

Localization of Autonomous Underwater Vehicles by Sonar Image Processing

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Abstract - A major percentage of underwater operations takes place in structured environments. This article presents a low cost way for underwater vehicle positioning in places like pools, tanks, water towers etc. The developed application calculates a 2D position using only a simple scanning sonar and a digital compass. An user interface has also been designed for this purpose. Various modes of sonar scanning were tested in a circular pool and the analysis of the results is presented here.

Keywords - ROV, Imaging sonar, localization, positioning

1. INTRODUCTION

The water covers more than 70% of total planet surface. Knowing this fact, the enormous demand of underwater operation in the last few years doesn't surprise us at all.

Pipelines, offshore-platforms, ship tanks, water reservoirs, are just some of modern objects that require underwater work. Divers are nowadays often replaced with remotely operated vehicles because of their low cost, no human risk and higher efficiency.

One of the major problems to be solved is underwater vehicle positioning. Common RF wireless networking is impossible in water. Systems are based on sound. They are usually expensive, delicate, and limited due to anchoring the transmitters.

Our idea was to concentrate only on familiar and simple-shaped environments, e.g. circular pool. This assumption gives us a choice to use a scanning sonar. In most cases, sonar is already a part of vehicle's equipment, used for some other purpose.

The main condition to make online work possible is fast edge detecting and fast image processing.

Developed algorithms with various modes of sonar scanning were tested in a circular pool and the results were analyzed.

2. COMMUNICATION DECODING

The communication with sonar was set up through a RS232 port and ROV's console [1]. The sonar accepts commands which are encoded in hexadecimal byte values and responds in the same way [2]. Bit decoding is needed to get useful information. Figure 1. shows the interface of the developed application for control and monitoring of scanning parameters. It gives user an ability to

change between different working modes or define custom values.

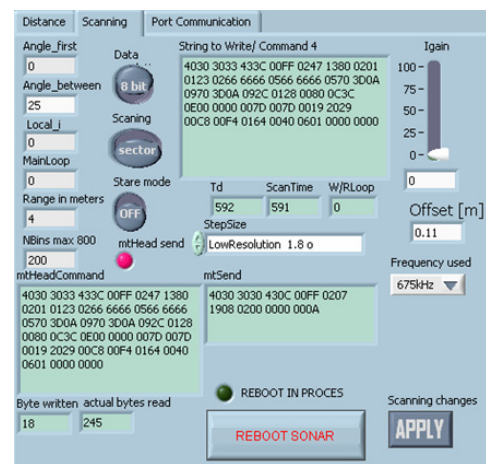


Fig. 1. Scanning control window

Scan lines in all directions represent an image like the one shown in Fig. 2. An arrow shows the vehicle position in the circular pool.

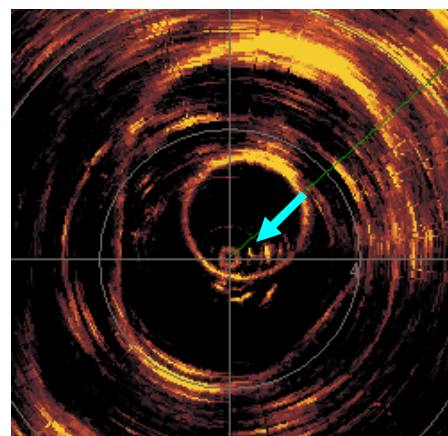


Fig. 2. Example of sonar image

Only the narrowest circle is the pool edge and all other circles are reflections. The goal was to take two scan lines with the sonar, extract proper distances, and with heading from ROV's integrated digital compass calculate the position (r and φ).

3. ALGORITHM DESCRIPTION

The algorithm starts from the assumption that the two distances d_1 and d_2 Fig. 3 are measured from the same point. Input parameters are:

- d_1, d_2 distances between vehicle position (T) and pool edge (D_1 and D_2).
- Angle δ between these two distances.
- Heading ψ

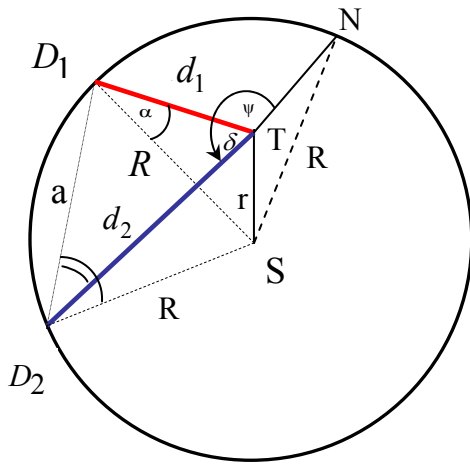


Fig. 3. Schematic drawing for calculating the vehicle position in circle

To calculate polar coordinates, some basic laws are used [3]. Variable a is the shared line of two different triangles: D_1D_2T and D_1D_2S :

$$a = \overline{D_1D_2} \quad (1)$$

$$\delta = \angle D_2TD_1$$

Line a is determined using Cosine Theorem.

$$a = \sqrt{d_1^2 + d_2^2 - 2d_1d_2 \cos(\delta)} \quad (2)$$

The angle difference between $\angle D_1D_2S$ and $\angle D_1D_2T$ is named angle α and we can easily come to the solution using equations (3), (4), (5) and (6).

$$\angle D_1D_2S = \arccos\left(\frac{a^2 + R^2 - R^2}{2aR}\right) \quad (3)$$

$$\angle D_1D_2T = \arccos\left(\frac{a^2 + d_2^2 - d_1^2}{2ad_2}\right) \quad (4)$$

$$\alpha = \angle TD_2S = \angle D_1D_2S - \angle D_1D_2T \quad (5)$$

$$r = \sqrt{R^2 + d_2^2 - 2Rd_2 \cos(\alpha)} \quad (6)$$

Fig. 4 shows the relation between the angles φ and ψ . So, now we can get other polar coordinates using equations (7) and (8).

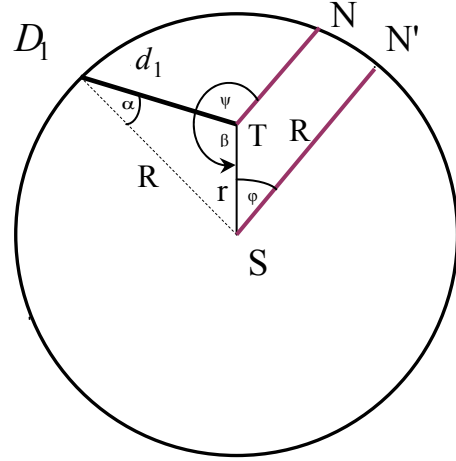


Fig. 4. Calculating the angle φ

$$\beta = \angle STD_1 = \arccos\left(\frac{r^2 + d_1^2 - R^2}{2rd_1}\right) \quad (7)$$

$$\varphi = \psi - \pi + \angle STD_1 \quad (8)$$

Because of the symmetry (Fig. 5) there exists one more point T' with the same distance d_1 and heading ψ .

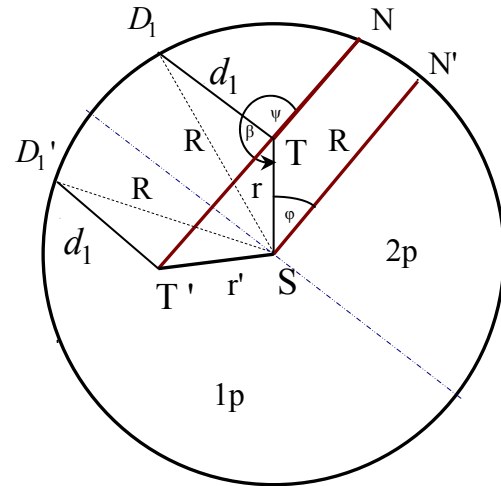


Fig. 5. Symmetry problem

Therefore, the angle φ is calculated for each semicircle 1p and 2p, according to relations (9)

$$\begin{array}{ll} \text{1p} & \text{2p} \\ \varphi = \psi - \pi + \angle STD_1 & \varphi = \pi - \angle STD_1 + \psi \end{array} \quad (9)$$

The problem is that it is not known in which part (1p or 2p) is the wanted triangle. The solution is first to calculate the value φ for both possible points T and T', and then simulate the distance d_2 for each point [4]. At last, the proper distance value is the one nearest to the measured value.

4. EXPERIMENTS

Algorithms were tested in a circular pool (h=1.21m, d=3.5m) using the application as in Fig.6.

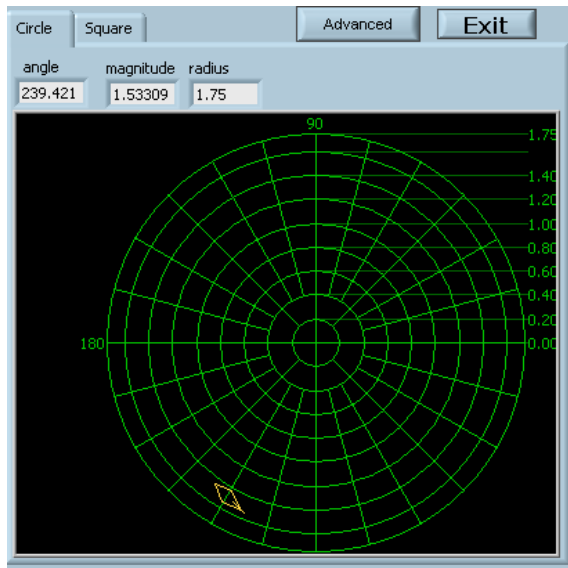


Fig. 6. Application for vehicle positioning

Floating objects were also set in the pool to test the robustness.

Scan line is the basis for edge distance extracting. Every detected distance is shown as an amplitude peak. The main rule is that the highest amplitude is the first reflection from the edge [5]. But, it is very important to distinguish that reflection from buoys and undesired multiple reflections from the edge.

The undesired reflection from the opposite edge shown in Fig.7 is always present but in most cases it can be easily eliminated because its distance ($d+d'$) is longer than the pool diameter.



Fig. 7. Undesired reflection from the opposite edge

Another undesired reflection is from the vehicle itself (Fig. 8).



Fig. 8. Undesired reflection from the vehicle

Reflection and other effects on scan lines are shown in Figures 9,10,11,12,13 and 14.

Different objects are marked with different colored arrows:

- black arrow** – edge
- red arrow** – noise
- blue arrow** – undesired reflection from edge
- green arrow** – undesired reflection from vehicle
- orange arrow** – floating object
- grey arrow** – unexplained peak

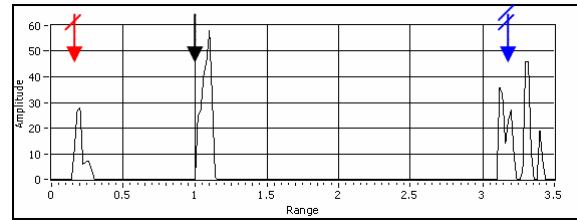


Fig. 9. Undesired reflection from the opposite edge

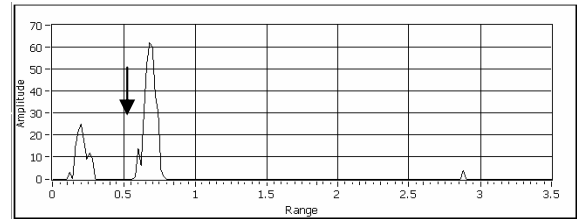


Fig. 10. The difference of detected peak edge and peak maximum. Also the edge position is variable.

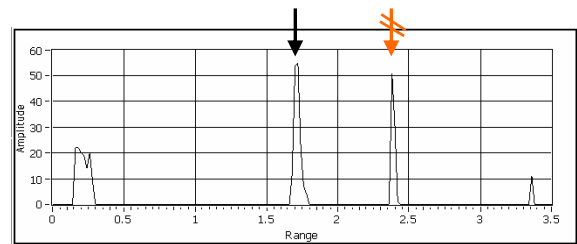


Fig. 11. Buoy effect: The buoy is 1m in front of the edge, but it is detected as 1 m behind.

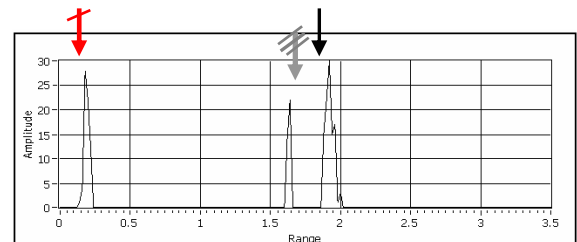


Fig. 12. Unexplained peak on 1.6m

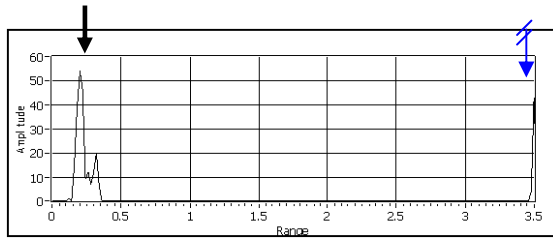


Fig. 13. Undesired reflection from the edge when the vehicle is very close to the edge. The sonar cannot detect distances under approximately 10 cm.

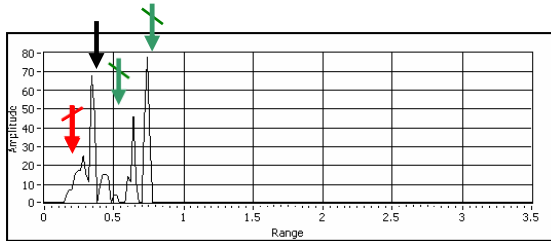


Fig. 14. Undesired reflection of the edge when the vehicle is close to the edge.

With the knowledge of the specific cases when the highest peak is not due to the pool edge, it is possible to recognize the edge [6]. Accuracy of sonar distance measurement is tested as shown in Fig. 15.

Table 1. Measurement results

n	d	d'	e	de	heading
1.	0.06	0.15	-0.09	/	224
2.	0.14	0.16	-0.02	-0.023	266
3.	0.23	0.23	0	-0.003	234
4.	0.33	0.33	0	-0.003	236
5.	0.45	0.45	0	-0.003	240
6.	0.53	0.53	0	-0.003	244
7.	0.62	0.61	0.01	-0.002	244
8.	0.73	0.73	0	-0.003	250
9.	0.84	0.85	-0.01	-0.004	252
10.	0.9	0.89	0.01	-0.002	254
11.	1.02	1.01	0.01	-0.002	258
12.	1.09	1.11	-0.02	-0.005	252
13.	1.20	1.21	-0.01	-0.004	262
14.	1.29	1.31	-0.02	-0.005	260
15.	1.41	1.41	0	-0.003	260
16.	1.50	1.51	-0.01	-0.004	262

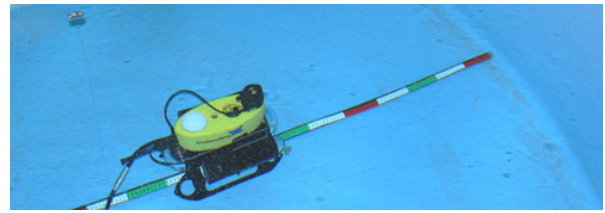


Fig. 15. Measuring the distance

The measurement results are given in table 1.

d - distance form the edge

d' - measured distance from the edge

e - distance value measurement error

de - standard deviation

heading - ROV's heading at the measuring moment

The error value is: $e=0.003\pm0.0017[m]$.

The position detecting speed depends on the method used (scanning or pointing), pool dimensions and scan line resolution. The accuracy depends on scan line resolution.

5. CONCLUSION

The results of the experiment have shown a very satisfying accuracy. The goal is accomplished in static position. Inferior results were obtained when the vehicle was moving because the movement distorts the geometric assumption. The solution to improve this method is to replace sonar with two static sonars.

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