ROV use for cave mapping and modeling

M. Stipanov*, V. Bakarić*, Z. Eškinja*

**Brodarski Institute LLC, Zagreb, Croatia (Tel: +385-1-6504-409; e-mail: marin.stipanov@hrbi.hr).*

Abstract: This paper describes a method for cave mapping and modeling with the use of an ROV equipped with a scanning sonar, depth sensor and an electronic compass. The method described was thought of and used by Brodarski Institute LLC for mapping and modeling of the "Vilina spilja" cave, located near Petrovac na moru in Montenegro. The result was a 3D digital model of the explored part of the cave, which was used for more accurate volume and water inflow estimation.

Keywords: ROV, cave mapping, cave modeling, cave exploration, scanning sonar

1. INTRODUCTION

The cave "Vilina spilja" is located in the hills above the town Petrovac na moru, Montenegro. The elevation of the entrance to the cave is 450m (Fig. 1). This cave is famous in the local area for the vast amount of fresh water contained in it. It has never been fully explored; therefore it is not exactly known how much water really is there, and what would be the full extent of the cave. "Vilina spilja" cave is filled with water even during the driest summer seasons, which is why local authorities are very interested in exploiting the cave as a water resource.

Fig. 1. The entrance to the "Vilina spilja" cave

This is why the information about the volume of the cave is very important, particularly for water inflow calculation.

2. PAST EXPLORATION AND MEASUREMENTS

The First exploration (Aqua Mont, 2004) of the "Vilina spilja" cave was carried out in May 2004, by a team of divers-speleologists from Belgrade, Serbia. That exploration revealed that the cave has a form of a tunnel. The divers explored, measured and mapped the first 220m from the entrance to the cave, reaching the total depth of 47m.

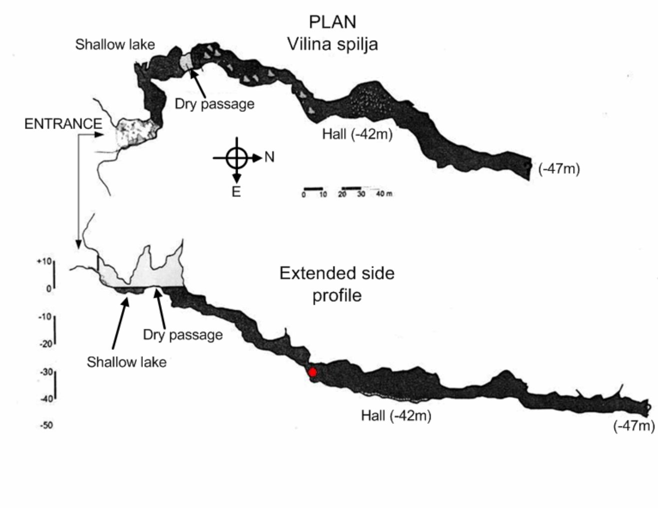

Fig. 2. First exploration resulting map

Mapping (Fig. 2) of the cave revealed that it starts as a quite curvy and narrow tunnel for the first 100m until the depth of cca. 40m, rest was described as a straight and wider tunnel which was explored only to the depth of 47m. The end of the cave was not reached due to water temperature (9°C), and oxygen limit. Divers' failure to reach the end of the cave led to the next (this) ROV exploration mission. Nevertheless, the first exploration provided a valuable insight to the cave layout, and allowed better preparation of the ROV mission. Distance from the entrance was measured by rope.

3. EQUIPMENT SPECIFICATIONS

A Benthos StingRay MKII ROV (Teledyne, 2007) system was used for the second exploration mission (Fig. 3). The StingRay MKII is a 4-DOF ROV equipped with four 0.5hp thrusters. Maximum operating depth is 350m, weight 40kg. Standard embedded sensory palette consists of an electronic compass (±1° error, 1° resolution), depth sensor (±1% of operating depth), and a high resolution color camera.

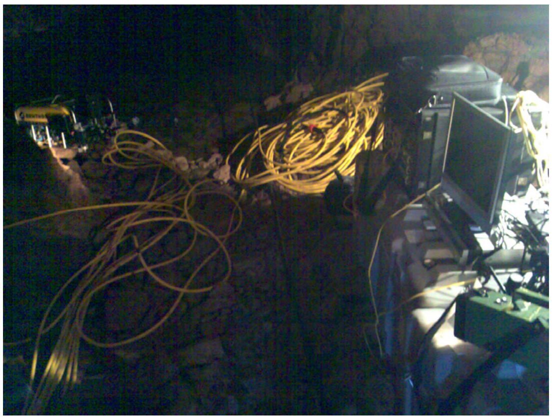

Fig. 3. Benthos StingRay MKII ROV system deployed

Tritech Micron scanning sonar (Tritech, 2007) was the only additional item used for this task. The Micron sonar is an extremely compact scanning sonar with a 360° spinning head (2° resolution), equipped with electronic CHRIP system. The beam width is 3° horizontal, and 35° vertical.

4. ROV INSPECTION AND MEASUREMENT MISSION

The mission objective was exploring the unexplored part of the cave, mapping and measuring of the entire cave. Since the cave has a form of a tunnel, the most intuitive way of measuring the cave is to sample the cross-section of the cave every few meters.

Fig. 4. StingRay ROV with installed Micron scanning sonar

In this method, the Micron scanning sonar (Fig. 4) was used for cross-section sampling. Every profile sample taken (Fig. 5) was logged along with the current ROV orientation taken from the built-in electronic compass, current depth taken from the built-in depth sensor, and the current length of tether released. Samples were taken every 2m of tether released. Every sample taken, the ROV would move straight forward for 2m of tether released, then turn in the direction of the next sampling point, and then without moving a sample is taken. Every sample is taken the same way.

This way, the 2m of cable length between samples represent the hypotenuse, and the depth difference represents the arm of the triangle used to calculate the real distance between every two neighboring samples (Fig. 8).

As simple as it sounds, carrying out the measurements was not as easy. “Vilina spilja” cave contains very narrow sections (Fig. 6) and sharp rocks (Fig. 7) on the sides which caused a lot of tether entanglements.

There was a real danger for the ROV to remain stuck in the cave to the point of need for diver assistance. The articulator on the StingRay MKII proved itself indispensable for such problems.

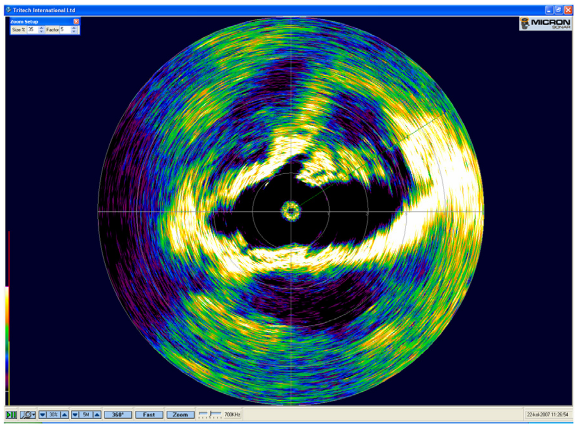

Fig. 5. Scanning sonar cross-section sample (11-26-55.bmp, cable released: 20m, depth: 6m, heading N-NE)

The rope that can be seen in Fig. 6, left by the diver-speleologists in the first exploration, was used by them to determine the distance from the entrance in the same way as the ROV tether in this case.

Fig. 6. Example picture of the inside of the cave

This rope helped a lot for the ROV pilot to find his way around the cave, but also posed an additional threat for tether entanglement as it can also be seen in Fig. 6.

Unfortunately, the primary goal of exploring the entire cave was not met. In fact, even less was explored than in the first exploration mission. The ROV got roughly 100m from the entrance to the cave (measured from the same point as the first exploration), and reached the maximum depth of 38m. As it can be seen in Fig. 2, the point reached (marked with the red dot) corresponds with the end of the narrow and curvy section, and the beginning of the straight and wider section. The cause of this was the tether rubbing against rough sides of the cave along the curves, which led to friction pile-up to the point of ROV maximum forward thrust force. In other words, the ROV could not pull the tether any more.

Fig. 7. Example picture of the side of the cave

Nevertheless, the mission was not a failure, because the section with the major depth difference was completely mapped and measured with much higher accuracy than in the first (diver-speleologists) exploration mission. The speleologists' method of measuring is similar to the method used here, but without the scanning sonar. That implies that their mapping method is highly subjective and based on a very limited number of measurement points due to limited oxygen quantity.

Higher accuracy volume calculation of the mapped section in this mission was of most importance, since the point reached would be the point of pump water intake in case of water exploitation of the cave. With the model presented in this article, local authorities are able to easily calculate the water inflow to the cave, as it will be explained in the section ahead.

5. "VILINA SPILJA" CAVE 3D DIGITAL MODEL

As mentioned before, four parameters were used for constructing the 3D digital model: cave cross-section scanning sonar image, current depth, current heading and released tether length.

The method used to construct the 3D model is shown in Fig. 8. In every point of sampling the current heading is used as a normal vector for the cross-section plane.

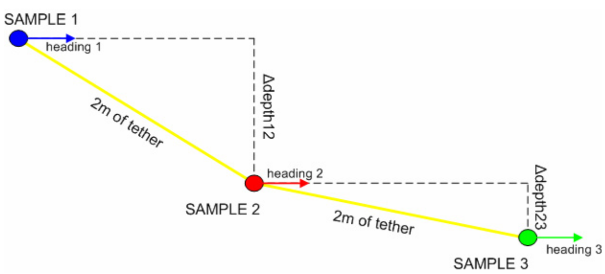

Fig. 8. 3D Model construction method

SolidWorks 3D design application was used for cave model construction. Since there were 36 samples, every scanning sonar sample image was digitized (Fig. 9) with minimum possible points.

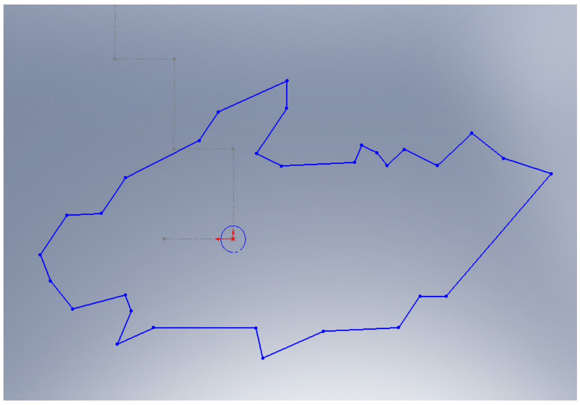

Fig. 9. Digitized cross-section scanning sonar image shown in Fig. 5

Using the rules noted before, it is quite simple to put all digitized profile samples in the right place (Fig. 10). The series of samples in 3D space represent a digitized version of the measured cave with a 2m sampling step.

With the use of the loft tool in SolidWorks, a surface between each pair of samples is easily extrapolated, thus forming a solid body representing the 3D digital model of the "Vilina spilja" cave (Fig. 11).

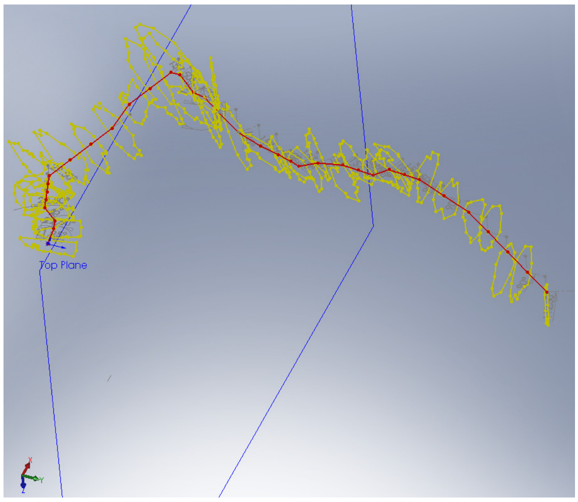

Fig. 10. Sampled "Vilina spilja" cave in NED (North-East-Down) coordinate system

This 3D model was used to calculate the volume of the modeled part of the cave (454.71m^3 of water).

For water exploitation, volume is not the most interesting parameter of "Vilina spilja" cave. Much more interesting parameter is the water inflow to the cave. This is planned to be measured by deploying pumps with the water intake at the end of the modeled section. The pumps will pump out the water making the water level fall. With pumps turned off, the water level increases, at a certain speed, to the default value.

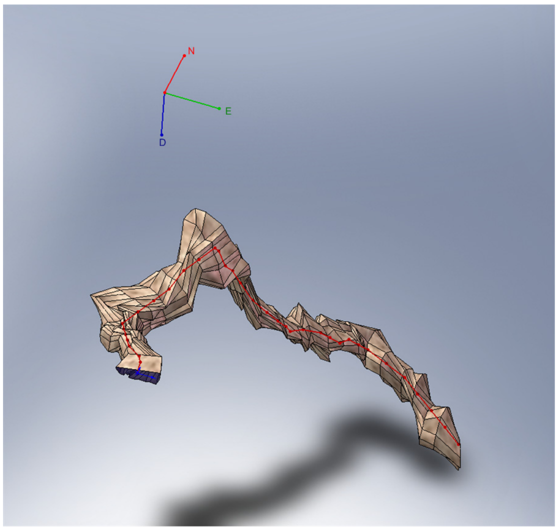

Fig. 11. 3D digital model of the "Vilina spilja" cave in NED (North-East-Down) coordinate system

The water level rise can be monitored more closely using this model (Fig. 12).

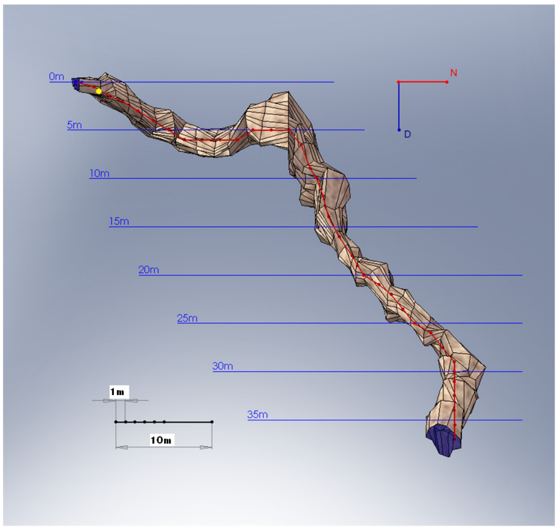

Fig. 12. "Vilina spilja" cave 3D digital model – side view

Shown table (Table 1.) contains volume values of sections, and the length of rope from the entrance to a particular water level. This way, cave water inflow can be monitored during water level rise, and can be estimated more accurately.

Table 1. Volume values table

Overall volume:	454,71	m3		
Level [m]	Volume under [m3]	Volume above [m3]	Volume to the first level above [m3]	Cable length to level [m]
5	338,25	116,46	116,46	18
10	202,52	252,19	135,73	38
15	172,84	281,87	29,68	44
20	143,87	310,84	28,97	50
25	107,85	346,86	36,02	58
30	72,25	382,46	35,60	66
35	18,26	436,45	53,99	74

6. CONCLUSION

Cave 3D modeling method described in this article is an example of a rare ROV technology use. It demonstrates that sensor data fusion expands the ROV application palette. The scanning sonar proved that it can be an indispensable tool even when used in an uncommon way, like here.

Since profile scan from Tritech sonar is plotted against direction from compass, it is relevant to know that the surrounding rocks do not affect the compass in any significant way. The ROV compass was tested in a test tank (350m long, 5m wide and 2m deep) in Brodarski Institute, which is surrounded by steel reinforced concrete, and shown excellent behavior. Therefore, taking in account that any classic speleological inspection is done using a magnetic compass, it is safe to conclude that the surrounding rocks had no mayor effect on the ROV compass. The Tritech sonar was tested in confined areas of the same tank, and shown little measurement error. In the cave, multiple scans were taken for every sample while holding position with the ROV. Since those multiple scans showed no difference in every sampling spot, and every profile plot was digitized by hand, it is safe to conclude that sound reverberation and multipath did not effect the measurement in any significant way.

The resulting 3D model represents a relevant advancement in underwater speleology. This way, the cave is mapped with much greater accuracy and detail, and includes no subjectivity in measurement.

The downside of this method lies in its incremental nature. Since the length of released tether is used for distance measurement, it allows a fast error build-up. The tether is not always ideally strained for the measurement to be as accurate as it could be using a positioning system. Also, the Benthos StingRay MKII used is not equipped with any form of stabilization except autodepth feature, so the majority of the stabilization was done by the pilot. Water in the cave is static thus making stabilization a lot easier.

Since no acoustic positioning system can be applied here, measurement error can be diminished only with the use of an IMU (Inertial Measurement Unit) for positioning. This method of mapping takes somewhat 1 hour per 100m of cave, therefore a quality IMU will not have a chance to accumulate any significant measurement error.

Therefore, a 6-DOF ROV with an integrated IMU for positioning and stabilization would be an ideal platform for this purpose.

6. REFERENCES

Aqua Mont, (2004) *Exploration of the "Vilina spilja" cave*, Technical report, http://aquamontservice.com

Teledyne Technologies Inc., (2007) StingRay datasheet, http://www.benthos.com/pdf/stingray2007.pdf

Tritech International Ltd., (2007) Micron Sonar datasheet, http://www.tritech.co.uk/support/support-datasheets.htm