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A COMPARATIVE ANALYSIS OF SIDE-LOOKING SONARS FOR RAPID CLASSIFICATION OF UNDERWATER INTRUDERS

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Abstract: *One aspect of NURC's 2008 efforts in port protection involves building a prototype system for countering a subsurface threat. Such a capability against underwater intruders in ports requires surveillance of the underwater domain and the means for response when intruders are detected. Multiple exercises and trials in 2007 and 2008 have provided opportunities to experiment with different side-looking sonars for the reacquisition and classification of an underwater intruder. A response vessel carrying the classification sonar was provided an intercept vector from a wide-area surveillance sonar. Both manned and unmanned response surface craft were used in the trials. The comparative results, analysis, and implications for the sonars are reported here. Preliminary conclusions show the possibility to reacquire an underwater contact with ease, and classify a contact as a diver with varying levels of success. The analysis and reporting follows a methodology used in earlier trials at NURC. The parameters correlated with successful classification are identified here. The relative performance of side-looking sonar compared to forward-looking sonar is considered.*

Keywords: *Port Protection, waterside security, underwater intruders, side-looking sonar, sidescan sonar,*

1. INTRODUCTION

An important aspect of harbor security is the enforcement of an exclusion zone, in which unauthorized entry is prohibited. The surveillance of an exclusion zone which extends below the water's surface is normally accomplished using a fixed monostatic active sonar. Such a sensor will detect and track an underwater contact, and provide a first alert of the presence of an unauthorized moving object in the exclusion area. Earlier work at NURC and elsewhere has shown that such detection sonars, now commercially available, are effective for the detection and tracking task with serviceably low false alarm rates [1-3].

In operations other than war, port authorities or military commanders are bound by the principles of self-defense. Specifically, this implies that response measures properly include a duty to warn, to prove intent, and to use proportional force to stop the threat [4]. This has been the starting point for much of NURC's port protection work in 2007-08.

Classification of unknown underwater contact is the next step after detection and tracking. Because of the limited range capabilities of classification sensorshigh-resolution sonar imaging, this step is best accomplished using a mobile sonar aboard a small response vessel.

2. DISCUSSION

The classification can be done with forward-looking sonar [5-7], but the authors considered that sidescan sonar might also be appropriate for the task. The classification quality of the sidescan images of intruders has so far been unproven. Some serendipitous sidescan images of divers have been collected, but until recent work at NURC in port protection [8], no systematic assessments of performance in the intruder classification role have been reported. The advantages of a sidescan sonar in this mission are

- The ability to search an area in the vicinity of an underwater contact to re-acquire it with the classification sensor is greater with a sidescan [8]. This could be very important if the detection and tracking sonar loses a contact.
- Sidescan sonars can be simple and inexpensive. Some high-end fish-finders for sports fisherman include an impressive sidescan capability for instance.
- Unlike forward looking sonars, a sidescan sonar needs only to sail past the contact in order to image it, without dwelling for a time in its close proximity with carefully matched velocity, and without lingering near a potentially dangerous attacker.
- Sidescan sonars are designed for higher speed underwater, with significantly less hydrodynamic than forward-looking sonar. This makes it unnecessary to retract the sidescan sonar during highspeed transits of the response vessel for rapid interception of a contact, whereas forward-looking sonar mounts can be damaged at high speed, and might even destabilize a small response craft during transit.
- The same sidescan and response vessel combination might serve straightforwardly in three different port protection missions: for seafloor surveys and for the seach for explosives in addition to classification of moving objects.

On the other hand, there are disadvantages of sidescan when compared with the best forward-looking sonars

- Sidescan sonar produces a snapshot image of a moving contact, vice "video-like" images formed by some forward-looking sonars. The video-like image provides additional classification cues based on the contact's body and limb motion.

The following parameters affect the image quality available from a mobile sonar, whether sidescan or forward looking (excluding 3D-imaging sonar):

- Horizontal beamwidth the most important parameter for determining image resolution.
- Horizontal beamwidth is determined by the nominal operating frequency and the size of the sonar transducer, with higher frequencies and larger transducers producing narrower beamwidth and higher image resolution.
- The bandwidth, or effective pulse length, affects the downrange resolution.
- Sonar altitude above the seafloor has a few notable effects on image quality, on the one hand because a sonar's field of view in a vertical plane is limited by the vertical beam width, and on the other hand because seafloor reverberation and clutter in the field of view can mask a contact's image.
- Ping rate is dictated by the two-way time of flight of sound across the total range of sonar coverage. For sidescan sonar, the ping rate can affect the cross-range resolution of a contact image. For forward-looking sonar it is the "video" frame-rate.
- Image quality can be degraded if the environmental conditions (wind and waves) cause rapid variations in the pitch, roll, or yaw of the sensor.

Some of the above parameters can be chosen by a system designer to approach an optimal imaging solution under ideal conditions. Foremost for imaging are

- Number of pixels on target. For side-looking sonar the speed of the vessel relative to the contact being imaged in conjunction with the ping rate dictates the number of pings on the target. When converted to a visual display, the number of pings equals the number of pixels in the cross-range direction. We use a guideline of a minimum of eight pixels in the along-track direction to obtain a classifiable contact of humanoid or other shape.
- Range to contact. Contacts at further range will have a lower signal-to-noise ratio than closer ones. This is due primarily to spreading and absorption losses (of acoustic intensity) in the medium. Images of more distant contacts are more susceptible to blurring by spurious sensor motion causing blurring of the image.
- Percent of screen dedicated to contact. A modern computer screen is capable of displaying more than 1 million pixels. Let us approximate the effective area of a sidescan display as 1 million pixels – arranged as 1000 by 1000. The guideline of eight pings was presented above as a minimum resolution in the along-track direction. Suppose each ping is represented by one pixel in the vertical direction and eight pings represents about 50 cm – the right order of magnitude for the shoulder width of a diver. Our vertical dimension then represents $1000/16 \approx 60$ meters. Suppose the range scale of the sidescan is set to 30 meters (each side) so

the horizontal dimension also represents 60 meters. A diver contact of about 1 square meter (2 m long X 50 cm wide) would thus occupy a paltry 0.03% of the display. Such an object is likely to be unnoticed, even when cued by another sensor. A minimum of 5% of screen area is proposed for recognizing that a contact is present in the sonar scene. Contact magnification can be accomplished by a combination of reducing the range scale (possibly looking at a one-sided sidescan display) and oversampling in the along-track direction – either in the acoustic domain or the display conversion.

A design trade-off study was conducted at NURC in 2007 to assess parameters of candidate sensors for classification of diver contacts. A subset of the data collected relevant to the three sensors exercised is presented in tables 1 and 2 below. A scoring system which combines sonar parameters as weighted sums was developed in order to rank sonars by overall performance, and the initial results are shown as weighted score in the second column. The sonar parameters follow or are derived from the sonar manufacturer's specifications whereas the weighting allotted to these were set by subjective judgment prior to any experimentation at sea. Sonars with higher weighted scores were expected to be better performers in the imaging task.

		Transmitter		Search Volume					Range Res	Azimuth - Horizontal Resolution			Physical Properties				
											Angle	Range	Weight		Dimensions		
MODEL	High-Level Criteria	f (kHz)	SL (dB)	R_{Min} (m)	R_{Max} (m)	φ_{Max}: Deg	θ_{Max}: Deg	Search Volume (m^3)	dr: m	# of φ beams	dφ: Deg	8-pixel range (m)	Kg	Kg	L (m)	W (m)	H(m)
	Values		200	1	50	60.00	45.00	33395.11	0.1	400.00	0.30	38.20	5.00	5.00	0.10	0.10	0.10
Supplier - Model																	
MarineSonic Centurion		600	215	20	75	0.30	40.00	494.1144	0.10	1.00	0.50	22.92	15.00	15.00	1.10	0.10	0.10
Weighted Score	0.49		1	0	1	0.01	1.78	0.30	0.00	0.00	0.00	13.20	0.33	0.33	0.00	0.00	0.00
TriTech SeaKing		325	215	1	100	1.00	50.00	4917.374	0.20	1.00	1.00	11.46	25.60	13.00	0.50	0.05	0.05
Weighted Score	0.31		1	0	1	0.03	2.00	2.94	0.00	0.00	0.00	6.60	0.20	0.38	0.00	0.00	0.00
Humminbird 987cx SI Combo		455	215	1	60	60.00	40.00	51575.1	0.63	1.00	1.70	6.74	1.54	0.70	0.08	0.05	0.05
Weighted Score	0.50		1	0	1	2.00	1.78	20.00	0.00	0.00	0.00	3.88	1.00	1.00	0.00	0.00	0.00

Table 1: Relevant specifications for three sidescan sonars

3. EXPERIMENTAL RESULTS

The three sidescan sonars listed in tables 1 and 2 exercised to systematically collect diver images in three separate trials over the past 18 months. All trials were conducted under the direction of NURC scientists, and all took place in waters in or near the Gulf of La Spezia. The operating areas were nominally similar, with water depth about 10 to 12 meters, and bottom composition of mostly sand or silt. Each sonar was attached rigidly to the vessel using a pole mount (without a tow fish) at a depth of 30 to 40 cm below the surface.

In March 2007, a Humminbird 997c SI Combo (455 kHz sidescan) was used aboard a small RHIB in calm sea conditions [8]. 60 images were available from the Humminbird sonar. 28 were open circuit, and 32 were closed circuit.

In November 2007, a Tritech SeaKing (325 kHz sidescan) was used aboard a small RHIB in calm sea conditions [6,7]. 16 intercepts were available from the Tritech sonar. 12 were open-circuit, and 4 were closed-circuit.

In April 2008, a MarineSonic Centurion (600 kHz sidescan) was used aboard an 8-meter vessel in choppy sea conditions. 27 images were evaluated from the MarineSonic. All were open-circuit divers.

A comparative analysis requires a comparable data set from each sonar under assessment. First, reacquisition was viewed as a prerequisite. Since the closed-circuit divers were either unrepresented (MarineSonic) or underrepresented (Tritech), an analysis across all three sonars could only take place with open circuit diver images. As a result, the total number of images evaluated was 28 from the Humminbird, 11 from the Tritech, and 27 from the MarineSonic. The images were classified independently by two expert observers, with subjective ratings of high, medium, or low classification confidence. The number of occurrences for each rating (high, medium, or low) from each observer is shown in figures 1-3. Sample images from the three sonars are shown in figures 4-6.

4. CONCLUSIONS

Looking at all three sidescan sonars together, it is clear that multiple passes with sidescan sonar would be required as a rule, operationally, for collecting a high-quality, high-confidence images of intruders. Since every pass on a contact is an opportunity for an image, the likelihood of classifying a contact with confidence increases with each pass. The number of passes required was studied for the Humminbird sonar [8]. Much the same could be done for the other two, but more data would be required.

Each sonar proved capable of providing images that were judged to be of high quality, although none could do so consistently and reliably. The scoring noted in tables 1 and 2 do not seem to provide a reliable predictor of the performance noted in figures 1-3. This could be due to the fact that environmental effects outweighed sonar performance parameters, especially in the case of the April 2008 test of the MarineSonic sonar, which was conducted by a remotely controlled vehicle, in open water outside of the port to avoid traffic, and in swells and chop atypical of a harbour environment. Because a detection and tracking sonar was not available for the Marine Sonic trials, moreover, divers were required to swim strictly along an underwater line between buoys, and the remotely controlled vehicle was required for safety to keep more than 10 m away from the line. The distance was typically greater than 15 m. The Humminbird and Tritech sonars, on the other hand, were vectored more precisely and to closer proximity by a diver detection and tracking sonar. This may have biased the data against the MarineSonics.

The higher frequency sonars (MarineSonic and Humminbird as compared with Tritech) generally provided better classification cues from the highlight associated with the body.

The presence of a shadow was often noted from the Tritech and Humminbird sonars. The shadow was often of high enough resolution to provide strong classification cues from the Humminbird. The test with the MarineSonic sonar did not provide shadows which were usable as classification cues. This was again probably due to blurring from vessel motion.

Bubbles are a prevelant classification cue, and as seen particularly in figure 5, the conditions duiring the test of the Tritech sonar was optimal for viewing the bubble trails, as they persisted for a long time with very little dispersion.

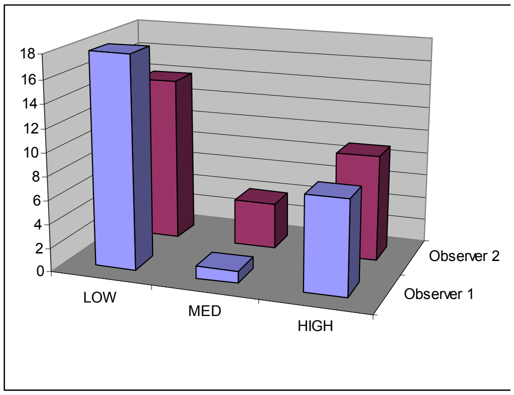

Figure 1: Ratings for MarineSonic sonar (Apr 2008)

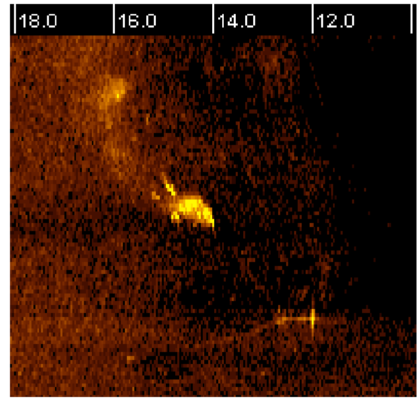

Figure 4: Sample image from MarineSonic sonar (Apr 2008, scale in meters from the sonar)

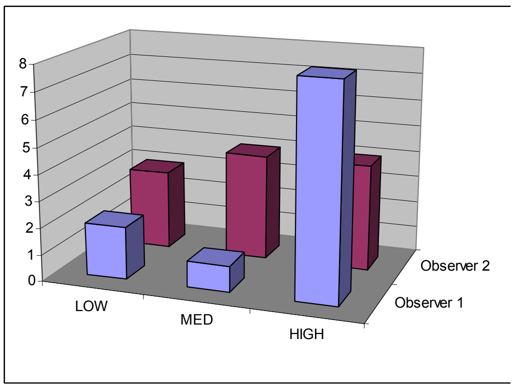

Figure 2: Ratings for Tritech sonar (Nov 2007)

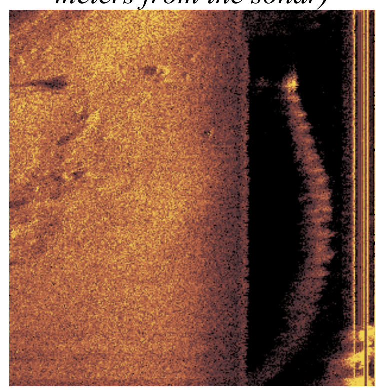

Figure 5: Sample image from Tritech sonar (Nov 2007, horizontal extent is 30 meters)

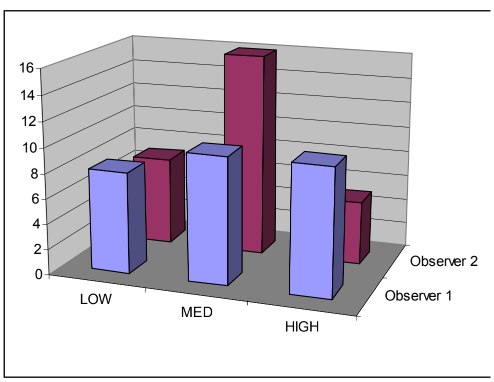

Figure 1: Ratings for Humminbird sonar (Mar 2007)

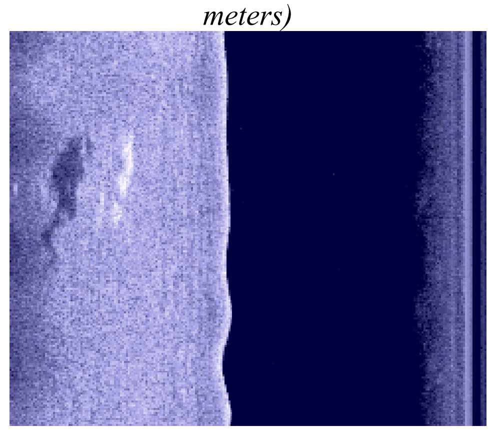

Figure 6: Sample image from Humminbird sonar (Mar 2007, horizontal extent is 12.5 meters)

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