THE MULTI-INFLUENCE PASSIVE MODULE FOR UNDERWATER ENVIRONMENT MONITORING

IGNACY GLOZA, KRYSTIAN BUSZMAN

Polish Naval Academy
69, Śmidowicza St., 81-103 Gdynia, Poland
igloza@amw.gdynia.pl

The threats to the operation of a ship close to the coast and harbor can be significantly different to those of deep-water operation. It is obvious that any operation in this environment requires a good understanding of how the ship's signatures behave. Quite a few different systems exist which can detect and track underwater moving targets. The most practical systems use underwater passive detectors. Therefore we often install in such environment multi-sensor measuring device to verify the whole situation. Designed by the Polish Naval Academy mobile multi-sensor module serves such purpose. This module consists of acoustic, magnetic, electric, seismic and pressure sensors fitted to the nonmagnetic tripod. This makes possible to measure signatures to high degree of accuracy in a variety of environments in real time.

INTRODUCTION

Sea mines characterize a dangerous threat to naval vessels. From the time when World War II ended sea mines have caused more damage to warships than all other weapons systems combined. Also being effective, sea mines are relatively cheap and represent an asymmetric threat. Sea mines are often activated by magnetic, acoustic or hydrodynamic fields of a passing vessel. Therefore, it is of high importance to reduce these fields to minimum.

A fundamental component in the process of signature redaction is physical fields measurement. Physical fields measurement is commonly carried out at a special range facility equipped with bottom-mounted equipment, but our solution is the mobile multi-sensor module. Detecting the presence of a surface ship and submarines by sensing their underwater acoustic magnetic or hydrodynamic fields has been exploited mainly in the area of undersea warfare.

First of all the term signature was created in the area of acoustic measurement and detection of a vessel's underwater sound pressure field. Like fingerprints or handwriting on a signed paper, underwater sound generated by a ship has characteristics that are unique to it. These characteristics can be used to distinguish them from others. Even though a surface warship's or submarine's magnetic, electric, hydrodynamic fields are not as unique as their acoustic, the term signature has been carried over to illustrate the spatial and temporal distribution of ship's other fields.

Characteristic profiles of the acoustic, hydrodynamic, magnetic, and electric signals related to a running warship or submarine are shown in Figure 1.

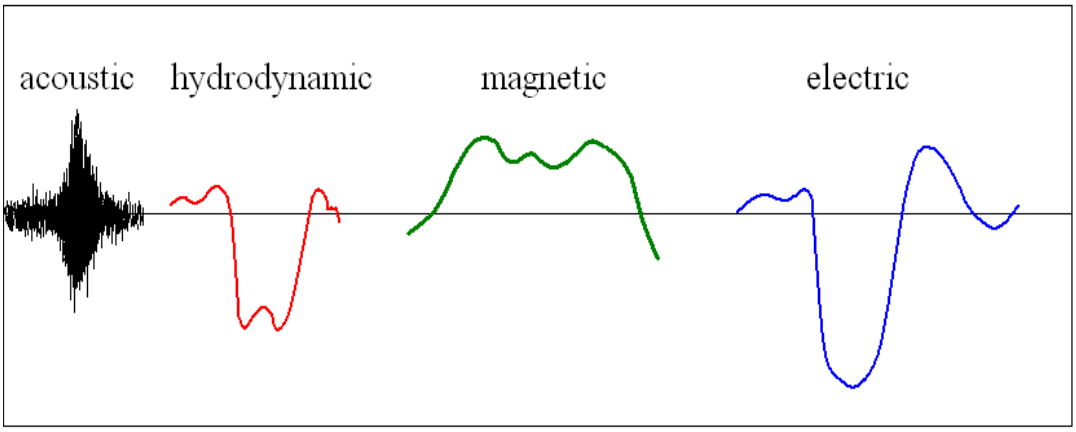

Fig. 1. Representative profiles of the different underwater signals connected with a passing vessel

The acoustic signature is due to any noise that the ship can be emitting from its engine, movement or propeller. Various sound reducing techniques are used in the design of vessels in other to decrease its acoustic signature. For example during creation you can change the underwater part of the vessel's hull and made it from materials that do not vibrate etc. Atmospheric noise is also generated into the sea environment. This is dominated at low frequencies by the almost continuous occurrence of global lightning storms. In addition, noise from land is propagated a long the sea floor and rising into the water. The hydrophones used here are omnidirectional, with low noise electronics.

The hydrodynamic signature occurs from a moving object in the water. In shallow water the sea floor pressure increases a little as the bow passes and then drops below a typical level. It rises for a second time as the stern passes and then returns to normal. The magnitude and duration of pressure are related to the hull shape and size, the water depth and of course the ship speed.

Signatures of a vessel can be separated into a few main groups: electro-magnetic, pressure, seismic and acoustic. The electro-magnetic signature is due to the different electric and magnetic fields that can be present around the ship due to its structure, engine and power supplies. The potential threat to a running ship because of its magnetic field, from sea mines are well known and understood. A standard countermeasure used to reduce this threat is the placement of degaussing (DG) coils on the warships and sometimes on other very important civilian ships. While discussing about electromagnetic signatures, it is usual to separate them into DC and AC signals. DC signals do not change with time and therefore are the same at any time when a measurement of them is performed. AC signatures depend on time and consequently low frequency measurements will depend on the time the influence is measured, while at high frequency, the influence can appear static because of its quick variation and only the time average can be measured. The magnetic fields are sensed using the triaxial fluxgate magnetometers.

The electric signature increases from the modulation made by the vessel's rotating machinery, of the small currents produced by the immersion of the unlike metals, such as the steel hull and bronze propellers, in an electrolyte, which is in this case the salt water. Active cathodic protection techniques also contribute to the electric signal signature.

Furthermore, the forced motion of conductive sea water across the Earth's magnetic field, such as that generated by the water displacement and the wake turbulence of a running ship, can create additional electromagnetic disturbances. Of course natural water movements, such as tidal currents, can create similar effects.

1. MEASUREMENT EQUIPMENT

Wide-ranging planning has been done to maximize the information which are obtained from the vessel measurements, because of the high cost of diversion of the vessel from her normal run. There is also of course a large amount of information. The module is designed to provide results in harsh environments where other systems will not function, such as in shallow water. Here are highly reflective and difficult conditions around different underwater devices.

The measurement of all elements of a ship's signature is essential to any assessment of a ship's vulnerability. Such measurements can be achieved by running the vessel at different speeds and headings over a fixed physical fields range or much more better over a mobile multi-sensor module.

The Polish Naval Academy has, for more than twenty years, been building up the technology and equipment to measure the physical fields emitted from Polish naval warships, submarines, divers and their apparatus, and other underwater noise sources. At the moment, the requirements are for a transportable detecting system which can be deployed easily in sheltered waters near the coastline or harbors.

The developed equipment is shown in Figure 2. All sensors and combined electronics are mounted on the underwater tripod; positioned during measurement on the sea bottom; sensors are connected by a cable. The measuring platform has an instrumentation necessary for recording and for some on-line analysis of the sensors data, plus the battery power supply for the complete module.

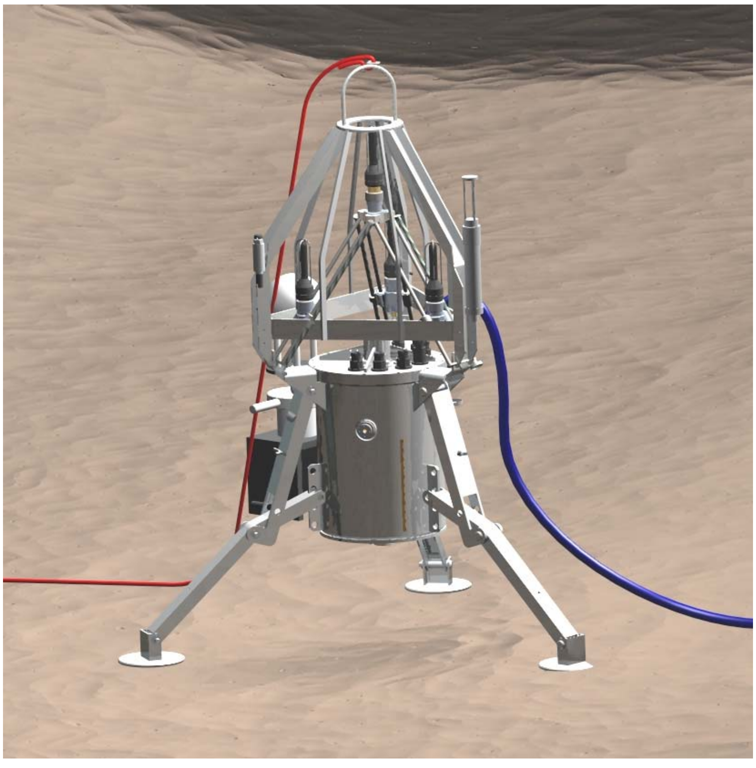

Fig. 2. the multi-sensor module for measuring physical fields

The whole unit is modular, transportable and very easily deployed in the shallow water. As noted before acoustic transmission losses, hydrodynamic reduction effects and the induced electric and magnetic field perturbations are all geographically dependent. Measurements are required under a variety of conditions and at quite a lot of locations with the intention that algorithms to predict the vulnerability of a sailing vessel or other underwater object at all locations can be formulated and verified.

Shelter from the wind and sea gets better the signature-to-noise ratio, eases the measured vessel handling and reduces the risk of damage to the module. Therefore calm and shallow waters are required for the best quality measurements. What more shallow waters improve the underwater acoustic, pressure and magnetic signal-to-noise ratios.

Data quality from the multi-sensor module is also improved by creation some measurement distant from harbor or coastal interferences, because noise arising from industrial, commercial and residential neighborhoods. Very important is also the 50 Hz tonal component from the national power network.

Additionally, the sea bottom should be relatively flat to simplify measurements and the subsequent mathematical modeling of the underwater procedure and of the module. What's more, sand stones or clay sea bottom compositions are preferred as these give the optimal bearing force support for the module. From slow up to medium ship's speeds, the ranging location must also be navigable through all points of the compass. This should allow to measure the full three-dimensional magnetic and electric signature fields to be approximated for all ship headings. In addition, an extensive radial range is necessary on a few bearings to obtain longer-range acoustic data. Maximum level hydroacoustic and hydrodynamic signatures have been measured when the maximum vessel's velocity was obtained.

The image of the hydroacoustic part of underwater module is shown in figure 3. Non-magnetic and non-conducting materials were used at the whole frame in order to minimize any self-induced perturbations in the magnetic and electric fields. In addition, sufficient separation was provided between sensors to minimize cross-coupling effects.

Fig. 3. Hydroacoustic part of the measuring module

The module have adequate rigidity to limit movement and vibration of all sensors. Furthermore, the module is strong enough to sustain deployment and loadings. This has a convenient, for easy installation weight.

This mobile multi-sensor module consists of:

- an underwater measurement platform with mounted sensors,
- a measurement console used to monitoring,
- a analysis signals and registration data unit – mounted on a measurement ship or a land measurement platform (e.g. car, container) on the seacoast,
- a communication module between underwater platform and measurement console; autonomous power supply source 12 V DC,
- a set of sensors:
  - hydrophones,
  - magnetic field,
  - compass with motion,
  - electric field,
  - sound velocity,
  - hydrodynamic pressure,
  - hydrostatic pressure.

The low profile of the module is necessary for shallow underwater measurements, manufacturing it less a risk to the water movements caused by the passing of the propellers overhead, and to the suction effects of ship's hull moving overhead at very high speed in the shallow water.

2. MOVING OBJECT BEARING CALCULATION USING FOUR HYDROPHONES

Measurement setup contains four hydrophones Reson TC4032 placed in space on nodes of tetrahedron forming a tetrahedral antenna. This kind of passive antenna is placed in order to make segments lines connecting centers of tetrahedral brinks parallel to X, Y and Z axis. It facilitates bearing angle calculations in XY and YZ planes.

In figure 4 there is shown a solution of hydrophones location in space. Red points shown each of sensors. Blue and thick lines line up with X, Y and Z axis. They are cutting themselves in center of Cartesian coordinates. Their ends are representing hydrophones, from which signals received are depend on signals came from pair of hydrophones placed at the end of brink with virtual measurement point.

Coordinates of tetrahedron nodes:

$$W1 = [-\frac{d}{2\sqrt{2}}, \frac{d}{2\sqrt{2}}, \frac{d}{2\sqrt{2}}]$$

$$W2 = [-\frac{d}{2\sqrt{2}}, \frac{d}{2\sqrt{2}}, -\frac{d}{2\sqrt{2}}]$$

$$W3 = [-\frac{d}{2\sqrt{2}}, -\frac{d}{2\sqrt{2}}, -\frac{d}{2\sqrt{2}}]$$

$$W4 = [\frac{d}{2\sqrt{2}}, -\frac{d}{2\sqrt{2}}, \frac{d}{2\sqrt{2}}]$$

where d – distance between hydrophones.

Coordinates of virtual measurement points:

$$B1 = [0, \frac{d}{2\sqrt{2}}, 0],$$

$$B2 = [0, 0, -\frac{d}{2\sqrt{2}}],$$

$$B3 = [0, -\frac{d}{2\sqrt{2}}, 0],$$

$$B4 = [0, 0, \frac{d}{2\sqrt{2}}],$$

$$B5 = [-\frac{d}{2\sqrt{2}}, 0, 0],$$

$$B6 = [\frac{d}{2\sqrt{2}}, 0, 0]$$

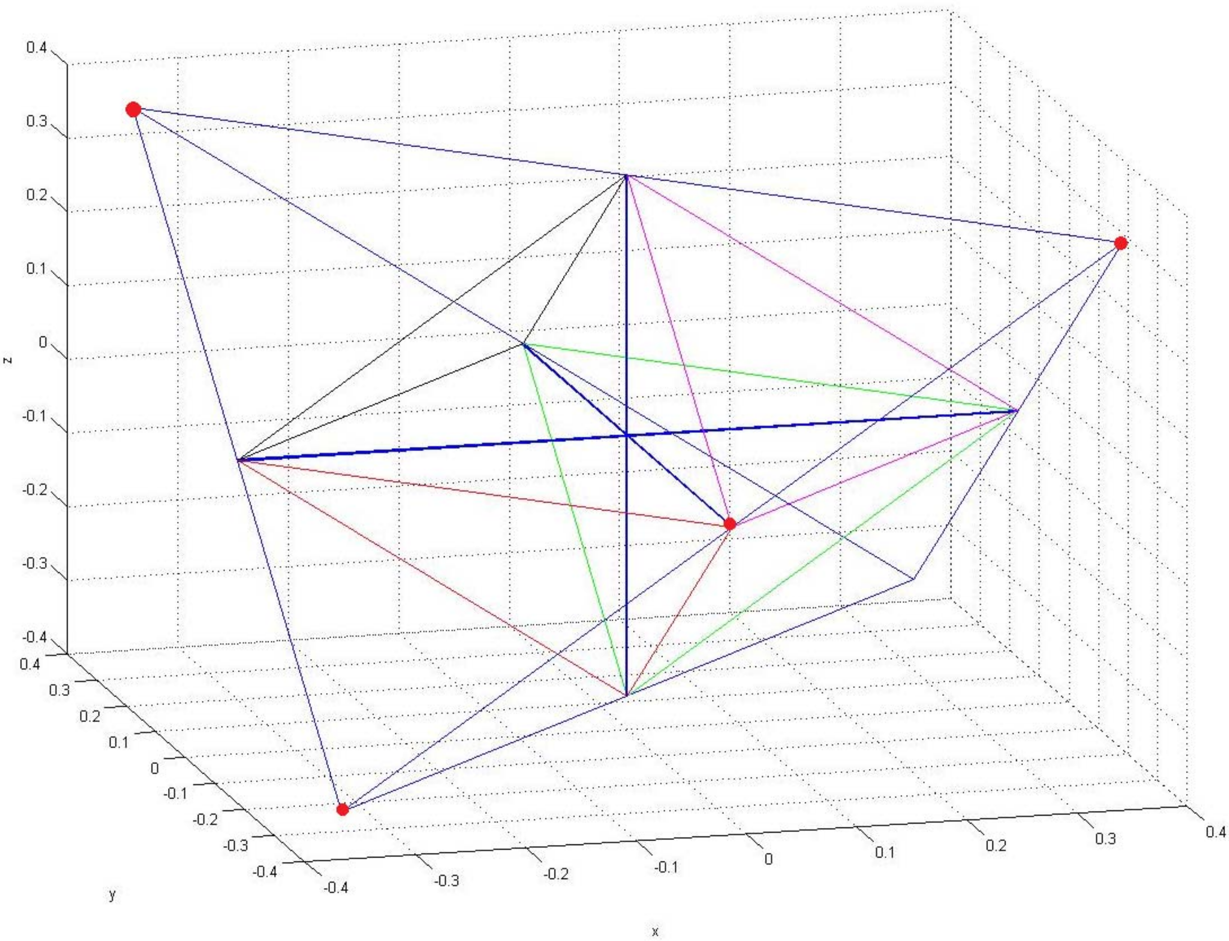

Fig. 4. Hydrophones placed in space

Formula for bearing calculation between vectors $\overrightarrow{P_0 B_X}\cdot$ and $\overrightarrow{W_X B_X}$ where P_0 is point of moving object.

$$\cos(\alpha_0) = \frac{\overrightarrow{P_0 B_X} \cdot \overrightarrow{W_X B_X}}{\left|\overrightarrow{P_0 B_X}\right| \cdot \left|\overrightarrow{W_X B_X}\right|},$$

$$\left|\overrightarrow{P_0 B_X}\right| = \sqrt{\left(x_0 - x_{B_X}\right)^2 + \left(y_0 - y_{B_X}\right)^2 + \left(z_0 - z_{B_X}\right)^2}$$

This formula is only used to check the main calculation of bearing.

After receiving signals from hydrophones it has to appoint six virtual signals depending on phase shifting for hydrophones. This operation enables to calculate angles based on cross spectrum equation:

$$\varepsilon = \arctan \frac{\operatorname{Im}\{G_{AB}\}}{\operatorname{Re}\{G_{AB}\}}$$

where G_{AB} – cross spectrum of A and B signals,

$$\alpha = \arccos\left(-\frac{\varepsilon}{k\Delta r}\right)$$

where $k = \frac{2\pi}{\lambda}$, Δr - distance between hydrophones.

Spherical coordinates where calculated based on formula:

$$\phi = \arctan\left(\frac{I_y}{I_x}\right)$$

$$\Theta = \arccos\left(\frac{I_z}{I}\right)$$

where :

$$I = \sqrt{I_x^{\ 2} + I_y^{\ 2} + I_z^{\ 2}}$$

$$I_x = -\frac{\operatorname{Im}\{G_{AB}\}}{\rho\omega\Delta r}$$

3. CONCLUSIONS

One of the most challenging aspects of harbor or coast security is providing the means to protect against threats from under the surface of the water. Several different systems exist which can resolve this problem, but a good one is a passive detection approach using a mobile sensors. In this paper I explained response surface methodology to optimize such design.

Underwater stealth for surface ships and submarines is realized through the application of the signature – reduction technologies. Ships and ship's structures generate hydroacoustic, magnetic, electric, seismic and hydrodynamic signatures. The stealth in our case means the smallest fields as possible.

ACKNOWLEDGMENTS

The investigation was supported by the Ministry of Science and Higher Education (Grant No OR00 0047 08).

REFERENCES

[1] Ross D., Trends in Merchant Shipping (1969–1980), Tetra Tech., April 1975.
[2] Bowles A., Noise rules for protecting marine mammals in 'Echoes' Acoust. Soc. of Am. 3(2), Summer 1993.
[3] Arverson P. T., Radiated noise characteristics of a modern cargo ship, J. Acoust. Soc. Am 107(1), January 2000
[4] Caldora Costa M., Giurgea S., Diffuse-Element Method and Quadtrees: Two Ingredients for an Adaptive Response Surface, IEEE Transactions on Magnetics, Vol. 38, No 2, March 2002.