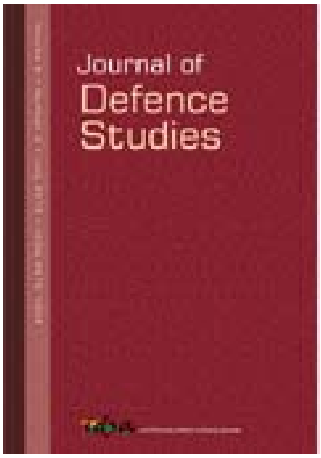

Effective Underwater Weapon Systems and the Indian Ocean Region

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Introduction

The Indian Ocean Region (IOR) has profound strategic relevance not only for the nations in the region but also for other countries.[1] The bulk of the world's merchant fleets transit through one of the busiest sea lanes in the world, via the Malacca Straits. Also, the presence of major petroleum exports originating from the Gulf, encourage the major powers of the world to have a strategic presence in the IOR. Present day naval strategies are not so much about exercising sea denial but about maintaining strategic presence, and switching to sea control whenever there is any threat to their own maritime interests. This calls for comprehensive situational awareness, and the continuous monitoring of both the surface and underwater fronts. The geographical location of India leaves it no choice but to be a major player in the IOR. Further, due to the growing energy needs of China in the recent past, and the bulk of its energy supplies transiting through the IOR, has encouraged both China and the United States to ensure their own strategic presence.[2]

In the above context, it is imperative that India has effective underwater weapon systems that are able to strike with precision when deployed. Moreover, from a strategic point of view, the fact that its adversaries accept that it possesses such weapon systems provides a huge psychological

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advantage. The scope of this commentary is India's underwater weapons, and how its torpedoes and mines are deployed in the moment of conflict either to cause damage or to intimidate the adversary. These weapons rely heavily on sensors to reach their targets, and subsequently guide torpedoes or detonate mines. Thus, the optimum performance of the sensors remains the key to the effectiveness of these weapon systems.[3,4]

The effectiveness of the sensors is ascertained from their sensitivity to the uncertainties of the medium.[5,6,7] Efforts by underwater researchers have translated into significant stability in sensor performance in varying underwater conditions, especially in blue waters. However, the post-Cold War era marked a shift in maritime strategy from a navy designed to engage an adversary with a blue water battle fleet to one focused on forward operations in the littoral waters.[8] The momentous advances in military technology during the Cold War era—particularly in achieving a better understanding of underwater propagation, and uncertainties related to the medium for designing improved underwater systems—was lost due to site specific characteristics in the littorals.[9] The tropical waters of the IOR have added further challenges for sonar designers and designs.[10,11]

The littoral waters are site specific due to varying propagation characteristics. To ensure an effective and stable performance, it is important to generate a detailed understanding of the medium parameters that impact sensor performance. The efforts of G. Wenz[12], followed by those of R.J. Urick[13], are noteworthy in understanding deep water characteristics that led to the design and development of algorithms that significantly improved underwater sensor performance in deep waters during the Cold War era. However, the effectiveness of these algorithms fell short in littoral waters due to random fluctuations of the medium characteristics. The attempts to import state-of-the-art weapon systems from the West have not been highly productive in our waters due to medium peculiarities, with the diurnal and seasonal temperature variations in the tropical waters aggravating the problem.[14]

Past efforts in deploying ships in deep waters to record ambient noise and collect oceanographic data for analysis and, subsequently, propose improved algorithms to mitigate the distortions of the desired signal due to medium characteristics, has not been a pragmatic option in the littorals. This is due to the coverage of a large sea area and the resource enormity required for such deployment in terms of scientific manpower and other logistic requirements. The Indian scenario is a little more peculiar due to the lack of coordinated efforts between the academic community that understands the technical possibilities and the operational component which deploys these assets.

This commentary is an attempt to bring out the variability's of the underwater medium parameters that impact the propagation characteristics of the sonar signals in the tropical littorals of the IOR. It brings out the limitations in sensor performance due the medium fluctuations, and proposes a new perspective of underwater data collection and analysis strategy for improving the performance of the sensors to facilitate improved availability of underwater weapon systems in the IOR. The proposal consists of a two-pronged approach, with fixed sensor deployment at strategic locations and the Underwater Glider concept for larger area coverage.

Tropical Littorals in IOR

The littorals being marked by the close proximity of the two boundaries—the sea surface and sea bottom—result in frequent and multiple interactions of sonar signals with the sea surface and the seabed, while propagating from the target to the receiver.[15] The sea surface and the sea bed are highly site specific due to local influences of surface parameters (wind, temperature, rain, etc.) on the former as well as the type and profile of the latter. In addition, the majority of marine life reside in the 5 per cent of the coastal waters the world over. Thus, the density of marine species is very high in the littorals compared to the blue waters, resulting in the higher absorption of the sound during propagation. These marine creatures are highly unique, depending upon local conditions. Thus, the noise filtering algorithms, and other studies in the advancement of underwater propagation in the deep blue waters to improve sonar performance were rendered ineffective in the littoral waters due to site-specific behaviour.

The shallow and deep water differentiation of the IOR underwater scenario has been made in two ways by the scientific community: hypsometric and acoustic.[16] The hypsometric definition is based on the fact that most continents have continental shelves bordered by the 200 m contour line, beyond which the bottom generally falls off rapidly into deep water. 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, shallow water conditions exist whenever the propagation is characterized by numerous encounters with both the sea surface and the sea floor. By this definition, some hypsometrically shallow water areas are acoustically deep; alternatively, the deep ocean may be considered shallow when low frequency, long-range propagation conditions are achieved through repeated interactions with both the surface and bottom. Shallow water regions are distinguished from deep water regions by the relatively greater role played in shallow water by the reflecting and scattering boundaries. Also, differences from one shallow water region to another are primarily driven by differences in the structure and composition of the sea floor. The sea floor is, perhaps, the most important part of the marine environment that distinguishes shallow water propagation from deep water propagation.

The tropical conditions of the IOR adds to the complexity of underwater propagation. The depth of the sound axis governs the acoustic propagation characteristics in any region. The tropical, temperate, and the polar regions are also differentiated by the depth of the sound axis depending upon the depth and thickness of the thermocline in these waters. Typically, the depth of the sound axis in the tropical waters is in the range of 1,000 m, whereas in temperate waters they are in the range of 400 m.[17] Furthermore, the diurnal and seasonal temperature fluctuation in the tropical regions is far more than in the temperate regions resulting in random surface disturbances due to wind variations.[18] Thus, one can very well appreciate the complexity of the propagation of sound in the tropical waters due to their shallow water characteristics.

Improved Sensor Performance

Advanced signal processing techniques have been applied successfully in numerous military and non-military applications like telecom, radar, audio processing, imaging, etc. However, sonar applications in the IOR have not profited from these advancements due to the site specific behaviour of these environments. The advanced nations have undertaken massive ambient noise mapping exercises at very high costs and efforts around their coasts and beyond to characterize the littorals, and adaptive signal processing algorithms specific to these characteristics have been incorporated to improve the detection and classification of underwater targets. Needless to say, these ambient noise mapping and propagation characteristics data are highly sensitive for the particular nation concerned as its absence can deny a specific advantage to an adversary in terms of effective sonar deployment or the detection of any underwater threat.

In 2001, the Americans undertook a massive acoustic and oceanographic experiment—ASIAEX 2001—in the South China Sea.[19] This experiment was funded by the Office of Naval Research (ONR) and undertaken by the Woods Hole Oceanographic Institute (WHOI) in collaboration with numerous academic institutes from China, Taiwan, Korea, Japan, Russia and Singapore. An enormous amount of acoustic and oceanographic data was collected, and the analysis results are being published in academic literature even today. This experiment highlights the fact that underwater sea experiments require massive infrastructure and human effort which are not feasible in academic settings only. Also, it is difficult the huge investments required for sustenance at sea for long durations. Needless to say, neither academicians nor defence experts can independently undertake this kind of study. Academicians can never appreciate the operational limitations of sonar deployment, whereas defence experts will always lack the understanding of complex signal processing possibilities.

The Way Ahead

Efforts to map ambient noise and oceanographic sound using ships have been able to provide only partial success due to the inherent limitations of human resource deployment at sea in harsh weather conditions for an extended duration. Further, area coverage is also limited due to higher infrastructure requirements as well as the ship itself contributing to the ambient noise being measured. The ship has to deploy hydrophones in a region for extended durations for data collection, and subsequently analyse the data offline. Besides enormous resource requirements to sustain the human component at sea for an extended duration, the data collection effort away from the laboratory situation in harsh sea conditions often leads to failure.

Sea experiments, and the high quality scientific analysis that follows, sometimes suffer from contradictions due to the very nature of the work environment of the two communities involved. The analysis capabilities of research community require high academic resource availability in laboratory conditions, whereas the sea going capabilities of the Navy or defence personnel sometimes 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 limit such possibilities. Unlike in the West, in India partnerships between the academia and the sea going forces have not been very successful in solving real naval operational issues at sea.

A two-pronged approach can be proposed at this stage: first, the deployment of fixed data collection sensors at strategic locations to undertake continuous data collection and analysis, with suitable onsite signal processing capabilities[20]; second, the deployment of Underwater Gliders (UGs) for larger area coverage in coastal waters.[21] The proposed method will also ensure a very important strategic advantage for India's weapon systems as, in the absence of these critical oceanographic and ambient noise data and their analysis results, the weapon systems deployed by its adversaries will not be able to attain precise performance in our waters.

Fixed Sensor

One preferred location based on the strategic relevance and convenience of accessibility could be shortlisted for undertaking a pilot project. The entire hardware for the data collection exercise and deployment aspect will have to be worked out based on the analysis strategy. The deployment strategy will have to be such that it is able to sustain long deployments without the damage/deterioration and obstruction of normal operations in the proposed site. Power and memory requirements will have to be appropriately worked out. The hardware design has to be well thought out for replication in other sites as well as be in keeping with varied environmental conditions.

The analysis strategy has to be well deliberated to be able to incorporate the majority of the medium characteristics, and the data collection effort should be all inclusive. Certain simulation, modelling and validation efforts will have to well planned, and be based on available literature and operational inputs. The analysis should be able to facilitate the designing of adaptive Signal to Noise Ratio (SNR) enhancement algorithms and effective operational planning for future naval operations. The documentation has to be very elaborate to present meaningful findings from the entire experimental effort, and also be able to facilitate the replication of the experiment in varied locations all over the coastline by multiple teams with and average understanding of the technical details.

Underwater Gliders

Developed in the mid-1990s, UGs have the potential to solve this important Anti-Submarine Warfare (ASW) problem specifically for the Indian scenario due to its inherent design features. It may be pertinent to mention that these UGs were initially designed for oceanographic data gathering missions. However, they were also developed to be deployed for a multitude of underwater applications depending upon the payload of sensors on board.

UGs are a type of Autonomous Underwater Vehicle (AUV) that are not propeller driven (like the conventional AUVs) but are buoyancy driven. They are characterized by their small size (2–3 m length and wing span) and 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 an underwater glider is attributed to Henry Stommel from the Woods Hole Oceanographic Institute (WHOI) and Douglas C. Webb in the mid-1990s.[22]

The buoyancy driven glider follows a saw-tooth path across the ocean depths due to its heavier-than-water body; it comprises of required instrumentation, sensors, and a 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 on-board sensors record data that is stored in an on board memory, and then transmitted via a wireless link to a shore monitoring station when it surfaces. When on the surface, it can receive instructions as well as update its position. Typically, the primary vehicle navigation system uses an on board Global Positioning System (GPS) receiver, coupled with an altitude sensor, depth sensor and altimeter to provide dead-reckoned navigation (Das and Kumar, forthcoming).

Conclusion

The IOR, with its strategic relevance and the role India as a nation is required to play to retain its reasonable hold over the region, demands effective situational awareness. However, the complex underwater channel behaviour in the IOR due to tropical littoral waters poses considerable challenges in ensuring effective underwater system performance. Modern sonars do have adaptive signal processing options to mitigate underwater channel fluctuation and random ambient noise behaviour; however, their performance is highly sensitive to the quality of oceanographic and ambient noise data. Efforts to collect oceanographic data with ships have not been very successful due to multitude of reasons. This has resulted in the sub-optimal performance of our sonars in these waters. Further, the vast Indian coastline extending up to 7,500 km further adds to the complexity in ensuring credible ASW capability.

Due to their inherently simple design and deployment mechanism, UGs are highly suitable for such an effort. Their small size, long endurance, low speed, and low cost can be programmed to undertake massive experiments for oceanographic studies and the mapping of ambient noise of our entire coastline. These can be deployed in groups repeatedly to maximize ground coverage. As compared to ship borne experiments, their deployment, the involvement of academic institutions, supported operationally by the Navy for high quality data analysis, will be very convenient in such missions.

Some strategic locations, like harbour mouths and critical offshore assets, will require more precise and effective weapon system performance, both for defensive and offensive requirements; thus, they may have to be mapped using fixed sensors. The mapping of the underwater environment and its enhanced understanding will certainly provide us the advantage of the improved performance of our sensors and guidance systems that could be denied to the adversary.

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