MINE SEARCH MISSION PLANNING FOR HIGH DEFINITION SONAR SYSTEM - SELECTION OF SPACE IMAGING EQUIPMENT FOR A SMALL AUV

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Basic problem in design of an AUV as a platform that will be used for detailed area search, is selection of space imaging equipment. It is followed by selection of navigation equipment required to achieve high resolution picture of searched area. As indicated in our former presentations, we are looking for resolution of 50 mm required to identify mine like objects. This regards objects resting on the bottom or buried in sediments. Two types of side scan sonars can be considered for detection and identification of bottom objects. Due to size, weight and power restrictions, a short range, high frequency sonar capabilities were found to be suitable for the task. Recent advances in SAS technology offer new capabilities regarding Search rate and resolution, but introduces additional requirements to a platform.

INTRODUCTION

Introduction of small automatic underwater vehicles (AUV) to every day oceanographic data collection, bathymetry and search tasks, creates high demand for miniaturized versions of marine equipment. Size, mass and power consumption of these products need to be substantially reduced without penalty of performance reduction. As return the society of underwater explorers obtains highly efficient tools able to carryout missions at fraction of cost of conventional surface. The gain compensate substantial effort required to adopt newest ideas end technologies. While sonar systems remain principal tools for underwater data transmission and space imaging, several new system emerged recently and require evaluation and utilization procedures. Further expectations regarding other equipments can be also expressed to indicate research and development opportunities.

1. OBJECT DEFINITION

Typical mine like objects posses simple shapes such as cylinders and spheres. Their dimensions are also limited. This is reflected in table 1 that lists objects used to evaluate side scan sonar capabilities in laboratory and field tests. The objects were selected to allow detailed study of influence of different sonar parameters on sonar imaging capability. We were interested not only in detection but also in shape recognition. Geometrical characteristics of the objects were very useful. The test results proved practical resolution of 50 mm of high frequency sonars at close field, and capability to describe shape of the objects. It was also found that to facilitate object recognition they need to be in-sonified at certain angle and limited distance

Tab.1 Shapes and dimensions of objects used in evaluation of high frequency side scan sonars

	Shape	Characteristic dimensions	Minimum value [m]	Maximum value [m]
	Sphere	Diameter	>0,3	<2,0
	Cylinder	Diameter	>0,3	<1,0
		Length	>0,3	<10,0
	Cuboid	shortest	>0,3	<2,0
	Truncated cone	base diameter	>0,5m	<2,0
	„Rocan”	Length	>0,6m	<2,0

2. SWATH WIDTH DEFINITION

Swath width of a side scan sonar is defined by sonar beam geometry. It is not equal to sonar range. Basic relationship between range, vertical width of a beam and field of view is shown on Fig. 1. Best images are generated at some distance from transducer. In practice, a kind of “dead zone” below sonar platform needs to be considered in search procedures. No usable image of this zone can be generated during single swath. For conventional side scan sonar (SSS) with vertical beam width of 50º dead zone spans to approximately 10% of sonar range. For tested 675 kHz sonar range is 50 m and dead zone is 5 m approximately. Same value was found for 935 kHz with beam of 35 and 30 m range. For a hypothetical synthetic aperture sonar (SAS) dead zone is approximately 20% wide. It means that in a case of 150 kHz and 150 m range SAS, usable image is generated further then 30 m while its platform is moving 10 m above sea bottom . To provide 100% bottom coverage sonar swaths must substantially overlap. This reduces real distance between parallel tracks of a platform and effective imaging rate accordingly. In the case of tested high frequency SSS practical distance between tracks is 40 m for 50 m range. For hypothetical 150 kHz SAS sonar distance between tracks is 100 m for 150 m range.

Further reduction of effective swath width can be expected at far end of the range. It was found during field tests of the high frequency SSS that data collected at this area gives lest detailed information regarding object characteristics. It is not only a problem of lower resolution, natural for real aperture sonar but also result of observation angle. It means that at far distance it is possible to detect an object but for classification purpose another approach needs to be made.

Considering search mission effectiveness for 100 % coverage and high detection probability, several tracks of sonar platform can be analyzed. As can be seen from Fig.1, real overlapping factor of imaged areas is very different depending on horizontal range from the centre of a track. Shaded zones are imaged 4 times, while zones between shaded zones are imaged 2 times only. Double imaging from two directions is very positive for object classification or identification while additional imaging gives no additional information and can be considered wasteful.

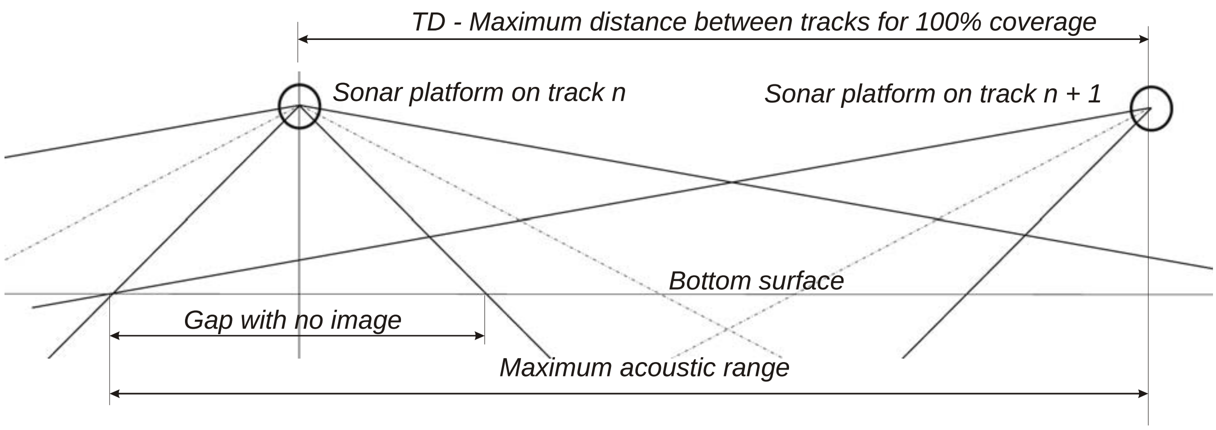

Fig.1 Sonar beams layout to cover 100% of the area

For 935 kHz SSS (30º beam) one side swath range is 30 m. Dead zone is 5m. TD <25 m
For 675 kHz SSS (50º beam) one side swath range is 50 m. Dead zone is 5m. TD <45 m
For 150 kHz SAS one side swath range is 150m. Dead zone is 30m. TD <120 m

It is visible that use of SAS for search operation would be very advantageous while compared to conventional SSS of the same spatial resolution. In theory effectiveness of such operation can be expressed by equation:

$$E_p \cong r_{ew} \cdot v_{mw}$$

where:

r_{ew} – effective range with 100% area imaging without unnecessary overlap

v_{mw} – maximum velocity available for assumed resolution and 100% cover of the area along a track for range r_{ew}.

According to this expression, SAS can be up to 6 times more effective than conventional SSS. The most prospective alternative to overlapping of swaths, to obtain 100% cover of an area during search operations is filing of the gap between images of left and right sides. Electronically scanned forward looking sonar can be utilized for this purpose. This solution requires more equipment and processing software but offers further increase of total efficiency.

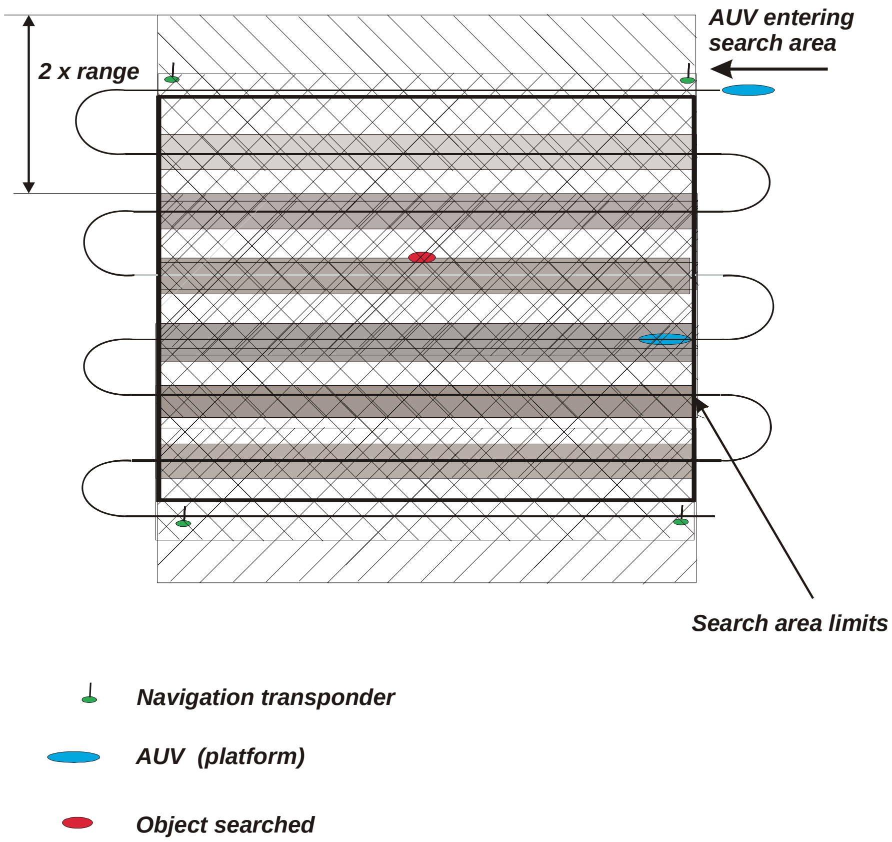

Fig.2 Basic idea of a sonar platform routing during search information

3. VEHICLE MOVEMENT DURING SEARCH AND IDENTIFICATION MISSIONS

Two basic types of mission can be considered for sonar imaging. The task of search mission is detection and initial classification of sound reflecting objects. The results are defined by efficiency and probability of detection of any object larger than assumed minimum. In mine hunting operations time of search giving high detection probability is of great importance for obvious reasons. Traditional method of searching considers use of a single sonar platform moving along several parallel tracks. This method was adopted for towed bodies and is continued by AUV operators. During operations reported to date single vehicles were used. However, application of un-tethered vehicles allows for operation of several vehicles during the same period, dramatically reducing time required for search operation to be accomplished.

4. IDENTIFICATION (CLASSIFICATION) MISSION

To obtain information that allows positive identification of an object specific data regarding its parameters are required. Usual method of identification is visual observation. This can be done directly by a human (diver) or remotely by ROV operator. However, in turbid waters or in case of old objects visual identification is difficult. Acoustic methods can be of great help in such conditions.

Effectiveness of a system used for identification can be expressed using object identification time T_p:

$$E_i \cong \frac{1}{T_i} \tag{1}$$

Where:

η_i =1 – (required) probability of identification

T_i - average object identification time

While considering selection of equipment to be used for identification, a sonar platform manoeuvres can be considered. The most useful seems to obtain object image from different directions. On fig. 3 there is a rectangle representing required route of the vehicle. The circles represent AUV circulations required to carry sonar at optimum distance from the object located at the centre of the rectangle. Shaded areas represent sonar imaged bottom for 10 m swath (one side) and 2.5 metre altitude.

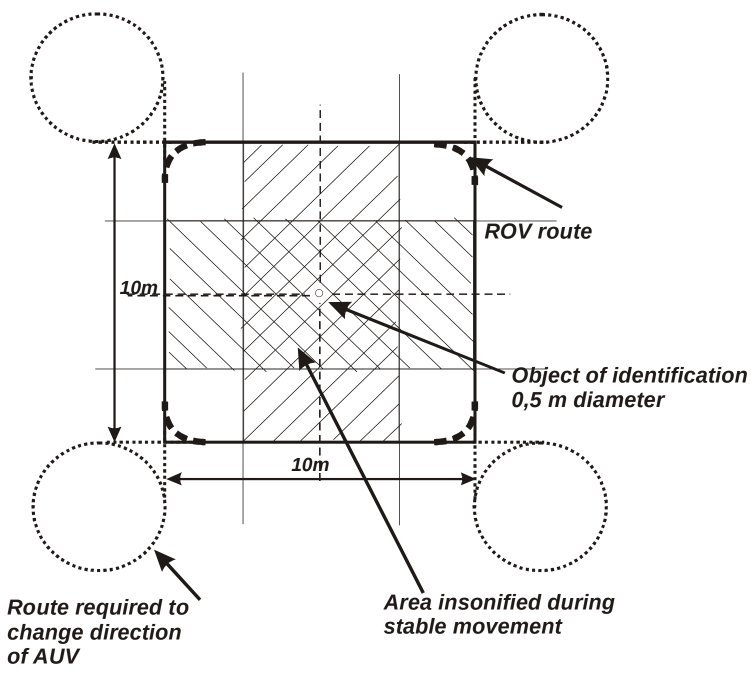

Fig.3 Route and manoeuvres of AUV during identification an object using conventional high frequency side scan sonar

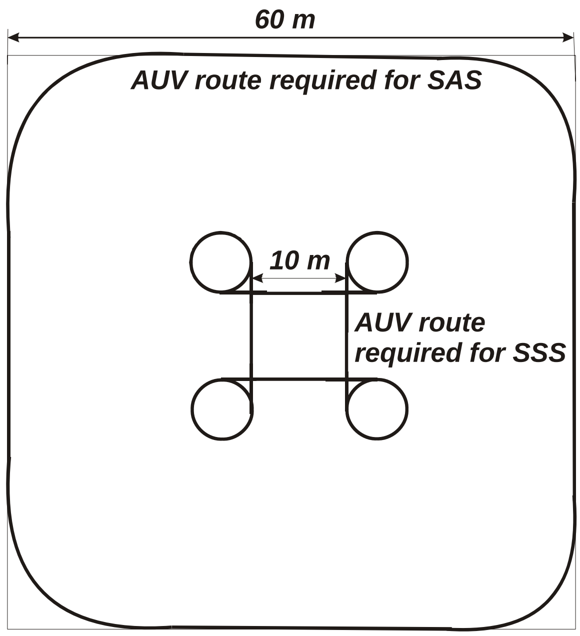

Fig.4 Route and manoeuvres of AUV during identification of an object using synthetic aperture side scan sonar

Identification of an object by means of SAS requires different approach (fig. 4). The object of interest must be observed from much longer distance, but AUV manoeuvres are less complicated. It was evaluated that identification time while using SSS is roughly the same as in case of SAS between 100 and 150 seconds.

5.   EQUIPMENT REQUIREMENTS REGARDING SONAR PLATFORM

Application of AUV as a sonar platform seems to be obvious. Its movement at the depth is comparatively stable and not restricted or disturbed. With no wave action or water eddies un-tethered underwater vehicles are really stable platforms.
Requirements of SSS regarding its platform are limited. This allowed to use such sonars on small vehicles for some time yet. Use of SAS introduces substantial requirements to its platform. In a case of a towed body main problem is its mechanical stability. Raw or pre-processed data can be easily transferred to a towing vessel. There is no need for data storage and no restriction regarding energy consumption. Physical size of transceiver an receiver poses no problem also as the sonar components are the only to be built in to a vehicle.
In a case of Autonomous Unmanned Underwater Vehicle (AUV) these requirements become critical. For this reason all the requirements regarding vehicle need to be defined. This was done for 150 kHz SAS.

The requirements of both types of sonar systems are compared in table 2.

Tab.2 Requirements of SSS and SAS bottom space imaging systems

	Parameter	Unit	SSS	Current SAS	SAS for small AUV
	Transponder length (real aperture)	m	0,5	1,2	0,6
	Sonar equipment volume	dm^3	2,5	60	10
	Sonar equipment mass	kg	5,3	20	10
	Data recorder volume	dm^3	0,2	2	1
	Volume of compulsory equipment suite (total)	dm^3	3,0	40	11
	Mass of compulsory equipment suite	kg	7	40	10
	Power drain (total)	W	22	100	30
	Memory capacity (50 hours)	Gbytes	5	300	300
	Position accuracy for imaging	mm	1000	< 1	< 1

While current status of SSS sonar technology with digital processing can easily be integrated into small platform, it is quite apparent from table that current SAS technology is not yet suitable for small AUV with 50–100 kg mass and 250 mm hull diameter. The SAS system arrangement and data management need some innovative solutions to reduce mass and volume. The changes can be based on unique motion properties of un-tethered vehicle available accuracy navigation equipment signal processing.

6. NAVIGATION

It is obvious that search for small objects with great level of certainty must be supported by high accuracy navigation system. It is possible to create bottom space image without excellent navigation using conventional SSS mosaicing technics. However, to obtain adequate search mission results a long period, sub-metre accuracy is required for both SSS and SAS sonars. For SAS a short time high accuracy position indicating system is crucial to its operation It can be achieved by means of inertial navigation platform supplemented by high quality Doppler velocity log. Long term positioning requires support of satellite navigation system. If properly operated (frequent satellite fixings) such a navigation suite can provide required positioning accuracy at investment cost of around 150 000 EUR. It would be supplemented by micro-navigation that can be achieved by additional sonar data processing.

Tab.3 Accuracy of positioning of surface vehicles and AUVs updating position while surfaced

	Navigation tool used above the water	Positioning accurany
	GPS (satellite global positioning system)	5-15 m
	DGPS (differential satellite global positioning)	0,3-3 m
	GPS differential satellite global positioning RTK	0,02-0,05 m

Tab.4 Positioning accuracy of a vehicle (AUV) mounted equipment

	Navigation tool used above the water	Positioning accurany
	Inertial platform and Doppler velocity log (DVL)	3 m/h (1 m/s)
	Magnetic compass and Doppler velocity log (DVL)	30 m/h
	Inertial platform only	0,6 M m/h
	Hydroacoustic tracking referenced to transponders	1 m

Tab.5 Accuracy of tools supporting positioning and sonar data processing

	Navigation tool	Accuracy
	Pich and roll measurement with inertial platform	0,01°
	Pich and roll measurement referenced to magnetic field	0,2°
	Heading measurement using inertial platform and Doppler velocity log (bottom referenced	0,02°
	Heading measurement using inertial platform only	0,05°
	Heading measurement using magnetic compass	0,5°

Navigation suite required by high definition sonar imaging defines platform specification to significant extent. Current technology allows for implementation of adequate equipment onboard of a 260 mm diameter vehicle.

7. STORAGE MEMORY CAPACITY

During underwater mission of AUV it is not possible to transmit sonar data to a place where they can be utilized. They need to be stored on board the vehicle. Thanks to hard disk and flash disk technology development, very high densities and high data recording rates are inexpensive and readily available. A few years ago it was possible to record easily SSS sonar data. Now it is true for SAS data also. Table 6. shows approximate requirements regarding recording equipment capacity for small AUV swimming at speed from 0,5 –1 m/s for SSS and 1 – 2 m/s for SAS.

Tab.6 Imaging rate and memory capacity available and required for traditional side scan sonar and synthetic aperture sonar (assumed resolution of 50 mm x 50 mm, 100% coverage, one side)

<table>
<tr><th>Platform velocity</th><th>SSS Imaging rate for 30m range</th><th>Data rate to recorder</th><th>Memory capacity for 50 hours mission</th><th>SAS Imaging rate for 150m range</th><th>Data rate to recorder</th><th>Memory capacity for 50 hours mission</th></tr>
<tr><td>m/s</td><td>km2/h</td><td>kbit/s</td><td>GBytes</td><td>km2/h</td><td>kbit/s</td><td>GBytes</td></tr>
<tr><td>0,5</td><td>0,072</td><td rowspan="2">150</td><td rowspan="2">5</td><td>0,162</td><td rowspan="4">8 000</td><td rowspan="4">300</td></tr>
<tr><td>1</td><td>0,144</td><td>0,324</td></tr>
<tr><td>1,5</td><td>0,216</td><td rowspan="2" colspan="2"></td><td>0,486</td></tr>
<tr><td>2</td><td>0,288</td><td>0,648</td></tr>
</table>

8. DATA POST PROCESSING AND OBJECT DETECTION

While conventional sonar data can be easily processed on board a AUV, SAS sonar data need to be processed after a mission. In spite of high computing power (parallel processing) that can be employed above the water, substantial time is required to build usable image. This time is of the same magnitude as the mission time. It means that in a case of 12 hour mission first results are available 24 hours after a vehicle with SSS was launched. Some data can be transmitted while a vehicle is at the surface, taking satellite navigation fixings. However, this solution can not be utilized for SAS data that are generated at very high rate and need to be stored.

Large amount of image data to analyse, requires automatic object detection and classification. It is important facility both in case of SSS data. For SAS sonar data it is almost compulsory. While its range is four times higher than that of SSS the image can not be presented on single screen with available resolution. It means that several images (screens) need to be in parallel or data analysis can last much longer than search mission itself. There are some reports indicating that suitable software is currently available.

9. CONCLUSIONS

The results of the project, partly reported in this paper, proves practical potential of high frequency side scan sonar as high definition imaging tool. Due to its small dimensions, low mass and low power requirement complete sonar can be operated using small AUV. However, it is important for vehicle system operator to be conscious of limitations of sonar vehicle system. The most important seems the information regarding real search rate, that is much lower than based on nominal sonar range. These limitations indicate requirements regarding improvements in conventional sonar technology and application of potentially more effective imaging devices.

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