Detection and Classification of Submerged Threats in Very Shallow Water Using the Quiet Interlude Processing System (QuIPS)

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Abstract-This paper describes the capabilities of the Quiet Interlude Processing System (QuIPS) in very shallow water (0 to 100 m) against undersea (mini subs, Autonomous Underwater Vehicles (AUVs), swimmer delivery vehicles (SDVs), etc.) and surface threats. QuIPS performs Matched Phase Matched Field Processing (MPMFP) in real time and data fuses contacts with non-acoustic, remotely sensed data and traditional plane wave acoustic data. No existing system has the capability to detect, classify, and track such threats in very shallow, noisy near shore and harbor environments where the acoustic arrivals at low frequencies are <u>not</u> plane wave.

I. BACKGROUND

The primary focus of Navy sonar systems over the past 40 years has been antisubmarine warfare (ASW) in deep water, and, more recently, in shallow water. However, shallow water ASW usually means "as shallow as U.S. submarines can go". There is now an ASW and Force Protection threat in very shallow water worldwide, and the Navy's plane wave sonar beamformers will probably perform very poorly at low frequencies at these very shallow depths. Present day plane wave sonar systems were designed to detect submarines in deep water. Over the past decade, as ASW operations transitioned to littoral waters (100 to 300 meter depths), the existing sonar systems have proven to be somewhat effective, although degraded in performance because the acoustic arrivals at low frequency are not plane wave. Now a new threat exists, that of small submersibles and semi-submersibles operating in the very shallow (10 to 150 feet water depths) around our Forces worldwide and near our nation's harbors. Unfortunately, today's ASW-based sonar systems are not effective in these very shallow water environments because the fierce interference from surface and bottom reflections prevent the propagation of planar sound waves that are essential for the operation of their beamformers and signal processing electronics. Recognizing this shortcoming, the Space and Naval Warfare Systems Command (SPAWAR) funded Neptune Sciences Inc. to develop a real time sonar processor with beamforming and signal processing algorithms to match the type of sound waves that propagate in very shallow water, referred to as *matched phase matched field processing*. Neptune Sciences is developing the **Quiet Interlude Processing System (QuIPS)**, a state-of-the-art sonar signal processing suite using matched field processing, as well as the normal plane wave beamformers to detect and track surface ship and submerged contacts in **very shallow water**.

To complement Neptune's **QuIPS** dry end processor, a very rugged and reliable array of underwater sensors (hydrophones) is needed. Fiber optic hydrophones represent the most reliable underwater hydrophones available, and Neptune's partner has developed the key fiber optic technology to produce the world's most reliable and lowest cost fiber optic hydrophones. This fiber optic sensor technology (which received the Photonics Circle of Excellence Award as "O*ne of the 25 most technically innovative products of 2002"*) has now been automated enabling low cost manufacturing of long arrays of sensors on a single fiber. Using this new technology, fiber optic acoustic arrays can be formed onto a single fiber with no splices, stripping/recoating, or optical couplers. The resulting arrays are inexpensive, easy to build, while retaining the reliability of the virgin fiber. **QuIPS** is an array geometry based processor and can accommodate any bottom array design from 0 Hz to over 44 kHz.

I. DISCUSSION

Neptune Sciences is producing a prototype bottom array system for very shallow water ASW, Force Protection, Harbor Defense, and Protection of Key National Assets along our coastlines. The proposed **QuIPS** system will include an all fiber optic underwater sonar array coupled with the shallow water signal processing suite and 4D visualization displays. In addition, the **QuIPS** system provides the capability to fuse non-acoustic, remotely sensed surface ship tracking data and nearshore oceanography and meteorology data. Neptune's accurate Global ELINT Tracker (GET) fuses satellite remotely sensed ship track data with local radar and other Radar Intelligence (RADINT) data, Communications Intelligence (COMINT) data, measurement and Signal Intelligence (SIGINT) data, and imagery to provide an integrated display of the complete surface/subsurface picture. Surface ship track information, such as the JMIE data, U.S. Coast Guard's National Vessel Movement Center (NVMC) and the Automated Information System (AIS), as well as some classified data sources, will also be input to **QuIPS** and fused with other tracking data. **QuIPS** is proposed to be connected to the Maritime Intelligence Fusion Centers (MIFCs) in Alameda and Norfolk.

II. QuIPS At-Sea Test Demonstration

Funding for a pilot project to demonstrate the feasibility of the system by collecting and processing data in real time has been requested and includes installation and operation of one array of the proposed system at a location specified by the sponsor. This section describes a typical **QuIPS** at-sea experiment near the entrance to San Diego Harbor.

Ports like San Diego and Norfolk have valuable Naval assets berthed at piers that may be vulnerable to attack from the water or harbor side (see Fig. 1). Recently the USS Cole and LIMBURG (see Fig. 2) have been attacked by crude motorized surface craft and loss of life and significant damage have occurred. More sophisticated submersibles (see Figs. 3 and 4) now exist, and these AUVs, ROVs, etc. are being developed by the U.S. Navy (see Fig. 5) so that they are "commercially available vehicles for a wide range of users [including terrorists] (economy of scale)." These more sophisticated vehicles are inexpensive, commercially available, and can carry lethal weapons, including WMD.

QuIPS has three modules as shown in Fig. 6: a state-of-the-art acoustic module to detect and track the submerged AUVs, ROVs, etc., threats; a non-acoustic, remote and local sensing module with sources such as (ELINT, local radar, COMINT, MASINT, etc., to attain Maritime Domain Awareness (MDA); and a massive data fusion engine to fuse acoustic and non-acoustic data for surface ship tracks and submerged contacts.

The CONOPS to integrate acoustic and non-acoustic data in an at-sea demonstration in San Diego already exists with **QuIPS**. **QuIPS** hardware is a LINUX cluster (see Fig. 7) with high resolution 4D data and geo-displays and <u>automation</u> and <u>data</u> <u>fusion</u> are the key elements in the **QuIPS**. The acoustic (i.e., sonar) track picture just outside the San Diego harbor is very complex (see Fig. 8 for the acoustic array location during Fleet Battle Experiment-India (FBE-I) in March 2001 with the track of Californian Highway, a commercial auto-carrier, also shown). Fig. 9 shows the broadband acoustic tracks for this time period and Fig. 10 shows the narrowband acoustic spectra and track of the auto-carrier Californian Highway. **QuIPS** matched phase matched field processor (MPMFP) detected the Californian Highway at a range of 9 km and at 0700Z. The plane wave beamformers' performance shown in Figs. 9 and 10, by comparison had an initial detection range of 2.7 km and an initial detection time of 0715Z.

It is obvious that:

1) **the Californian Highway's narrowband harmonics make the undersea acoustic environment very noisy and complex in frequency space.**
2) **MPMFP showed significant potential as compared to traditional plane wave beamformers.**

The non-acoustic, remote sensing data is critical for two reasons:

All surface ship tracts must be accurately estimated in a "crystal clear" picture to:

1) **detect and track possible surface ship threats (cruise missile shooters, small boats carrying WMD, etc.)**
2) **declutter the acoustic track picture identifying all non-threat tracks so that threats of interest can be classified more accurately.**

No "one type" of non-acoustic, remotely sensed acoustic data available to **QuIPS** currently is a "silver bullet" to achieve MDA by itself. ELINT data is valuable, but is passive and relies on a ship actively using its radar. Local radar, when available, is critically important but has limited detection range. Fusing SAR data into **QuIPS** is also critical to attain MDA, and has been proposed.

Norfolk Harbor

Fig. 1. U.S. Forces afloat have little or no protection from seaside for attack from submerged vehicles carrying WMD.

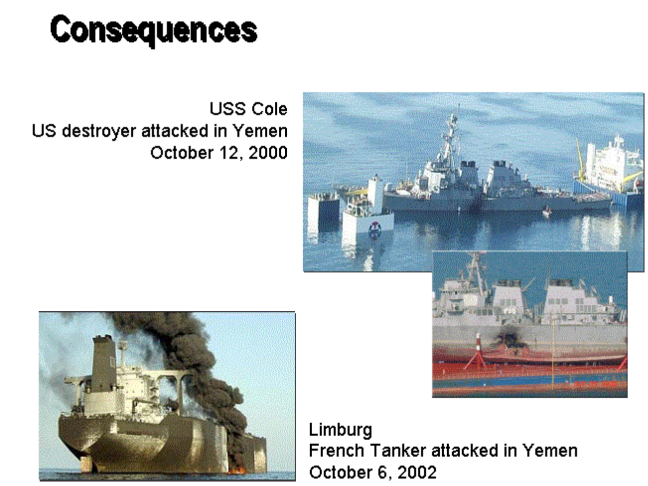

Fig. 2. USS Cole and LIMBURG suffered loss of life and significant damage from unsophisticated small boats.

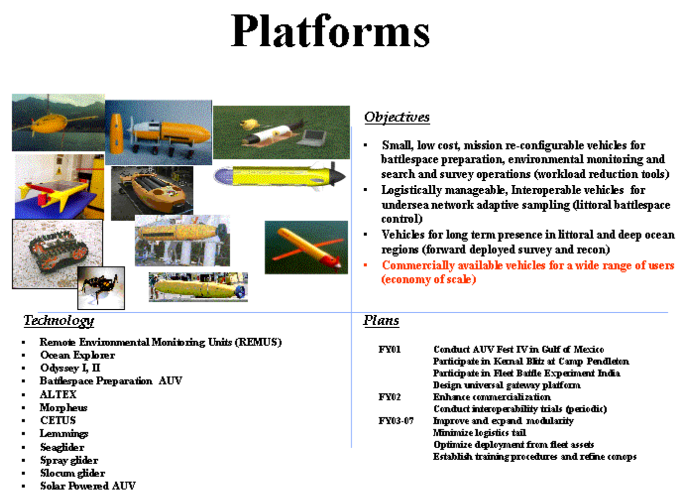

Fig. 5. AUV technology is in rapid advance as evidenced by ONR's web page.

Fig. 3. Some Threat Vehicles identified by the CIA.

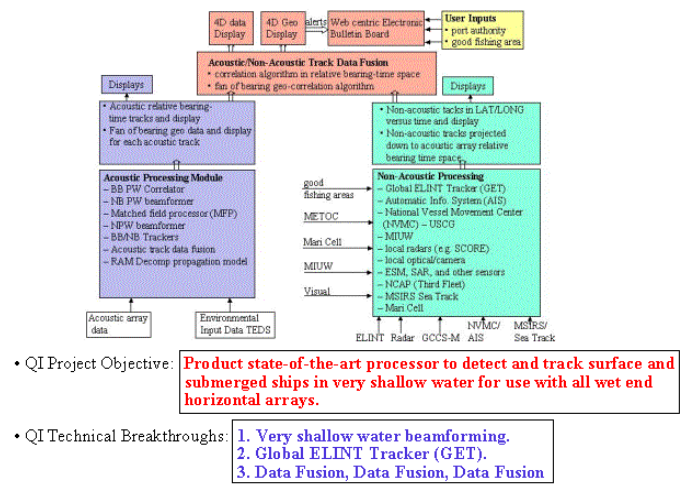

Fig. 6. The Quiet Interlude Processing System (QuIPS)

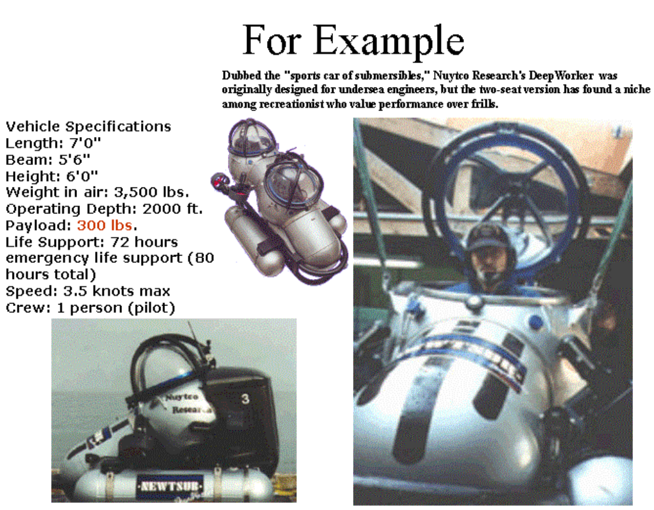

Fig. 4. An example of an inexpensive ROV.

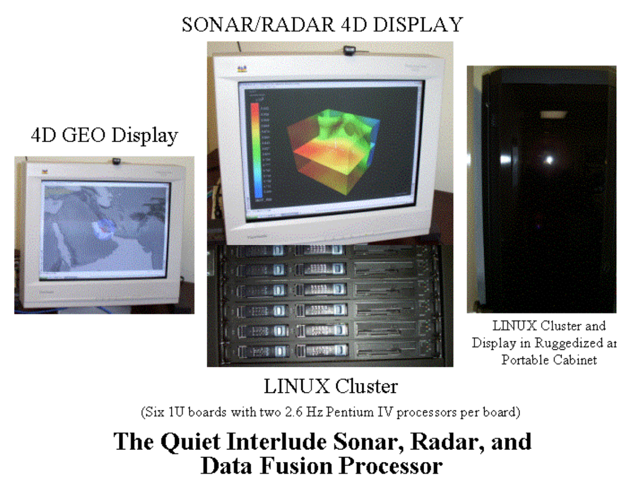

Fig. 7. The QuIPS Hardware – Powerful and Portable

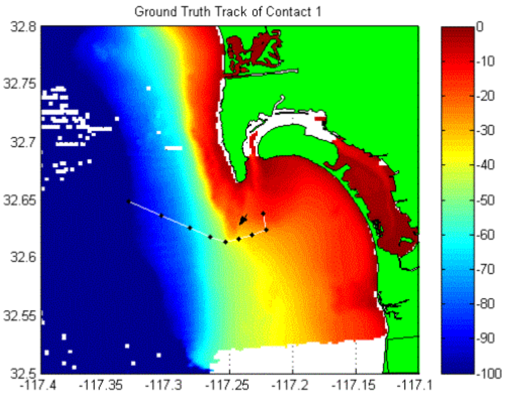

Fig. 8. The ground truth track of the Californian Highway, as it approaches the Port of San Diego, CA, based on the onboard log provided by K-Line Co., Japan. Bathymetry data, provided by NAVO, is shown in color (meters). FBI-I array location and orientation (213.5° T) shown by arrow.

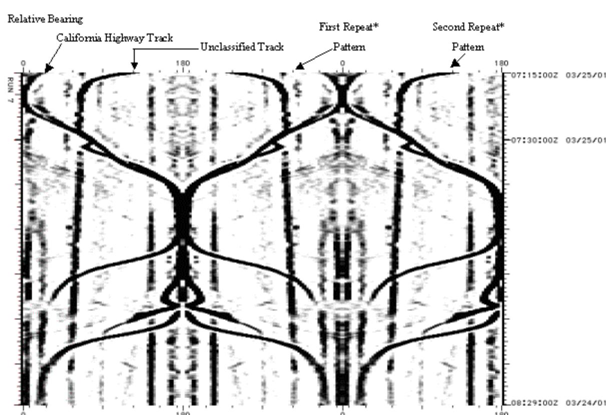

Fig. 9. Data Fusion of Relative Bearing-Time Tracks from Three Broadband Correlograms Operating on Three Different Frequency Bands.

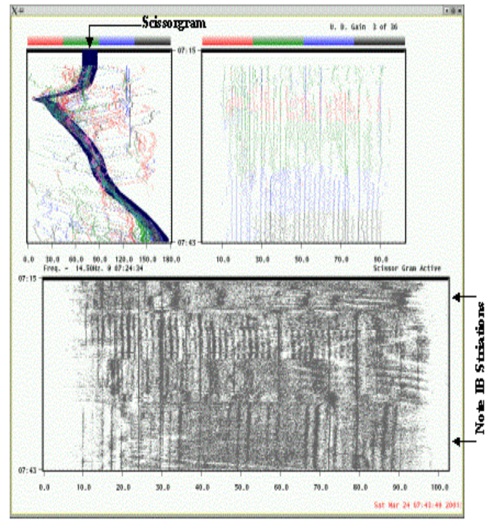

Fig. 10. Scissorgram for surface ship showing typical narrowband acoustic lines.

III. Conclusions

QuIPS fills the very shallow water sensor gap, and is a most innovative product in many ways. **QuIPS** is very flexable in the wide range of wet end arrays that can be used with the dry end processor. **QuIPS** can be designed to detect a swimmer breathing apparatus on the high frequency end of the acoustic spectrum to narrowband lines from a mini sub on the low end of the acoustic spectrum using the same dry end processor with very different wet end arrays. **QuIPS** can be used for a wide variety of nearshore applications for very shallow water ASW, Force Protection worldwide, and harbor defense/port security.