EXPERIMENTAL EVALUATION OF HIGH FREQUENCY SIDE SCAN SONAR AS OBJECT SEARCH AND IDENTIFICATION TOOL

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Paper presents initial results o laboratory tests of the sonar selected as a short range tool for an underwater vehicle. It is intended for bottom located object search and identification. To evaluate sonar imaging capability expressed by its resolution, several parameters were investigated. First group of parameters regards the sonar itself, while the second regards an object material and dimensions and shape. Their cross-influence was investigated for different distances from hydrophone to an object of interest and different hydrophone elevation angles. Experiments were performed in a shallow water laboratory tank.

INTRODUCTION

Side scan sonars are currently principal tool for sea bottom imaging. Several types of side scan sonars are used for search and identification of a bottom feature investigation and bottom located object search and identification. Principal effort is devoted to medium and long range equipment. Much less is known about search for small objects at short and very short range seen from low attitude limited by water depth. Limited amount of the application related data makes selection of suitable equipment and configuration of this equipment for best results. Important part of equipment performance evaluation is definition of parameters for comparison. Qualitative measure of the performance is “object recognition” capability that requires high level of intelligence that means human operator involvement. Qantitative measure is resolving force of sonar system in given condition was selected that means capability to distinguish echo signals approaching a sonar hydrophone (transducer) from two pints in space that differ in location, surface orientation and acoustic signal reflectance coefficient.

1. TEST FACILITY

Experiments were performed in experimental tank that is 30metres long and 3 metres wide that allows measurements up to 20m. Important limitation of the tank is its depth of 1.5 metres. To allow several experiment run in controlled conditions dedicated facility was built for the transducer articulation. The equipment arrangement is shown on fig. 1. It consists of a wheeled carriage driven on a bridge across the tank. Geared electric motor controlled by frequency inverter allows for accurate control of carriage acceleration and speed. However, for easy comparison of sonar images, all measurements were done at he same speed of 0.3 m/s. Resulting movement of an investigated transducer set across the tank is quiet and can be repeated as many times as required.
A sonar transducers are mounted to the carriage by means of vertical support and simple tilt articulation arrangement. The solution gives capability to control transducer depth and elevation angle. Elevation angle can be changed changed between 5º to 50º, in 5º steps.

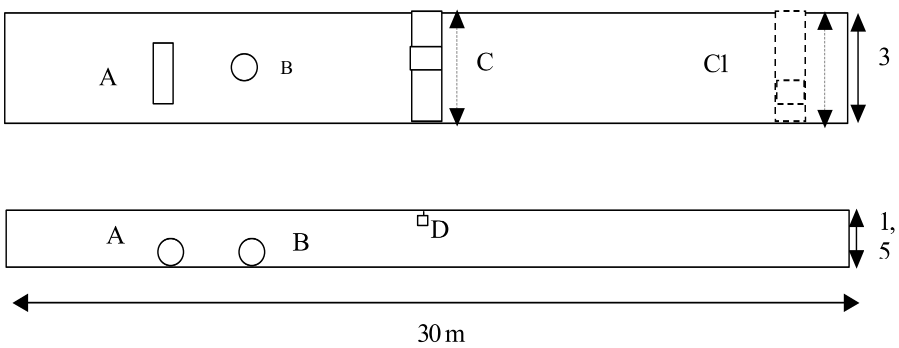


Fig.1 Sonar transducer location and orientation facility (top view and side view)

A and B - example objects (A cylinder, B-sphere);
C - movable carriage with transducer support.
D - transducerd

2. ACOUSTIC CONDITIONS

Basic geometry of the experimental tank and nominal acoustic beams of the sonar transducers used for evaluation can be seen on figure 2. As seen on the figure distant objects can only be seen from very small angle. That limits acoustic signatures that can be used for object recognition. Further factors affecting measurements are originate from the tank wall and material. Its concrete structure has low attenuation capabilities. Therefore one can expect various multi-pass and interference problems. However, these phenomena are static and can be treated as permanent background noise. Different signal processing techniques can beconsidered for removal of such a noise from sonar data. The example background noise for elevation angle of 25º for 935 kHz and 625 kHz transducers can be seen on fig. 2 also. On

635 kHz chanel image, the signal like area, m from the ransducer is unwanted feature of this channel. Its origin is unknown.

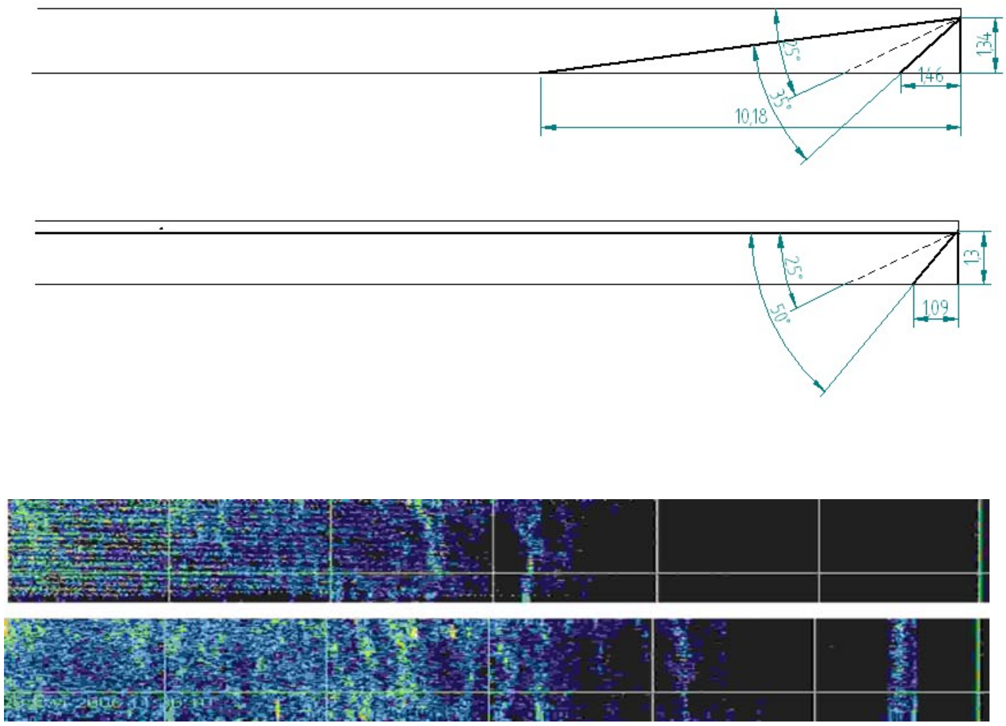


Fig. 2 Geometry and background noise for 935 kHz and 675 kHz transducers in rectangular concrete experimental tank

3. OBJECTS USED IN SONAR PERFORMANCE EVALUATION

To evaluate different significance of different parameters on sonar performance several objects were prepared. Shapes were representative for objects usually searched at see. They were manufactured of different materials and were solids and shell structures.
The objects are listed in the table :

Tab.1 Objects used in sonar performance evaluation

Nr	Object shape	Material	Length	Width or diameter	Heigth	Thickness
			m	m	m	mm
1	Sphere	GRP Composite	-	0,6	-	6
2	Cylinder	GRP Composite	1,00	0,50		5
3	Conical (Manta)	GRP Composite	0,98	0,49	0,47	5

4	Rectangular plate	GRP Composite	-	0,60	0,52	3
5	Parallelepiped solid	GRP Composite	0,20	0,30	0,12	
6	Rectangular solid	PET plastic	0,1	0,80	0,25	-
7	Cylinder solid	PET plastic	0,65	0,080	-	-
8	Land mine	GRP Composite	-	0,33	0,095	8

Generally it was found that for frequencies used in tests neither material nor thickness noticeable influences imaging.

4. SONAR DATA

The sonar used for evaluation is a two channel, conventional signal side scan sonar with digital presentation of sonar data. It was purpose modified to allow parallel operation and direct comparison of two transducers different working frequencies.
The sonar transducer specification is as follows:

1. 675 kHz transducer active element
   - Length: 375 mm
   - Height: 4.5 mm
   - Beam pattern @ 3dB: 0,45 deg x 50 deg
   - Approximate range: 50 – 80 m
2. 935 kHz transducer active element
   - Length: 375 mm
   - Height: 3.0 mm
   - Beam pattern @ 3dB: 0,3 deg x 35 deg
   - Approximate range: 30 – 50 m

Maximum range resolution in both cases
@ 800 bins per line: 0,01 m for 10 m range
0,05 m for 50 m range

Transmitter source level: 208 dB
Transmitter pulse length: 50 – 200 μs
Receiver sensitivity: 2 mV
Gain control range: 80 dB
Data sampling rates: 5 - 200 μs
Data resolution: 8 bits

5. SPATIAL LOCATION OF SONAR TARGET AREA

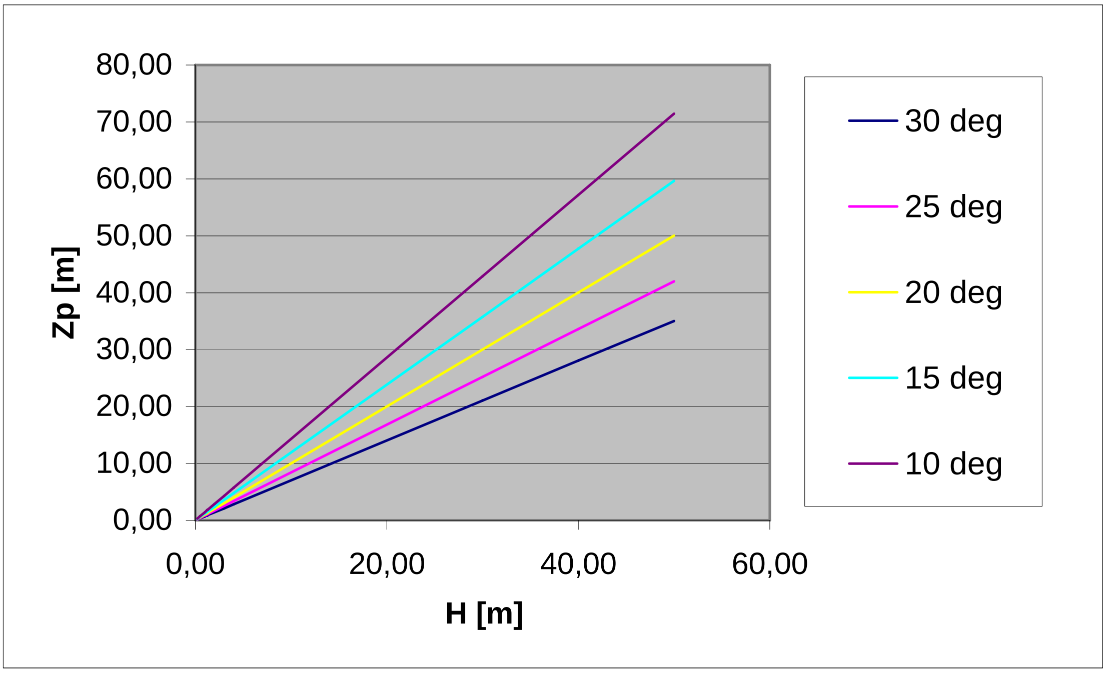


Fig.3 Minimum theoretical horizontal distance from for 675 kHz transducer to the insonified area for different altitudes and elevation angles

The extension of imaging capability below theoretical range was investigated during transducer elevation influence tests. Experiment started with 50º elevation angle, that was decreased in 10º steps to 10º. There were no differences in imaging for different elevation angles as far as complete object was insonified by acoustic beam. These tests showed that 675 kHz transducer performs much better at very short distances. It is due to wider beam of this transducer (50º in vertical). Narrower beam (35º in vertical) of 935 kHz transducer means that object remains out of beam at much larger distances.

6. ADJUSTABLE SONAR PARAMETERS

Operating frequencies are an intrinsic properties of the transducers resulting from physical parameters of active ceramics and electronic circuity. The ability to compare results for two frequencies in exactly the same conditions is great value of investigated equipment. Imaging capability, expressed by image resolution, was investigated for several variables. These are as follows: sensitivity, contrast , gain, resolution range, transducer altitude and elevation angle and of course frequency. Significant number of sonar parameters several objects and number of ranges indicates extensive effort required to obtain valuable results.
Some of the parameters (sensitivity, contrast and gain) can be set for one of two transducers separately. Other parameters are set for two transducers at the same time.

The sample record of a series of measurements is shown on fig. 4. For both channels the following parameters were identical : range -10m, resolution - 482 bins contrast - 25dB, sensivity - max. The gain parameter was switched from 100% to 20% in 20% steps The results are visible from bottom to top of the screen image. For every gain set two mirror like records were generated that represent two way movement of the transducer set. Vertical lines are 2m spaced, but no slat range correction were not implemented. It means that close objects appear shorter than their actual dimensions

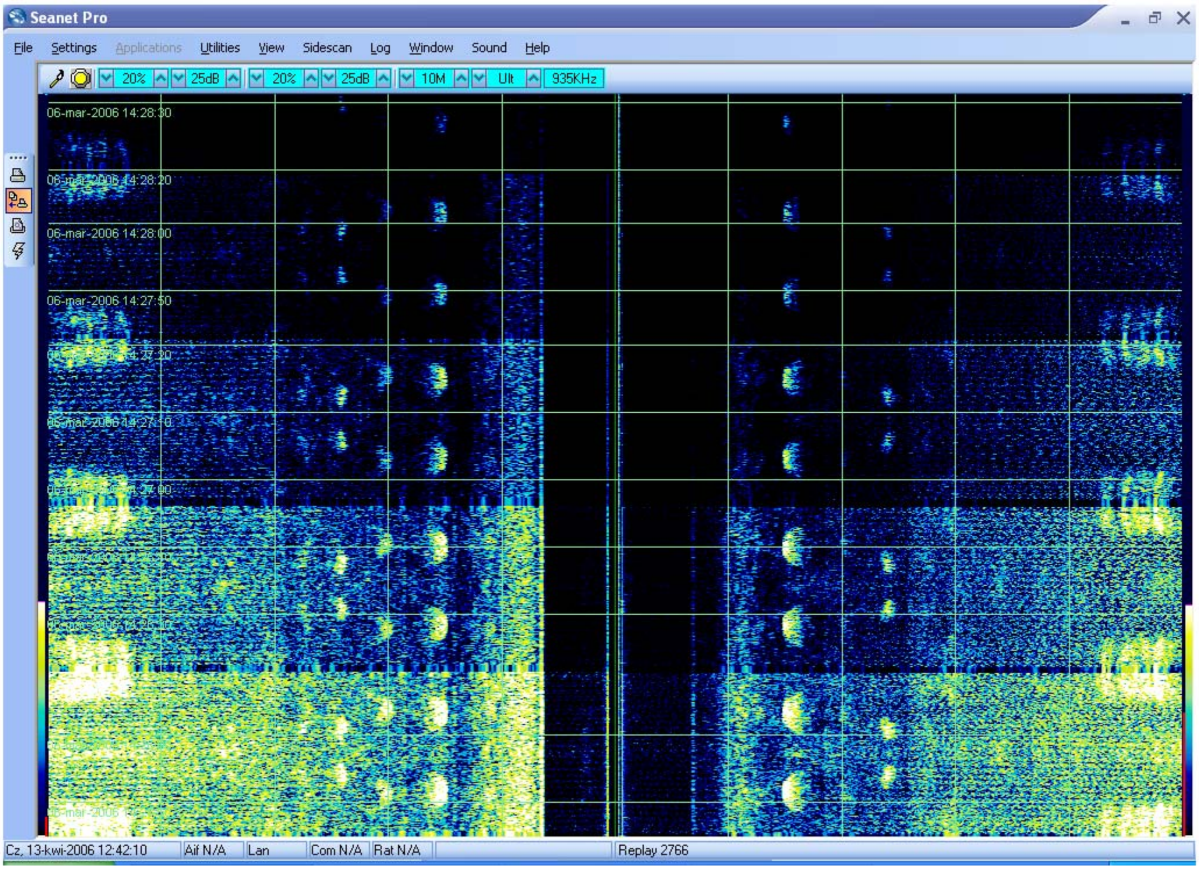


Fig.4 Sample record of a series of sonar runs with gain as variable parameter

Left side represents 675kHz channel.
Right side represents 975 kHz channel

First object from the middle:	GRP composite model of a MANTA like shape
Second object from the middle:	GRP rectangular at 4,9 m distance
Third object from the middle:	GRP composite plate at 7,64m distance close to the wall (multiple echoes)

7. THEORETICAL SPATIAL RESOLUTION

Along the track resolution.

By an azimuth resolution (δ_a) we generally mean the minimum linear distance between two objects located at the same range, which echoes system (sonar) is able to distinguish.

A radial azimuth resolution (δ_r) is the minimal angle between two objects at the same range, which echoes system (sonar) is able to distinguish.

The Rayleigh Criterion defines dependence between a transducer length (l) and azimuth resolution (δ_r) and it says that two objects are distinguished when an angular distance between them is larger than an angular distance between direction of maximum and first zero of a cross section of directional characteristics.

The azimuth resolution of side-scanning sonar is given by: [1]

$$\delta_r = \arc \sin(\lambda / l)$$

for $l >> \lambda$: $\delta_r \approx \lambda / l$

A far zone (Fraunhofer's zone) azimuth resolution (δ_a) depends on distance (R) [1][2]:

$$\delta_a = R\, \lambda / l$$

where,

δ_a - azimuth resolution

R - range in metres

λ - wavelength of signal in metres

l - antenna length in metres

and a zone border is: $r = l^2 / \lambda$

The azimuth resolution (δ_a) for a near zone ($r < l^2 / \lambda$) is approximately equal a transducer length : $\delta_a \approx l$

All the tests were done in near zone (zone borders at 82 and 63 m) according to this definition.

It means that azimuth resolution at both channels may not be better than 0,375m.

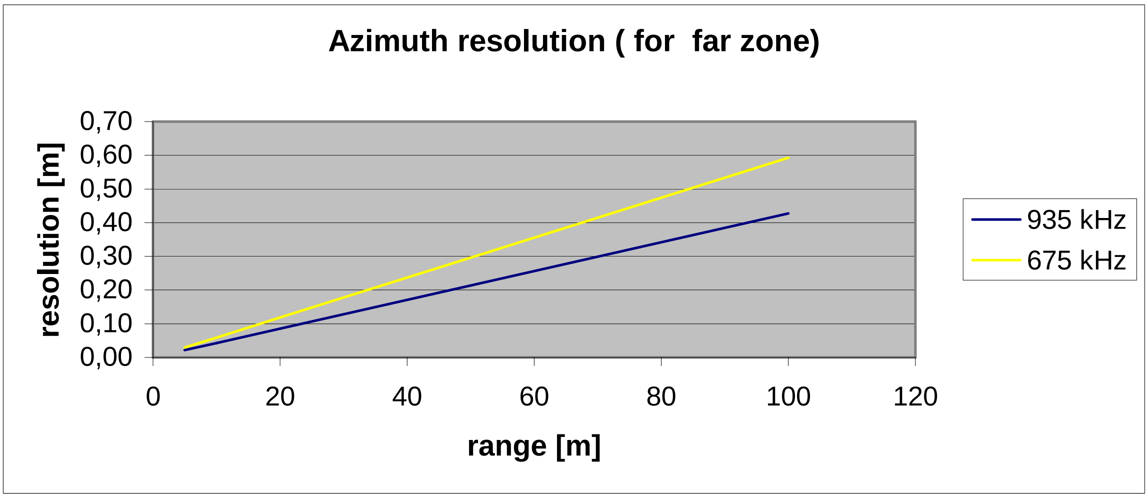


Fig.5 Azimuth resolution in a far zone for 935 kHz and 675 kHz transducers

Resolution in a propagation direction (range resolution).

The range resolution Δr is defined as minimum linear distance between two objects that can be distinguished on an sonar image line. For single frequency it can be expressed as:

$\Delta r = c\tau/2$

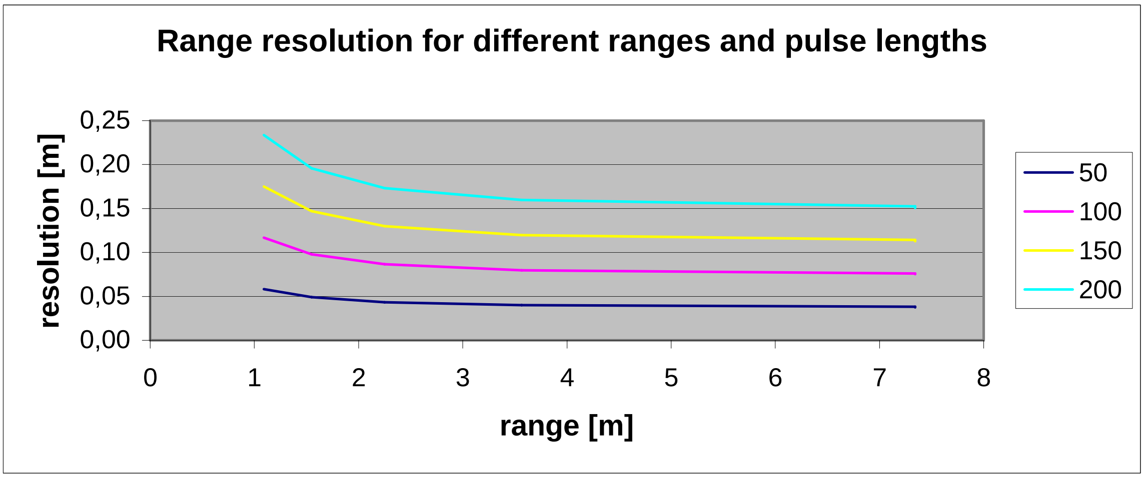
were
τ – pulse duration time (transmitter pulse length)
c – sound velocity

According to this equation the only way to improve range resolution is to shorten pulse duration . To preserve same signal energy and available range signal (pulse) power needs to be increased proportionally. A sonar pulse can only be shortened to certain limit. Between 10 and 20 periods are required to generate adequate directional characteristics. Due to substantial vertical width of SS (35˚ and 50˚) acoustical beam, range resolution Δz varies for different directions. It is expressed by the following equation:

$$\Delta z = c\tau/(2 \sin(\varphi)) \quad [1]$$

were:
φ – angle of pulse direction to vertical

For short ranges and small values of angle φ resolution is poor and improves for longer ranges were $\Delta z \approx \Delta r$



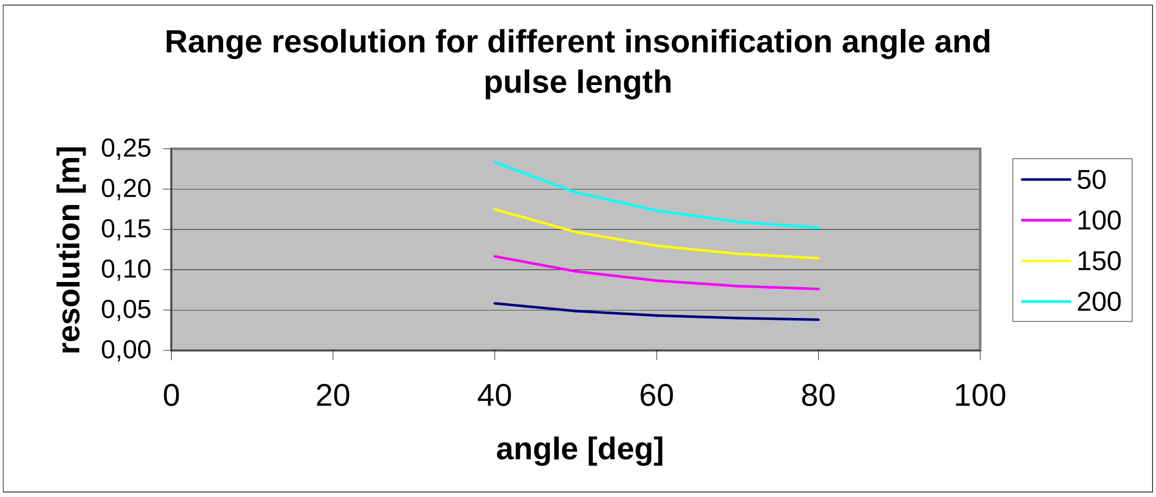


Fig.6 Depth resolution for different ranges [m] , insonification angle [°] and pulse length [μs]

In the case the sonar system used for tests range and resolution are selected by operator.

The program that makes the sonar signal processing samples every sonar line to generate images. Number of samples per line can be selected for different ranges according to the table below. This superimposes further limitations on physical resolution defined above.

Range	Number of samples per single sonar image line					Resolution
m						m
6	60	120	178	424	472	0,012
10	100	198	294	396	482	0,021
20	-	200	396	488	590	0,034
30	-	298	494	594	794	0,037

Signal strength resolution.

Sampling resolution of the sonar signal strength corresponds to levels of grey or tones if colours used to display sonar data on a screen. The system tested, samples the signal amplitude to 8 bit resolution that corresponds to 256 levels of grey. It is not feasible to use complete scale in linear form. Effective way of presenting information is feature sensivity and contrast manipulation that allows better separation of signal strength (averaged for) of neighbour-ous spacial samples. The sonar system uses AVG (automatic variable gain) feature to compensate for a signal loss with range due to natural attenuation. It provides similar presentation of similar signal strength irrespective to it origin along sonar image line.

Shape recognition

In current phase of shape recognition capability was rather qualitative and subjective. It means that to identify an object experienced human operator is required. For quantitative evaluation of shape recognition capability combining of three above values is required. This can lead to automatic shape recognition.

8. REAL SPATIAL RESOLUTION

Real spatial resolution achiewed in tests is sow on figure 5.

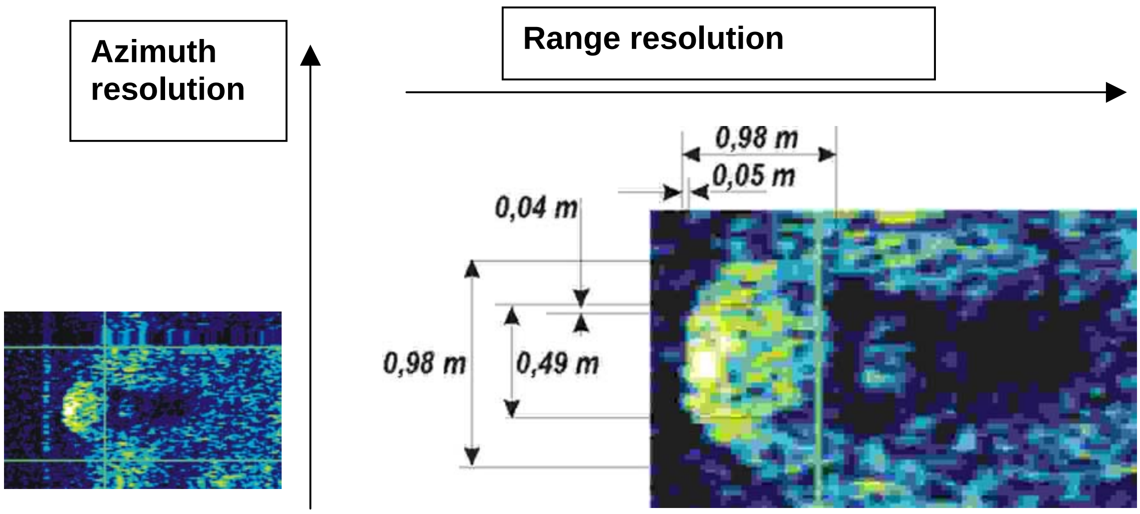


Fig.7 Practical resolution of real sonar image for near are achieved in laboratory tank tests

9. SUMMARY

1. The differences between results obtained with transducers of different frequencies are apparently visible. 975 kHz frequency offers much better object shape definition.
2. The along the track (azimuth) resolution at short distance seems to be much better than indicated by theoretical considerations. It require further investigation and redefinition of azimuth resolution for near zone imaging applications.
3. To obtain good shape definition an object needs to be insonified from adequate angle range. Current results indicate this angle range at 30 to 60 degrees from vertical for short range operation.
4. To make interpretation of sonar images more straightforward compensation of slant range and synchronization of display speed against linear transducer speed are recommended.
5. The next phase of experiments will be focused on change of geometry of the transducer/ object arrangement. It is planned to allow evaluation of the same parameters at longer ranges.
6. The tests will also be repeated for smaller (shorter) transducers and chirp modulated signals.

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