerged in water. But with the restriction of technology, the underwater Great Wall hasn't been investigated in detail.

Fig. 1 Water inlet of the Great Wall

Fig. 2 Workingsituation of survey boat

2.2 Data acquisition

Sonar(sound navigation and ranging system), combined with magnetometer as a remote sensing method was applied in traditional underwater archaeology(Zhao, 2006). The typical sensor system contains sonar, side scan sonar, bottom profiler, magnetometer and others, detecting significative abnormal phenomenas. But the remote sensing data got from this system could not meet accurate position(Liu, 1995). RC-S2 Hydrographic Remote Controlled Boat is a new kind of remotely operated survey boat developed in Japan. Compared with traditional underwater archaeological work, it has the advantage of safe and simple data acquisition, single operation, rapid deployment, and automatic navigation and return. Particllarly, it can synchronously exquisite variety of data using GPS and sonoprobe equipped on boat, and the depth could reach 80m at most.

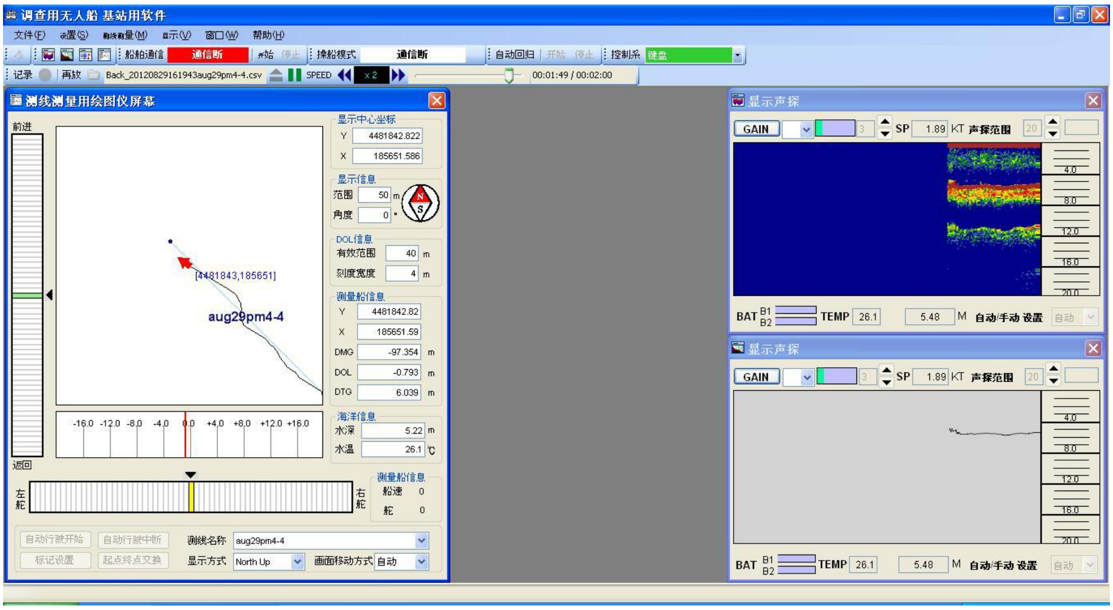

Fig. 3 The real-time transmission interface of data collection

A	B	C	D	E	F	G	H	I	J	K	L
Y值	X值	水深	水深＋吃水	测线名称	起点Y	起点X	终点Y	终点X	DMG（距起点的距离）	DTG（距终点的距离）	DOL（距测线的偏差）
4481921.907	186381.178	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-10.278	65.033	5.632
4481920.614	186380.174	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-9.618	65.694	7.13
4481920.615	186379.692	5.5	5.65	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-9.15	66.162	7.245
4481920.8	186379.26	5.5	5.65	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-8.686	66.626	7.171
4481920.8	186379.26	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-8.686	66.626	7.171
4481921.548	186378.682	5.52	5.67	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.944	67.368	6.585
4481921.959	186378.6	5.5	5.65	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.765	67.547	6.206
4481921.835	186378.481	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.679	67.632	6.356
4481921.274	186378.146	5.47	5.62	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.49	67.821	6.981
4481920.437	186377.742	5.5	5.65	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.302	68.01	7.891
4481919.55	186377.237	5.44	5.59	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-7.027	68.285	8.874
4481918.99	186376.434	5.45	5.6	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-6.384	68.928	9.612
4481918.901	186375.452	5.44	5.59	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-5.452	69.859	9.937
4481919.273	186374.546	5.47	5.62	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-4.483	70.828	9.796
4481920.005	186373.897	5.46	5.61	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-3.676	71.636	9.243
4481920.966	186373.526	5.46	5.61	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-3.083	72.229	8.4
4481920.966	186373.526	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-3.083	72.229	8.4
4481923.099	186373.53	5.51	5.66	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.57	72.742	6.33
4481924.202	186373.76	5.56	5.71	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.525	72.786	5.204
4481925.285	186374.033	5.6	5.75	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.527	72.784	4.087
4481926.352	186374.233	5.6	5.75	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.463	72.849	3.004
4481926.352	186374.233	5.6	5.75	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.463	72.849	3.004
4481928.461	186374.364	5.59	5.74	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.078	73.233	0.926
4481929.419	186374.518	5.59	5.74	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-1.995	73.316	-0.041
4481929.419	186374.518	5.54	5.69	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-1.995	73.316	-0.041
4481930.781	186375.638	5.49	5.64	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-2.752	72.56	-1.634
4481931.062	186376.472	5.52	5.67	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-3.492	71.819	-2.109
4481931.079	186377.38	5.59	5.74	aug29am3-4	4481911.597	186445.6354	4481929.863	186372.5724	-4.369	70.942	-2.345

Fig. 4 CSV format data storage file(including the fields of x coordinates, y coordinates, water depth, the name of the survey line, GPS latitude and longitude value, and speed)

As a result of diverse natural and artificial landscape, the underwater topography is really complex, the RC-S2 Remote Controlled Boat has been applied to investigate the whole underwater topography except those inaccessible areas sheltered by trees. In the center of the water, the measuringline is made of 3 meters interval and in the model of automatic navigation, while boundary, the investigation was preceded in model of manual controlling due to its irregularshape. The operating state of the survey boat is showed in Fig. 2. The velocity of boat in automatic navigation is 1m/s， and the time interval of sampling is 500ms. In this case, 27, 229 sampling points were collected. With higher sampling density, slight variant of underwater topography could be reflected, which could meet the requirements of underwater terrain models. Fig. 3 is the real-time transmission interface of data collection, and Fig. 4 is the data storage format. Another kind of verifying lines with 10 meters interval were laid perpendicular to the measuring. Through two measured value of intersection point of two groups of lines, the accuracy of the acquisition results could be checked. In consideration of the demand of interpolation and visualization later, the range of research region was manually extracted from remote sensing image(Reservoirborder.shp).

3 DATA PROCESSING AND ANALYSIS

3.1 Check of the accuracy of data collection

Two measured values were extracted respectively from the intersection of the two sets of survey lines. According to the classical statistical methods, the maximum, minimum and averages of 103 pairs of extracted intersections were analyzed(Table 1). And the two sets of data were liner fitted simultaneously(Fig. 3). It can be seen from Table 1 and Fig. 1, the difference between the average value of the measured value and the verification value is only 0.03, and the minimum value of the two sets of values of the difference is 0, the maximum is 0.39. This may be due to the signal in the measurement process encountered the suspended solids or the shoal of fish after it transmitted, and the signal returned, received before transmitting to the bottom. In addition, the correlation coefficient R^2 of liner fitting of two sets is 0.998, it showed that two measurement results at the same place are very close. So the measurement results are reliable, they can be used for topographical interpolation.

Table 1 Statistical characteristics of the two sets of measurements

	Maximum/m	Minimum/m	Average/m	Max$\|(x_i-y_i)\|$ /m	Min$\|(x_i-y_i)\|$ /m
Measured line values (x_i)	22.27	1.81	11.97	0.39	0
Verification line values(y_i)	22.30	1.91	12.00		

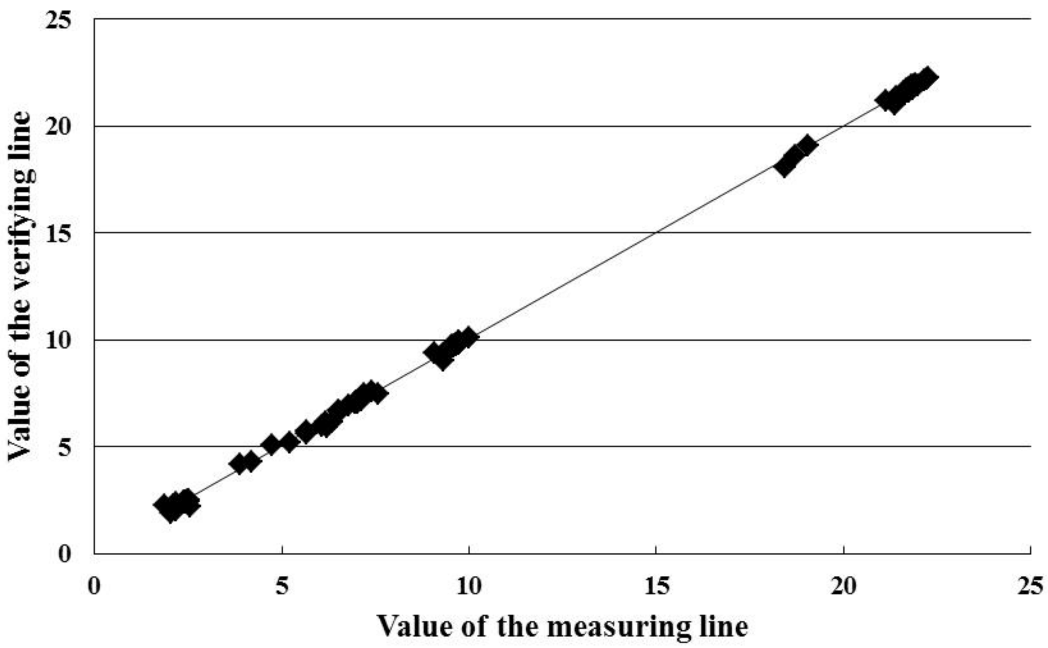

Fig. 5 The diagram of Measured line values-Verification line values

3.2 DEM generation of the study area

There are mainly three categories of data sources for DEM Production: First, image data, mainly from airborne/satellite imagery; Second, ground measurement data, namely ground point data collected from field observations. Third, the topographic map, DEM of the National Topographic Database is established based on topographic maps at various scales(Tang, et al., 2006). In this paper, DEM was generated by interpolation of water depth data collected by RC-S2 surveying boat. In ArcMap, data collected by RC-S2 surveying boat was exported to cjd.shp vector layer according to coordinates. For reservoirs, as underwater terrain is just with minor undulation, “Topo to Raster” in ArcGIS10 is used to express the underwater DEM. The Topo to Raster tool is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs). It is based on the ANUDEM program developed by Michael Hutchinson. The interpolation procedure has been designed to take advantage of the types of input data commonly available and the known characteristics of elevation surfaces. The method uses an iterative finite difference interpolation technique. It is optimized to have the computational efficiency of local interpolation methods such as inverse distance weighted interpolation, without losing the surface continuity of global interpolation methods, such as kriging and spline. It is essentially a discretized thin plate spline technique (Wahba, 1990), in which the roughness penalty has been modified to allow the fitted DEM to follow abrupt changes in terrain, such as streams and ridges.

The Topo to Raster tool, an important interpolation component in ArcGIS10, is located in Spatial Analysis module of ArcToolbox. In the Topo to Raster Tool window, add both cjd.shp layer and Reservoirborder.shp layer. Then select the names of height field from “Field” option of cjd.shp layer, and specify the “Type” value as “Contour” or “PointElevation” according to element type; “Type” value of the Reservoirborder.shp layer is specified as “Boundary”, and this layer is used to determine the valid range of the interpolation. Output range of the interpolation result is consistent with the Reservoirborder.shp layer, pixel size of output is 0.5m, the output result is ReservoirDEM. To ensure that the interpolation results did not appear positive value (above water surface), the maximum value of z was appointed as zero, and the rest with default settings in windows. As shown in Figure 5, the ReservoirDEM was then generated after the implementation of terrain interpolation.

As shown in Figure 7, the remote sensing image was overlaid on DEM. From the enlargement of the lower left corner of Figure 7, it can be clearly seen that a narrow strip protruding from the north end of the Great Wall water inlet extends to the southern end of the water outlet. For the strip, make section line 1, 2 and 3 on its straight, left and right side, then make section line 4 and 5 in its vertical direction. It can be seen from Figure 8 and Figure 9, both ends of water inlet and outlet are high, while the middle part is low. Both sides of the protruding part is bellowing the protruding part. In view of the data collection frequency of the RC-S2 survey boat, it can be inferred that this stripe is the trend of the underwater Great Wall.

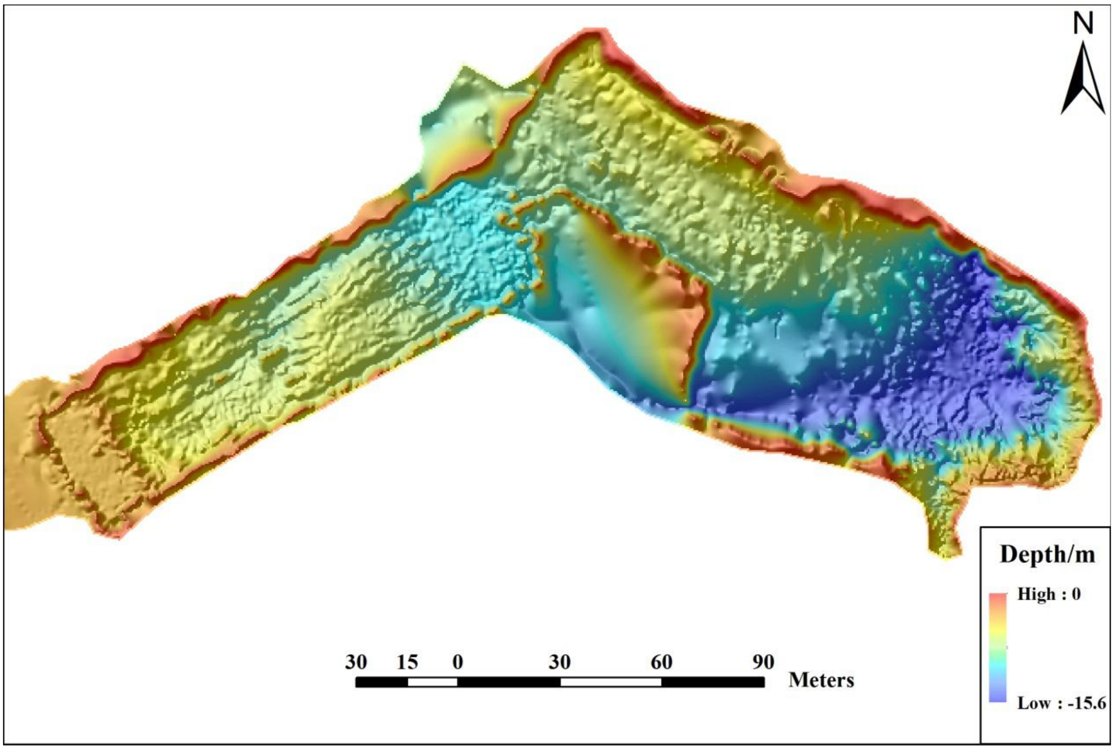

Fig. 6 Underwater terrain interpolation result of Huanghuacheng Great Wall

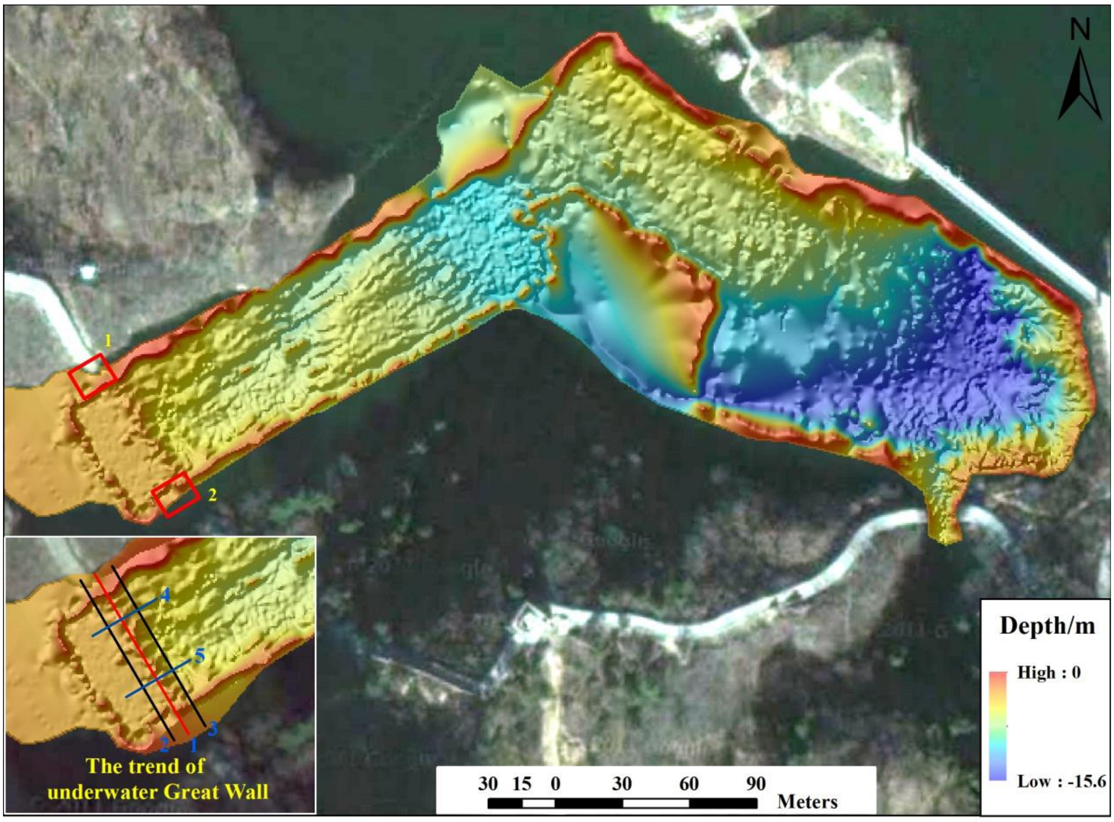

Fig. 7 Layout chart of DEM and the image (red box 1 is water inlet, red box 2 is water outlet)

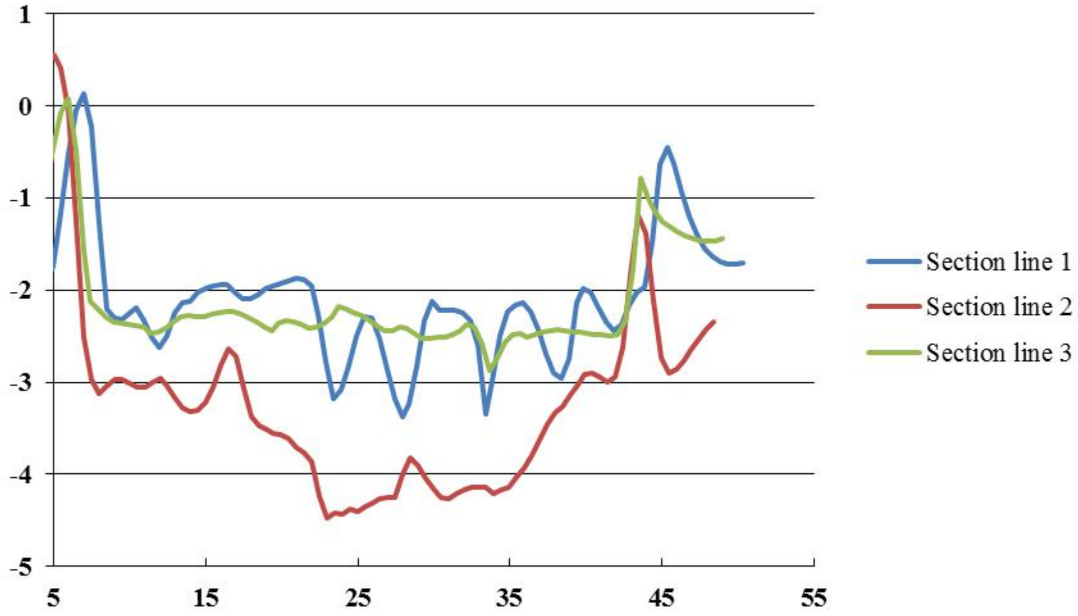

Fig. 8 Section line 1, 2 and 3

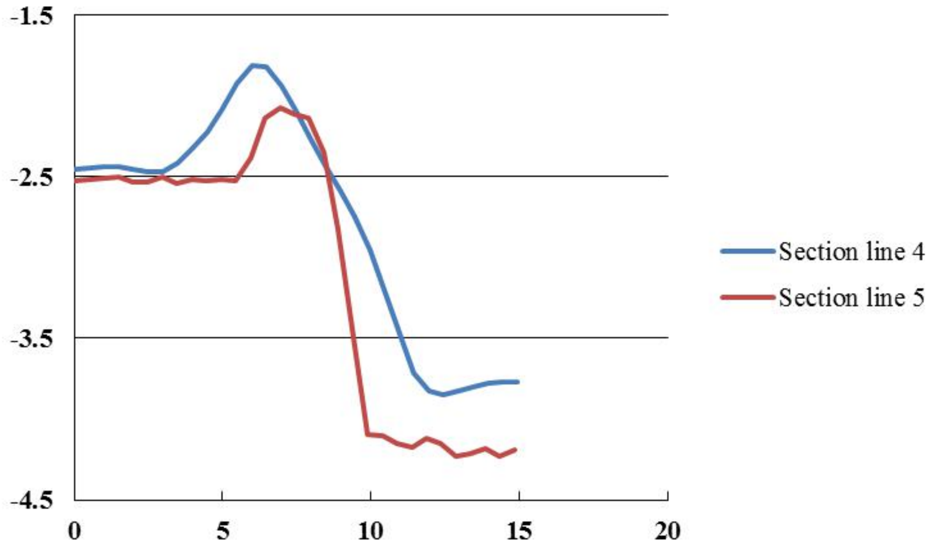

Fig. 9 Section line 4 and 5

4 SUMMARY AND CONCLUSION

As sensor data obtained by the traditional underwater archeology can not correspond to the accurate position data, with the use of RC-S2 Survey Remote Controlled Boat, current topography status of Xishuiyu Reservoir was obtained, thus current height and orientation of underwater Huanghuacheng Great Wall relic were reflected. The results showed that: (1) The RC-S2 survey boat is able to collect bathymetric data at a 500ms sampling interval, determine the point location by GPS with high sampling density, can reflect the subtle changes of the underwater terrain, thus meet the requirements of building underwater terrain model. (2) The specific location and trend of the underwater Great Wall can be clearly distinguished from the high-precision DEM produced by depth data, and it was consistent with the result of field verification, proving the reliable scientific basis for excavation and protection of underwater cultural heritage. (3) The successful application of RC-S2 in the Huanghuacheng underwater Great Wall area opened up new prospects for wide range investigations of underwater ruins with high precision.

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