New Perspective for Oceanographic Studies in the Indian Ocean Region

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Introduction

India's location in the Indian Ocean Region (IOR) compels it to play a larger strategic role in the region.[1] The growing energy needs of China—with the Gulf continuing to be its most preferred source—further causes the Chinese merchant fleet to transit the IOR. To ensure uninterrupted supply of energy resource, the Chinese have started to increase their presence in the region and this has, in turn, encouraged the Americans to also deploy their marine assets in the region.[2] Keeping this in mind, for India, the emerging maritime concept of sea control requires enhanced situational awareness in the region to ensure sea denial when required. Technology has a significant role to play in such a situation and, effective sonar deployment, thus, becomes an inescapable requirement.[3]

Conventional sonars, designed for blue-water operations, present suboptimal performance in the littorals due to site-specific behaviour of the underwater channel.[4] The tropical waters in the IOR further degrade sonar performance due to random fluctuations in the surface parameters like temperature and wind.[5] Today, adaptive signal processing options are available in modern sonars for neutralizing the impact of underwater channel distortions and ambient noise. However, in the absence of credible

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oceanographic and ambient noise data on specific locations of sonar deployment, these signal processing techniques are rendered ineffective.[6] Adaptive signal processing options refers to the availability of algorithms that can be dynamically altered during deployment by the operator or even with automated inputs regarding the environmental (ambient noise and the underwater channel distortions) conditions to facilitate optimal performance of the sonar. Thus, there is a need to undertake detailed scientific oceanographic data collection/analysis and ambient noise mapping exercise all along the vast Indian coastline. Such an effort will give a definite edge for our own military sonar deployment, while denying the same to our adversaries, due to improved sonar performance.

Oceanographic data collection and ambient noise mapping effort for the entire Indian coastline extending over 7,500 km is a daunting task with enormous infrastructure investment. Furthermore, the involvement of academic institutions with credible analysis capabilities, very vital for such scientific experiments, has been absymally poor due to their difficulty in participating in sea experiments in harsh weather conditions. Historically, such missions have been undertaken using ships that can cover limited areas with large infrastructure requirement in terms of manpower and deployment costs. In the mid-1990s, underwater gliders were developed for such oceanographic studies owing to their small size, long endurance, low speed and low cost.[7] An underwater glider design, development and deployment effort with appropriate payload of sensors will be able to effectively address this all-important aspect of improving sonar performance for our military platforms and even non-military platforms in the IOR.

SONAR EVOLUTION

Military technology development—more specifically, that of underwater sonars—got a very big boost during the Cold War. The superpowers invested enormous amount of money on sea experiments to bring down the uncertainties of the ocean medium for improving sonar performance and reliability. This initiated joint research efforts by academia and the defence forces for data collection at sea and their analysis. One of the landmark achievements of such research efforts was ambient noise mapping of deep waters by Wenz[8] that is valid even today for varying sea states and shipping densities. Efforts by researchers[9] in understanding the undersea environment with extensive sea experiments contributed immensely towards improved sonar performance in deep waters.

The collapse of Soviet Union and the end of the Cold War marked the strategic shift of the naval war theatre from blue waters to the more focussed forward operations in the littoral waters. This resulted in a total shift in the global maritime doctrine and naval battle strategy. The significant stability of sonar operations in the deep waters due to generalized underwater channel behaviour was no more valid in the littorals.[10] The enhanced impact of the random ambient noise behaviour and fluctuations in the underwater signal propagation characteristics in the littoral waters severely degrade reliable sonar performance.[11]

The littoral waters are marked by the close proximity of the two boundaries, namely, the sea surface and the sea bottom, leading to repeated interaction of the sonar signal with these boundaries, resulting in their high sensitivity to the local site-specific surface and bottom characteristics.[12] In the deep waters, the signal propagation is more or less due to refraction around the sound axis, consequently minimizing the sea surface and bottom interaction. Further, it is well known that 95 per cent of sea creatures inhabit 7 per cent of the shallow coastal waters and these marine creatures are highly specific to the location, resulting in enhanced modification of the sonar signals. The marine creatures, due to their vocalization, also contribute appreciably to the ambient noise in the region, thereby impacting sonar performance in the specific location.[13]

There have been two accepted types of shallow water definitions among the scientific community: hypsometric and acoustic. Hypsometrically one assumes that the 200 metre (m) contour line marks the end of the continental shelves for most of the continents and there is an abrupt fall of the sea bottom beyond that. Therefore, shallow water is taken to mean continental shelf waters shallower than 200 m; shallow water represents about 7.5 per cent of the total ocean area. Acoustically, the shallow water is characterized by multiple interaction of the propagating signal with the sea surface and the sea bottom. Thus, acoustically, depending upon the latitude of the location, the deep water could behave like shallow waters due to multiple interaction of the sonar signal with the bottom and the sea surface. The depth of the sound axis varies from 1,800 m near the equator to 50 m near the poles due to temperature variations.[14]

INDIAN OCEAN REGION (IOR)

The IOR, owing to its tropical location, demonstrates complex fluctuations in the propagation characteristics due to random diurnal fluctuation in the surface parameters. The littoral waters in the extended

Indian coastline further add to deteriorated sonar performance in the IOR.[15] Unlike the temperate region (North Pacific and North Atlantic oceans) where most of the advanced navies operate typically, the surface parameters of the tropical seas do fluctuate randomly and even the depth of sound axis is far less (of the order of 200 m in tropical waters compared to 1,500 m in temperate waters). Thus, a hypsometrically deep-water area behaves like an acoustically shallow region in the IOR, thereby degrading sonar performance.[16] The sonar performance can be improved only with enhanced ambient noise and underwater channel characterization to facilitate mitigation of the distortions generated by them.

The strategic importance of the IOR and the specific location of India within the IOR automatically ensures its participation in the region as a strategic player. Consequently, India has embarked on a more focused anti-submarine warfare (ASW) maritime doctrine with high-value submarine projects being launched and acquisition of strategic submarines being pursued. Real-time deployment of these platforms will necessitate higher levels of situational awareness of the underwater environment with effective sonar performance. Further, the ability to deny the enhanced sonar performance for the adversary will certainly provide India strategic advantage. The prevailing security scenario comprising low-intensity conflict being waged by our adversaries through subversive forces, both within and outside our national boundaries, has further enhanced the role of coastal security. To ensure effective coastal security, reliable sonar performance is essential and this can be ensured only with detailed ambient noise and oceanographic mapping of our entire coastline.[17]

In the year 2001, the Woods Hole Oceanography Institute (WHOI) concluded a massive underwater experiment— ASIAEX 2001—in the South China Sea.The experiments were funded by the Office of Naval Research (ONR) of the United States. The detailed report has been released for public view recently.[18] These experiments extended for several years and were presented as mere academic efforts; however, their military application was a primary focus. The main aim of these studies was to understand the acoustic signal behaviour in the tropical, littoral waters. Numerous academic publications thereafter presented varied aspects of ambient noise and underwater channel characterization in tropical, littoral waters, and also mitigation techniques for improved sonar performance.

Efforts to undertake ambient noise and oceanographic mapping using ships have been only partially successful due to the inherent limitations of human resource deployment at sea in harsh weather conditions for extended durations. Further, the area coverage is also limited due to higher infrastructure requirements, with the ship itself contributing to the ambient noise being measured. The ship has to deploy the hydrophones in a region for extended duration for data collection and then analyze the data offline subsequently. The data collection effort away from the laboratory situation in harsh sea condition often leads to failures and enormous resource requirements to sustain human component at sea for extended duration.

Sea experiments followed by high-quality scientific analysis, at times, get limited due to the very nature of work environment of the two communities involved. The analysis capabilities of research community require high academic resource available in laboratory conditions, whereas the sea-going capabilities of navy or defence personnel, at times, limits their ability to undertake credible academic data analysis. Online data analysis can certainly improve the effectiveness and efficiency of such efforts; however, the practicality of the requirements limits such possibilities. In India, partnerships between the academia and the defence forces have not been able to generate effective results for solving real naval operational issues at sea.

UNDERWATER GLIDER

The underwater gliders developed in the mid-1990s have the potential to solve this important ASW problem, specifically in the Indian scenario, due to their inherent design features. It may be pertinent to mention that these underwater gliders were initially designed for oceanographic data-gathering missions; however, they were also developed to be deployed for multitude of underwater applications depending upon the payload of sensors onboard.[19]

These gliders are a type of autonomous underwater vehicle (AUV) that are not propeller driven like the conventional AUVs and are instead buoyancy driven. They are characterized by small size (2–3 m length and wing span) due to the simple design; long endurance (over six months or over 3,000 km) as they are propelled by buoyancy engines; low speed (< 0.5 m/s) in the absence of propeller-driven engines; and low cost to facilitate mass production and deployment. The vision of underwater glider is attributed to Henry Stommel from the WHOI and Douglas C. Webb in mid-1990s.[12]

The buoyancy-driven glider follows a sawtooth path across the ocean depths due to its heavier-than-water body comprising of required instrumentation, sensors and control mechanism. The vehicle covers a forward distance during its dive, depending upon the lift generated due to its hydrodynamic form (body and wings) and its angle of attack. The trim angle and its buoyancy are controlled by internal mechanisms, using pre-programmed controllers as a function of depth. At the desired depth, the buoyancy engine acts to make the vehicle lighter by operating a hydraulic pump. The vehicle then glides upwards, till a pre-planned depth or till the water surface. During each flight, the onboard sensors record data that are stored in an onboard memory and then transmitted via a wireless link to a shore monitoring station when it surfaces. When on surface, it can receive instructions as well as update its position. Typically, the primary vehicle navigation system uses an onboard global positioning system (GPS) receiver coupled with an altitude sensor, depth sensor and altimeter to provide dead-reckoned navigation.

The ONR, US Navy, is running a programme named Autonomous Ocean Sampling Network, under which three operational commercially available gliders have been deployed. These are the 'Slocum Electric Glider', developed by the Teledyne Webb Research; 'Sea-glider', developed by the University of Washington; and 'Spray', developed by the Scripps Institute of Oceanography (SIO) and WHOI. Approximately 160 commercially available gliders of these three types were reportedly operational in 2009. These three are known to be the most widely used gliders all over the world. Many more such missions are reportedly being operated all over the world by numerous groups for research purposes and varied applications.[21]

India's requirement of oceanographic studies keeping in mind its geopolitical location in the IOR and the typical underwater challenges of ensuring effective sonar performance is a unique predicament. The long coastline further adds to the challenges of large area coverage for such studies. As mentioned above, the use of the underwater glider has been extensively reported in the West, primarily for such studies, due to its unique features of slow speed, low cost and long endurance.[22] India's emergence as a recognizable economic and political power at the global level necessitates that it recognizes the strategic relevance of effective underwater sensors in the IOR and critically deliberates on the proposed option for improving technologies such as sonar performance.

Thus, the indigenous development of underwater gliders is a viable option. The effectiveness of design and development for the glider specifically for the IOR can only be ensured with stage-wise evolution of the design and development with repeated validation of each and every stage onsite. The low cost and custom-made design for the IOR has been reported with optimistic results for design and development of an underwater glider suited for the unique tropical, littoral waters near the Indian coast.[23]

CONCLUSION

The underwater glider proposed for oceanographic studies presents itself as a viable option for improving sonar performance in the complex tropical littorals of the IOR. The AUVs and others that are propelled offer better speed and more effective control; however, they do suffer from higher self-noise, corrupting the recorded data and interfering with the analysis. The slow speed of an underwater glider provides better measurement and analysis of the finer details of the underwater parameters. The low cost facilitates multiple simultaneous deployments for larger area coverage, and some could even be expendable in case of poor weather conditions. The underwater glider, with its buoyancy engine concept, has extremely low self-noise and long endurance compared to its competitors. The site-specific behaviour in the littoral tropical waters in IOR will require multiple sorties of such gliders at distributed locations.

The learning software/hardware built into the underwater glider can be programmed with intelligent algorithms during the pilot project that can be replicated in the other locations for a mass study programme to map the entire coastline. The pilot project could be undertaken for validating the self-learning algorithms designed with extensive field experiments, backed by laboratory simulations in collaboration with the academia, by the deployment agency.

The large-scale deployment required for the entire Indian coastline will facilitate mass production, thereby further bringing down the cost. The successful design and development of the underwater glider for deployment in IOR could open substantial opportunities for India in the region and also, propel it towards more optimum exploration of the undersea resources and naval deployments. The naval applications could include reconnaissance, surveillance, mine hunting, harbour patrolling, coastal security, etc., whereas non-military applications could include monitoring the marine ecology, anthropogenic noise monitoring, among others.

NOTES

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