AUSTRALIAN

DEFENCE FORCE JOURNAL

Journal of the Australian Profession of Arms

NO. 127

NOVEMBER/
DECEMBER
1997

Detection of Submerged Vessels Using Remote Sensing Techniques

By Squadron Leader G.G. Wren, RAAF and
Squadron Leader D. May, RAAF

Introduction

Conventional mission proven technologies for the detection of submerged vessels involve both acoustic and non-acoustic techniques. These techniques are highly effective in sector location of submerged vessels. However, their ability to conduct wide area surveillance (WAS) and provide regular reporting is limited. Submerged vessels may also be detectable using oceanographic remote sensing technologies. Elevated sensors on a Low Earth Orbit (LEO) satellite, or aboard an Uninhabited Aerial Vehicle (UAV), may provide improved capabilities to satisfy the spatial and temporal requirements of WAS[1]. This article considers the potential application of oceanographic remote sensing techniques to the detection of submerged vessels.

Acoustic techniques comprise active and passive sonar which requires the insertion of sensors into the water either to detect sound waves produced by the vessel's propulsion systems (passive) or detect reflected sound waves emitted by the sensor system itself (active). Detected information is transmitted back to an air or seaborne platform where processing is carried out. Besides visual detection, the primary *non-acoustic* method is Magnetic Anomaly Detection (MAD). This technology is mature and is used by the RAN and the RAAF's long-range maritime patrol aircraft.

There are several emerging techniques in oceanographic remote sensing for detecting submerged vessels. These methods range from the direct detection of the vessel structure, to indirect detection through analysis of the effect the vessel has on the surrounding marine environment. Advances in technology, such as detector sensitivity, are now making the operational use of these techniques more feasible.

Wide Area Surveillance

Conventional acoustic and non-acoustic detection techniques have limited application to wide area surveillance (WAS). A predominant reason is the limited range of the detection technique due to the nature of the physical phenomena being sensed. For example, MAD detects the local disturbance in the earth's magnetic field caused by a concentrated ferromagnetic body (e.g. a vessel's hull). However, given that magnetic field strength reduces with the cube of the distance, the range of such sensors is limited; current sensors are only effective out to a few thousand feet. Acoustic detection over a wide area requires the extensive deployment of sonar buoys or towed arrays and the data fusion of their responses to provide a surveillance picture.

Another limitation of conventional techniques to WAS concerns revisit time, that is, the period between successive surveillance of the same area. The entire Royal Australian Navy (RAN) fleet would, at maximum effort, have difficulty maintaining adequate coverage over Northern Australia alone, with each vessel being required to cover about 300 km of coast each day[2]. The minimum revisit time required to provide adequate warning of a vessel's advance across our closest maritime approach is about five hours (around half a vessel's transit time)[3]. Moreover, it takes around 25 days for a maritime patrol aircraft to provide repeated radar coverage of Australia's area of direct military interest (ADMI)[4]. This estimate suggests that revisit times for acoustic coverage of the ADMI would be significant.

Elevated sensors in LEO[5], or on high-altitude UAVs, may provide an opportunity to satisfy the spatial and temporal requirements of WAS. While platform issues are of interest, this article will focus on the merits of the sensing techniques. Contributing factors include advances in minimising submarine signatures making passive acoustic detection increasingly difficult.

Overview of Environmental Characteristics

There are two methods by which a submerged vessel could be located: direct and indirect detection. Direct detection involves locating the vessel structure itself; the indirect method involves the detection of environmental anomalies caused by the presence of a submerged vessel.

Direct Detection

Submerged vessels may be directly detectable by observing how a hull absorbs or reflects blue-green laser light (450-550 nm)[6]. This response could be used to create an image with the vessel appearing as either a bright spot in the normal background scattering of the ocean, or as a hole.

Indirect Detection

All other methods of detection are by indirect means. These are classified into: physical surface effects, optical effects and thermal effects.

Physical Surface Effects

The major physical surface characteristic is the wake developed by a vessel when it is mobile. The characteristics of the wake will be a function of the speed, depth and size of the vessel. Three separate hydrodynamic phenomena are either directly or indirectly caused by the wake: the Benoulli hump, Kelvin waves, and the surface effect of internal waves.

The Benoulli Hump. If a submarine travels at high speed near the surface of the ocean it produces a characteristic hump of water which is sometimes referred to as the Benoulli hump. The size of the Benoulli hump decreases rapidly with submarine speed and depth. For example, the height of the hump reduces from about six centimetres to one millimetre when a given submarine reduces it's speed and increases it's depth from 20 knots and 50 metres to five knots and 100 metres, respectively[7].

Kelvin Waves. Kelvin waves are produced by both ships and submarines and are responsible for the characteristic "V" shaped wake that can be seen to linger behind a moving vessel. They have an angle of approximately 39° which is independent of the size of the vessel or the speed at which it is travelling[8]. Kelvin waves, like the Benoulli hump, reduce rapidly in size with submarine speed and depth. Using the above example, the wave size reduces from about two centimetres to immeasurably small.

Internal Waves. Internal waves are periodic variations in the temperature and density of water at depths near a *thermocline*, an ocean layer in which the temperature drops and the density rises sharply with increasing depth. The period of internal waves, known as the Brunt-Vaisala period, varies with time and location but is typically between 10 and 100 minutes[9]. The displacement of water associated with internal waves is influenced by many factors, including atmospheric pressure variations, ocean currents, and the presence of a submarine. In addition, internal waves are often formed in areas where the ocean bottom is irregular and the tidal range is large. Internal waves are rendered visible on the surface because the internal currents generated modulate the small scale surface waves overlying the internal waves, which leads to periodic variations in surface roughness[10].

In the case of Benoulli humps and Kelvin waves it is clear that reasonable precautions could be taken to avoid detection by limiting speed and remaining at sufficient depth. However, this is not the case with internal waves which seems to be the most promising physical effect to exploit for the detection of submerged vehicles over a wide area.

Optical Effects

The oceans are populated with organisms that either emit light when they are disturbed (known as bioluminescence), or scatter light under all conditions. Such effects may be detectable above the ocean surface and may be used to reveal the location of sub-surface vessels.

Bioluminescence. The turbulent wake of a moving submarine will naturally cause a local disturbance of the surrounding bioluminescent organism population inducing them to emit light. The blue-green component of this light will propagate the greatest distance and may well be detectable beyond the ocean's surface. The intensity of blue-green light is attenuated by a maximum factor of approximately two for every seven meters it travels through water[11]. At this rate, light passing upward through 50m of water will be attenuated by about 21dB; through 200m of water the attenuation would be around 86dB. It may be possible that a turbulent wake could rise to the surface bringing the bioluminescence with it, however it is more likely that the wake would collapse behind the submarine due to suppression by distinct ocean layers. Another possibility is that the emission of light by excited organisms at one depth may induce other organisms closer to the surface to emit light. While it has been reported that relays of such empathic responses have been observed, what is not known is whether such a mechanism could reveal the location of a submarine[12]. Furthermore, there appears to be very little knowledge at this time regarding the geographic, seasonal and depth distributions of such organisms. One major limitation for the detection of bioluminescence is the overpowering background noise contributed by the sun and the moon which would render a detection system useless during the day-time and possibly also under certain night-time conditions.

Light Scatterers. There are layers of organisms in the ocean which scatter light. The motion of these layers caused by vessel generated internal waves may be detectable. However, again the geographic, seasonal and depth distributions of such organisms is not well known.

Thermal Effects

All active submerged vessels generate heat which is dissipated through the seawater (conventional and nuclear submarines), as well as through the atmosphere (conventional submarines).

Thermal Transfer to Surrounding Seawater. Conventional and nuclear submarines draw in substantial quantities of seawater specifically for the purpose of cooling. In the case of a nuclear submarine producing about 190 MW of useful power, about 188 MW of heat energy is released into the ocean. While this appears to be massive, heat transfer calculations reveal that at a speed of about five knots, the temperature immediately behind the submarine only rises by about 0.2 degrees Celsius. This temperature differential will diminish rapidly as the submarine moves further away. In addition, this slightly warmer water, as it rises to the surface could, depending on the depth it was generated, eventually encounter water of the same density at which point it will rise no further and therefore not be detectable on the surface.

Thermal Transfer to the Atmosphere. Unlike nuclear submarines, diesel powered conventional submarines need to surface periodically in order to re-charge their batteries. This process, known as snorting, requires two pipes to be raised near or above the surface. The first pipe, raised above the surface, is used to draw in fresh air to run the diesels. The second pipe is usually kept just below the surface and allows exhaust gases (and, therefore, heat) to escape.[13] The heat emitted through the exhaust gases of a conventional submarine may be detectable above the normal sea temperature. The major limitation with this method of detection is that a conventional submarine in normal operation only needs to snort for about two hours in every 24[14].

Detection Techniques

Direct Detection

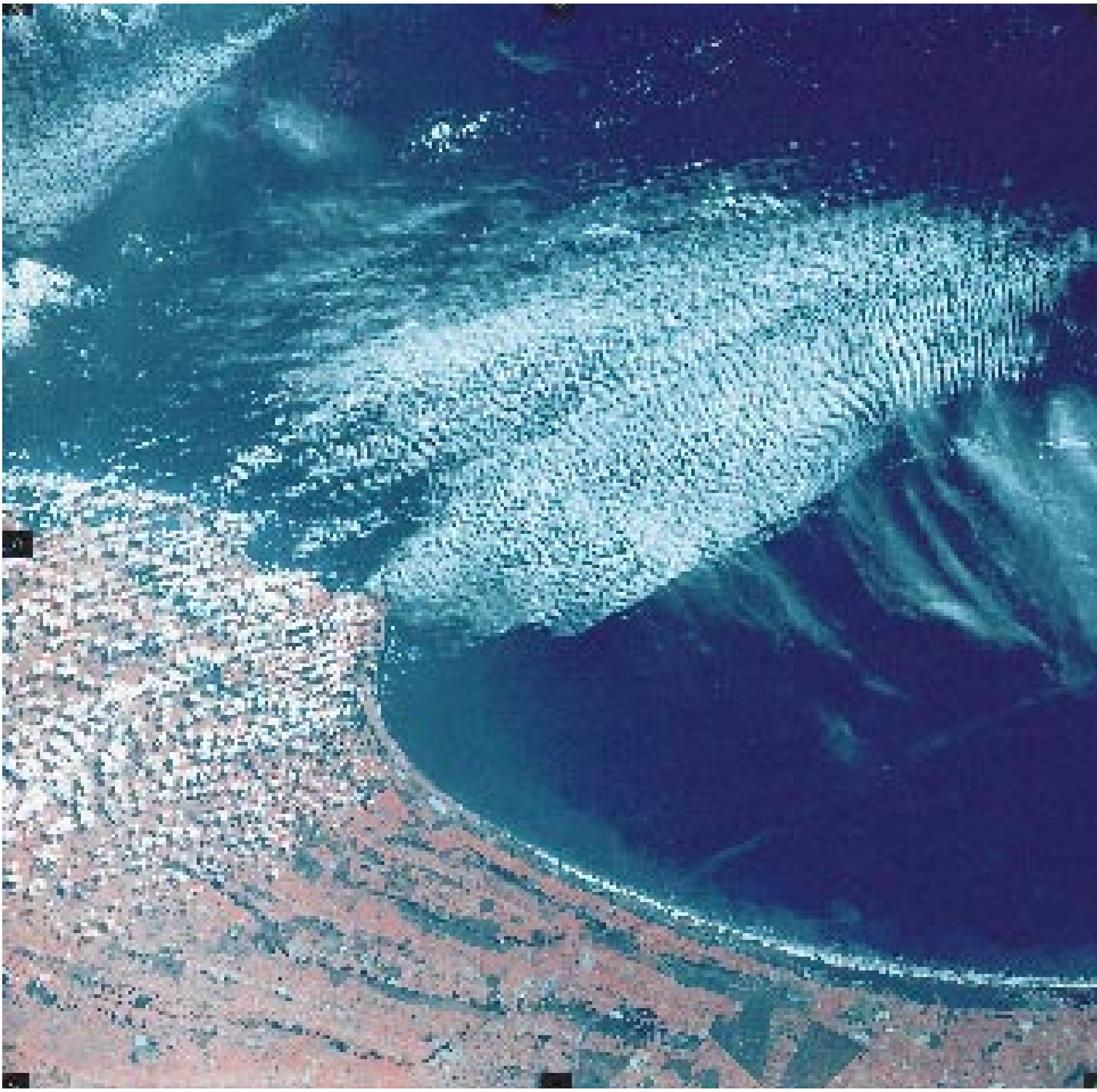
The ability of Laser radar, or LIDAR (LIght Detection And Ranging), to penetrate the water's surface, reflect from an object and then be detected remotely, makes this sensor a potential candidate for the detection of submarines. However, this technique is limited by the inability of LIDAR to penetrate clouds and other high attenuation effects caused by fog, haze and atmospheric pollutants[15]. Despite these limitations, it is reported that the Swedish have used this technique to detect submarines in national waters from an airborne platform[16], although the effectiveness of this system is not known. In addition, the US Defense Advanced Research Projects Agency (DARPA) has developed and tested an airborne LIDAR system for the purpose of detecting mines at sea[17]. The system, known as the Airborne Laser Radar Mine Sensor (ALARMS), uses a pulsed blue-green laser operating at 510 nm. Trials of the system showed that the laser shadow cast by the object under inspection produced the best results at depths of up to 200m. An Australian application of LIDAR, the Laser Airborne Depth Sounder (LADS), uses the time difference between surface (blue) and the sub-surface (green) reflections of a 532 nm (yellow-green) laser, for sub-surface laser ranging.

To improve the accuracy of depth soundings using lasers, an understanding of effects such as turbidity (absorption and scattering) of the water is required. A number of techniques using low frequency electromagnetic pulses (Electromagnetic Bathymetry), used for airborne prospecting for mineral deposits, has the potential to measure sub-surface targets with no restriction due to turbidity. However, with all such measurements, some false targets are likely to be observed due to returns from other submerged objects such as whales.

Indirect Detection

Physical Surface Effects

The physical surface effects caused by a submerged vessel may be detectable either by accurate measurement of the ocean surface height or by imaging the ocean's surface. LIDAR is well suited for precision measurement[18] and may be suitable for the detection of the Benoulli hump or Kelvin waves. However, the effectiveness of this technique will be severely limited by the depth and speed of a



Satellite imagery c

submarine. Synthetic Aperture Radar (SAR) is well known for its ability to monitor wave patterns and determine sea surface roughness[19], and has been shown to successfully detect internal waves.

Recent developments in Laser Doppler Velocimetry, a mature technology, may now permit the remote measurement of fluid parcel velocities in the ocean using the Doppler shift of a laser beam. However, a number of artefacts such as the effects of waves, and turbulence in the ocean, will also cause a Doppler shift of the laser beam. Preliminary studies suggest that these artefacts can be eliminated, but further studies of the phenomenology and signal processing are needed to confirm the feasibility of the technique. The military application of this technology includes the detection of the propeller wakes, and possibly internal waves.

The Seasat satellite launched in 1978 effectively imaged ocean surface features such as internal waves and ship wakes using SAR[20]. Subsequent reports

of a coastal region.

claim that Russian scientists have demonstrated a way of detecting submerged submarines using microwaves reflected from internal wave generated surface effects[21]. These claims were further investigated in July 1992 by an unclassified joint US/Russian experiment which clearly detected waves beneath the surface, although no submarines were used in the experiment[22]. The experiment made use of, among other things, SAR imagery from the ERS-1 satellite which was complimented by in situ and other remotely sensed data.

Optical Effects

The successful detection of bioluminescence will require visible spectrum radiometers with sufficient spatial and radiometric resolution to enable the low level of emitted light penetrating the surface to be detected. One major limitation of this technique, however, is that it is limited, at the best, to use at night. Further investigation is needed to determine resolution requirements. The scattering of sunlight (or moonlight) from the movement of marine organisms or surface effects caused by internal waves has been observed using ship-borne optical sensors[23] and may be possible using elevated sensors.

Thermal Effects

Passive. Methods for remotely detecting localised increases in water temperature include the measurement of thermal infra-red and microwave radiation. The localised intensity of this radiation is highly dependent on submarine depth and speed. As previously discussed, the temperature increase due to the presence of even a large nuclear submarine is very small and would only provide a weak surface signature. However, the snorting of conventional submarines may be detectable as a localised point source on the ocean surface. Landsat 5 carries IR sensors with an instantaneous field of view of 120m x 120m[24] and some sensors have a 0.1°C thermal precision capability[25]. Even at such resolutions it is unlikely that the average temperature rise over a 120m x 120m area would be detectable.

Active. Water, when irradiated with a laser beam, exhibits strong Raman scattering; the ratio of energies in the two strongest scattered lines is temperature dependent. Even though passive detection may be minimal, preliminary estimates indicate that a system based on LADS should have the capability to measure temperatures to an accuracy of at least 0.1ºC to a depth of 50m in moderately clear water, with a depth resolution of about 1m.

Conclusion

Conventional detection of submerged vessels has involved both acoustic and non-acoustic techniques. Several contemporary oceanographic remote sensing techniques, ranging from direct detection of the vessel structure using laser light, to indirect detection using analysis of the effect the vessel has on the surrounding marine environment, have potential for application in this area.

The *direct* detection of submerged vessels using blue-green laser light appears to have merit based on airborne applications by the Swedish. US defence researchers have also successfully used this technique to detect underwater mines. Such successes indicate there is merit in investigating the feasibility of a space-based submarine detection systems based on LIDAR.

Submerged vessels also generate a diverse range of *indirect* effects on the surrounding marine environment; these are categorised as physical, optical and thermal effects. While such effects are highly variable, being dependent on submarine type and operational parameters, they do provide potential means of detecting submerged vessels using both airborne and elevated sensors.

Physical effects range from the production of a wake which may be detectable on the surface, to the generation of internal waves which manifest themselves through subtle surface effects. Of the physical effects, detection of internal waves is probably the most realistic approach; detection of Kelvin waves and the Benoulli hump is severely limited by submarine depth and speed. Indeed the detection of internal waves using SAR is an area where the majority of research seems to have focussed.

Optical effects range from the stimulation of marine micro-organisms to emit light (bioluminescence), to the scattering of light by the movement of organisms in an internal wave. The scattering of light from the surface effects of internal waves is perhaps the most promising detection phenomena of the optical effects. While this technique has been experimentally verified, it is probably only feasible during the day or in the presence of sufficient moonlight. The potential for detection of a submerged vessel via its bioluminescent wake requires more research to determine if this is even feasible. This technique will require highly sensitive electro-optical sensors to detect the relatively low levels of light produced. Furthermore, its restriction to night-time use makes its use impractical as a singular surveillance sensing technique.

The most significant *thermal effects* are caused through the heat sinking of nuclear submarines and the snorting of conventional submarines. A nuclear submarine’s cooling water thermal discharge appears unlikely to be detectable unless the submarine is stationary and also at, or near, the surface; the most likely scenario is when the vessel is in port. The detection of a conventional submarine snorting may be more feasible, although the opportunities to observe this procedure are infrequent (two hours in 24) and not practical for some approaches to the Australian coast. Preliminary estimates indicate that an active system based on LADS should have the capability to measure thermal changes.

The detection of submerged vessels continues to be an area of active research interest, for both military and civilian applications. While current mission proven methods use acoustic and non-acoustic techniques, advances in a range of technologies are continuing to make optoelectronic techniques more feasible. Several airborne platforms have demonstrated the viability of a number of these sensors. Their development into elevated sensors may provide an opportunity to satisfy demanding WAS and revisit time requirements.

One area in which the Australian Defence Organisation has extensive expertise and knowledge is laser transmission in the marine environment which has application to search, surveillance, and salvage missions; specific applications include the detection of mines, submarines and submerged unmanned vehicles.

NOTES

1. "Elevated" refers to conditions of altitude, endurance and operational safety which may be unsuitable for conventional air platforms.
2. Babbage, R., *A Coast Too Long: Defending Australia Beyond the 1990s*, Allen and Unwin, Sydney, 1990, p.71.
3. Gale, Squadron Leader W., *The Potential of Satellites for Wide Area Surveillance of Australia,* Air Power Studies Centre, RAAF Fairbairn, 1991, p.210.
4. Gale, Squadron Leader W., *The Potential of Satellites for Wide Area Surveillance of Australia, op cit*, pp.3-1 to 3-2.
5. An orbital inclination of 150 would cover the north and north-western maritime approaches.
6. Longer wavelengths (around 530 nm) are used for turbid water, while the shorter wavelengths are used for blue seas.
7. Stefanik, T., *The Nonacoustic Detection of Submarines,* Scientific American, March 1988, p.29.
8 Scully-Power, P. and Stevenson, R.E., *Swallowing the Transparency Pill,* Proceedings/ December 1987, p.151.
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10. Report of the SCOR Working Group, *Opportunities and Problems in Satellite Measurements of the Sea*, Unesco Technical Papers in Marine Science - 46 1986, p.12.
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13. Marriott, J., *Submarine: the capital ship of today*, Ian Allan Ltd, 1986, p.43.
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15. Report of the SCOR Working Group, *op cit*, p.32.
16. Stefanik, T., *op cit*, p.27.
17. Naval Mine Warfare, *Sonars: still a bright future*, International Defense Review Supplement, November 1989, pp.24-25.
18. Skolnik, M.I., *Introduction to Radar Systems,* McGraw-Hill, 2nd Edition 1980, p.565.
19. *Ibid,* p.517.
20. Report of the SCOR Working Group, *op cit*, p.28.
21. Beardsley, T., *Making Waves,* Scientific American, February 1993, p.13.
22. Gasparovic, R.F., Etkin, V.S., *An overview of the Joint US/Russia Internal Wave Remote Sensing Experiment,* IGARSS '94, pp.741-742.
23. Titov, V.I., *Investigation of variations of Long Surface Wave Parameters by Optical Techniques During JUSREX 1992,* IGARSS '94, p.756.
24. *The Landsat 5 Spacecraft*, ACRES Data Sheet, August 1989.
25. Report of the SCOR Working Group, *op cit*, p.32.

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Squadron Leader Wren joined the RAAF in 1981 and has served at No. 6 Squadron, Aeronautical Research Laboratories (F/A-18 Structural Test Program), No. 77 Squadron and Air Force Office (Airworthiness Certification). He is currently Deputy Director of Space Systems (Technology) within Force Development (Aerospace), Australian Defence Headquarters, Canberra. In addition to his Defence role, Squadron Leader Wren is active in the national space effort, and is a member of a number of national committees. He is a graduate of the University of Western Australia and Texas A&M University [Msc and PhD (Aerospace)].

Squadron Leader May joined the RAAF in 1982 and has served at the RAAF Telecommunications Unit Sydney, Air Headquarters Australia (Maintenance Branch), 114 Mobile Control and Reporting Unit and 301 Air Base Wing (Senior Radio Officer). He is currently Deputy Director of Space Systems (Technology) in Force Development (Aerospace), Headquarters Australian Defence Force, Canberra. Squadron Leader May is a graduate of the Western Australian Institute of Technology (Bachelor of Engineering (Communications)) and The University of New South Wales (Masters in Engineering Science (Aerospace)).