DEVELOPMENT OF A SYSTEM FOR INTRUDERS DETECTION BASED ON ELECTRIC FIELD MEASUREMENTS

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Abstract

The interest for Harbour Protection Systems has increased since 9/11. The industry is developing systems capable of detecting small underwater threats as divers, UUV, ROVs or SDVs. Nowadays, the great majority of systems use the active acoustic theory to detect and track the threats. The active acoustic systems have the problem that they are detectable. Also, the acoustic field close to the harbour is very noisy and reverberating decreasing the detection probability. This paper introduces a system called PESMR (Portable Electric Signature Measurement Range) developed by SAES based on electric field measurements. The PESMR system is passive and uses electric field sensors to detect the UEP (Underwater Electric Potential) and ELFE (Extremely Low Frequency Electric) influences of the threats. The final goal is to use an Integrated Harbour Protection System (IHPS) with multiple PESMR systems to create a protection barrier and an underwater threats safety area. The sea trials have been done with one PESRM to check the detection range of divers and a real passive electric dipole. In this paper the results of the sea trials are discussed. These values will be used to plan the separation of the multiple PESMR sub-systems to create the electric protection barrier.

Keywords: Underwater Threat Detection, Electric Influence, UEP, ELFE, Detection Range.

1 INTRODUCTION

Traditionally, detection systems in marine environments have based on acoustic and magnetic static influences in order to detect, and in some cases classify, vessels, surface vehicles and submarines (in Figure 1 it is presented the Intruder Detection Sonar DAB developed by SAES). Nowadays, the trend of continuous decreasing in the level of the acoustic and static magnetic influences radiated by these platforms has motivated the necessity of taking into consideration other influences in the systems focused to detect them. In this way, the incorporation of new sensors, with a progressive increase in their performances, in currently developed detection systems it is permitting to monitor, apart from the classical acoustic and magnetic static influences, the electrical (static or UEP and alternating or ELFE), alternating magnetic, hydrodynamic (pressure) and seismic influences.

Figure 1. Acoustic Intruders Detection System manufactured by SAES.

Among the new sensors, electric field ones are showing to be an effective means to detect intruders in marine environments. They can be used individually, integrated in electric field sensor nets or making part of multi-influence systems in order to increase detection probability in the marine areas to be protected. The electric influence in the marine environment is generated by the coexistence of dissimilar metals in vessels and marine vehicles and platforms and it is propagated through the seawater that acts as the electrolyte.

Harbour environments are of particular interests among the areas to be protected due to the high number of persons that works in them and by their economical and strategic importance. The effective protection against the wide range of surface and submarine threats to which are faced, requires the development of intruder detection systems with the highest possible degree of effectiveness.

The goal of this paper is to describe the development of a harbour multi-influence protection system. It is particularly centred in the study of the detectability of divers and small underwater vehicles (UUVs and SDVs) based on the electric field generated by their equipments. The document describes the simulations carried out regarding detectability of UUVs and SDVs and the performed sea trials using a SAES's developed electric field-meter located at the sea bottom with the aim of detecting divers and a passive cylindrical-shaped dipole made of iron and zinc.

2 PREVIOUS RELATED WORKS

SAES has a long experience in the design of naval mines: in the 90's the moored mine MO-90 was developed incorporating magnetic and acoustic influences. At the end of 90's the Underwater Multi-Influence Measurement System (UMIMS) was developed, incorporating magnetic, acoustic, pressure, electric and seismic influences. Both systems are shown in Figure 2.

Figure 2. MO-90 moored mine (left) and UMIMS (right).

UMIMS incorporates SAES' designed and manufactured SET-200/P electric field sensor (shown in Figure 3) to measure the Underwater Electric Field at sea. It is a precision, ultra low noise device that enables the measurement of very low-level electric fields. This sensor operates by measuring the voltage difference between two points in seawater. The electrodes SET2-802 are placed at such points and they act as sensing elements (differential transducer). The amplifier SET2-801 amplifies the very low level signal provided by the electrodes pair.

Figure 3. Electric Field Sensor SET-200/P manufactured by SAES.

MINEA is a last-generation multi-influence mine develop by SAES that apart from acoustic and magnetic also detects electric, pressure and seismic influences and incorporates a sonar emissions detector.

The advanced MINEA mine has been designed and tested based on the stringent operational and performance requirements defined by the Spanish Navy and incorporates state-of-the-art signal processing algorithms implemented on reprogrammable microprocessors that allows the selection of specific targets and enhances its ability to identify and ignore minesweeping systems.

Three types of mines have been developed making part of MINEA: cylindrical bottom mine, low profile bottom mine and moored mine. They are shown in Figure 4. The exercise mine modality incorporates the capability of recording the detected influences, a recovering system and a ship-mine acoustic link.

The exercise mine system includes Control Equipment, common for the three mine types, to configure previously the operational parameters of the mine using an infrared data link. The control equipment also enables to handle the mine along the exercise using an acoustic link, including the change of the operational parameters.

The exercise mine has not explosive charge, although its shape, dimensions and operational modes are similar to the actual combat mines with the aim to provide a realistic training system.

Figure 4. Advanced MINEA mine types: moored mine (upper left display), low profile bottom mine (upper right display) and cylindrical bottom mine (lower display).

SAES has a wide experience in research actions related with the electric field generated by different types of vessels, vehicles or sweep systems and its propagation. For instance, SAES has been involved in activities related to propagation of an electric field generated by a sweep system with active anodes. These activities make part of a project that combines the research and design of a multi-influence sweep system for the Spanish Navy. The simulation of the electric field generated by an electric sweep gear composed by 8 electrodes is shown in Figure 5.

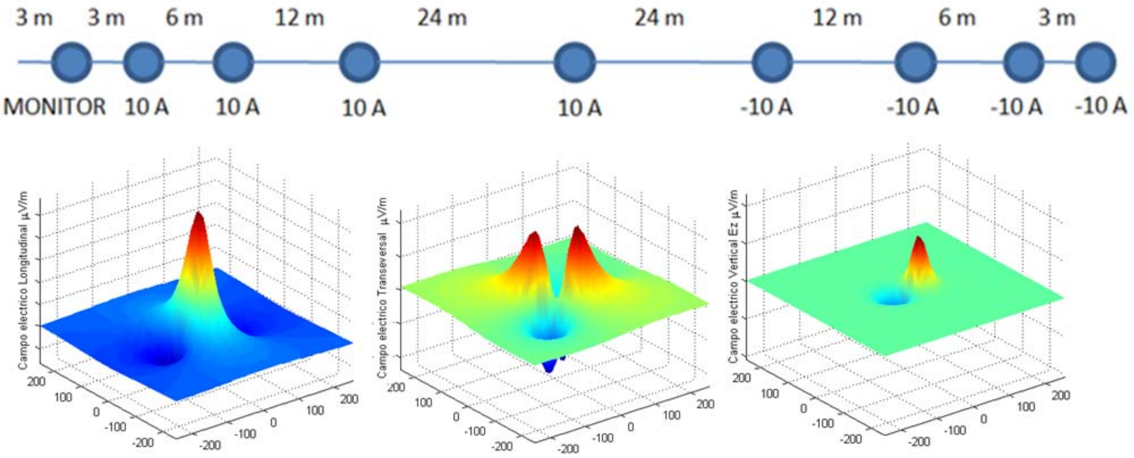


Figure 5. Electric field generated by an electric sweep gear composed by 8 electrodes.

Several research studies about static electric field generated by vessels of medium and large length and their detection distance have been developed comparing electric field results in real environments with software and simulation models. Moreover, SAES has led research activities about influence of the own system or the seafloor in measurements and conductivity in electric field and its propagation. In Figure 6 it is shown the simulation of the electric field influences generated by a ship.

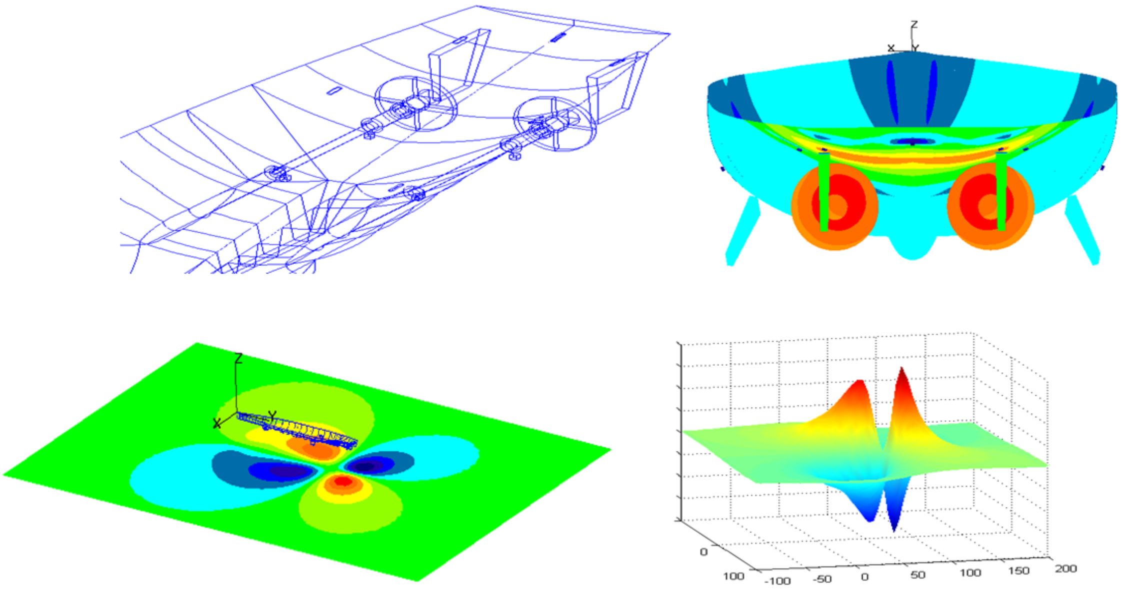


Figure 6. Simulation of the electric influences generated by a ship.

SAES has combined its technological capability in the development of underwater measurement equipments with its wide experience in electric field generation and propagation. These factors have permitted the development of a system for intruder detection based on the analysis of the electric field measured with the PESMR (Portable Electric Signature Measurement Range) system.

3 UNDERWATER ELECTRIC FIELD

The electrical signature of a metallic device is composed of the static electric component (UEP) and the alternating electric component (ELFE).

3.1 Underwater Electric Potential sources

The static electrical signature of a metallic device (UEP) is due to the electrical currents generated by the galvanic corrosion process. The corrosion is an electrochemical process originated by the use of dissimilar metals submerged in a conductor medium. A galvanic corrosion process is activated when a galvanic cell (shown in Figure 7), composed by the components related below, is formed:

- **Anode**. It experiments an oxidation process. It is the element that corrodes due to the losing of electrons and the generation of positive ions.
- **Cathode**. The reduction of the water takes place on it. Hydroxyl ions (OH-) are produced. These are combined with the positive ions of the anode, completing the electrical circuit.
- **Electrolyte**. It is the conductor medium for the electrical current
- **Electrical link**. This link is necessary for completing the electrical circuit. The electrons flow from the anode to the cathode.

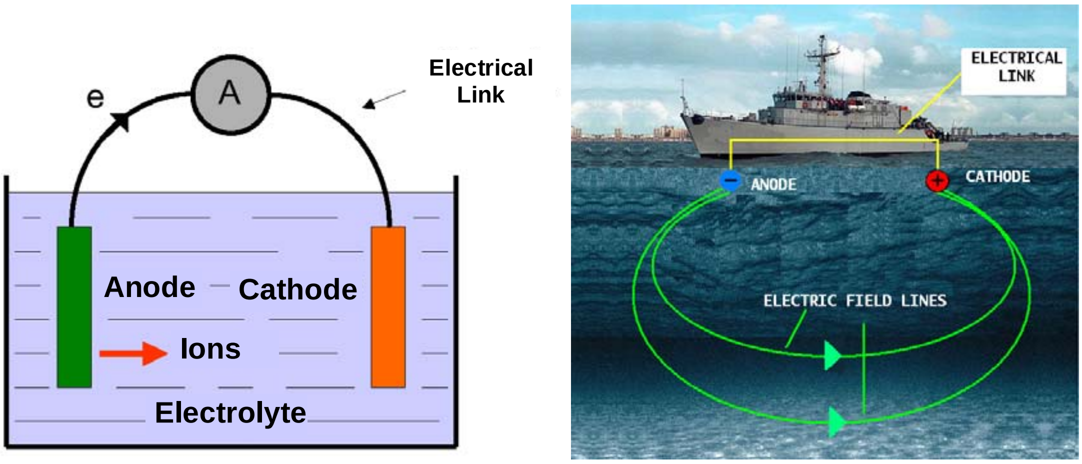


Figure 7. Galvanic corrosion cell process (left) and galvanic corrosion cell in a ship (right).

Each of the metallic elements of the device will act either as an anode or as a cathode. The electrolyte in our case is the seawater. Due to electrochemical reactions of reduction (into the cathode) and oxidation (into de anode) the corrosion currents are generated. These currents flow from the anodic material to the cathodic one through the electrolyte. As the water sea conductivity is different from zero, an electric potential in different points of the sea is produced. The measurement of the electric potential between two points provides the electric field measurement.

Cathodic protection systems are used in order to avoid the corrosion. We can differentiate two kinds of systems: passives and actives systems. Passive systems use sacrifice anodes, meanwhile active ICCP (Impressed Current Cathodic Protection) systems use impressed current anodes and electrodes of reference. Frequently, active protection systems contribute, in a significant way, to increase the target electrical signature.

3.2 Extremely Low Frequency Electric sources

The underwater alternating electric field or ELFE (shown in Figure 8) is originated by the following sources:

- Modulation of the corrosion current. The corrosion current is modulated by the propeller rotation, as consequence an alternating electric frequency appears corresponding to the propeller revolutions. If there are several propellers rotating at the same time with different speeds, the output is an alternating electric signal corresponding to the frequency of the propeller with the highest rpm value, amplitude modulated by the frequency of the propeller with the lowest rpm value.
- Power supply ripple in the machinery of the target. A frequency corresponding to the power supply frequency appears.
- Ripple in degaussing systems and active cathodic protection systems.
- Modulation that experiments the ICCP current caused by the variation of the resistance between the axis and the target hull.

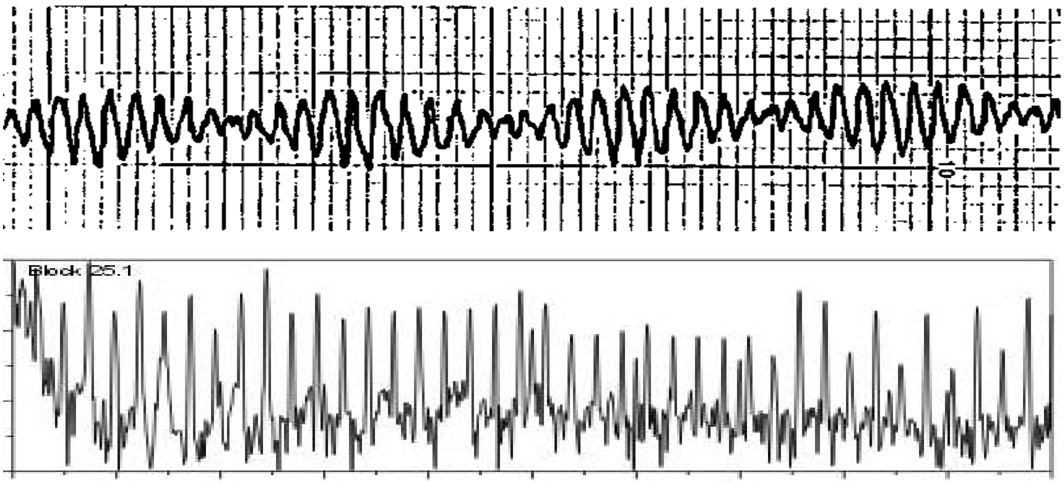


Figure 8. ELFE influence, Time waveform (upper display) and spectral analysis (lower display).

Nowadays the power supply ripple is widely reduced and therefore its contribution to the underwater electric field is normally very scarce. If the target does not include an active cathodic protection system, the main underwater electric field source will be the modulation of the galvanic currents by the propeller rotation and the ELFE signature will depend on the propeller revolutions and the galvanic current strength. If an active cathodic protection is included, the impress anode output current modulation has to be considered also. In this case, the ELFE signature will depend on the propeller revolutions, galvanic current strength and electrical resistance on the propeller axis.

4 DETECTION OF INTRUDERS BASED ON ELECTRIC FIELD

4.1 Detection distance versus source strength

This section presents a novel research about minimum detection distance for an electric field sensor with a resolution of 300 nV/m as a function of the galvanic current of the source.

It is assumed that the galvanic current source is a dipole whose poles are separated 1 m and the imaginary line center that connects them is located along their axis of reference. The dipole depth is 10 meters and the sea bottom is at 20 meters. Electric field is measured at different horizontal distances at a depth of 10 meters. The obtained electric field measurements correspond to the horizontal component, that is, to the longitudinal and athwartship components. Figure 9 shows the minimum detection distance as a function of the current of the source.

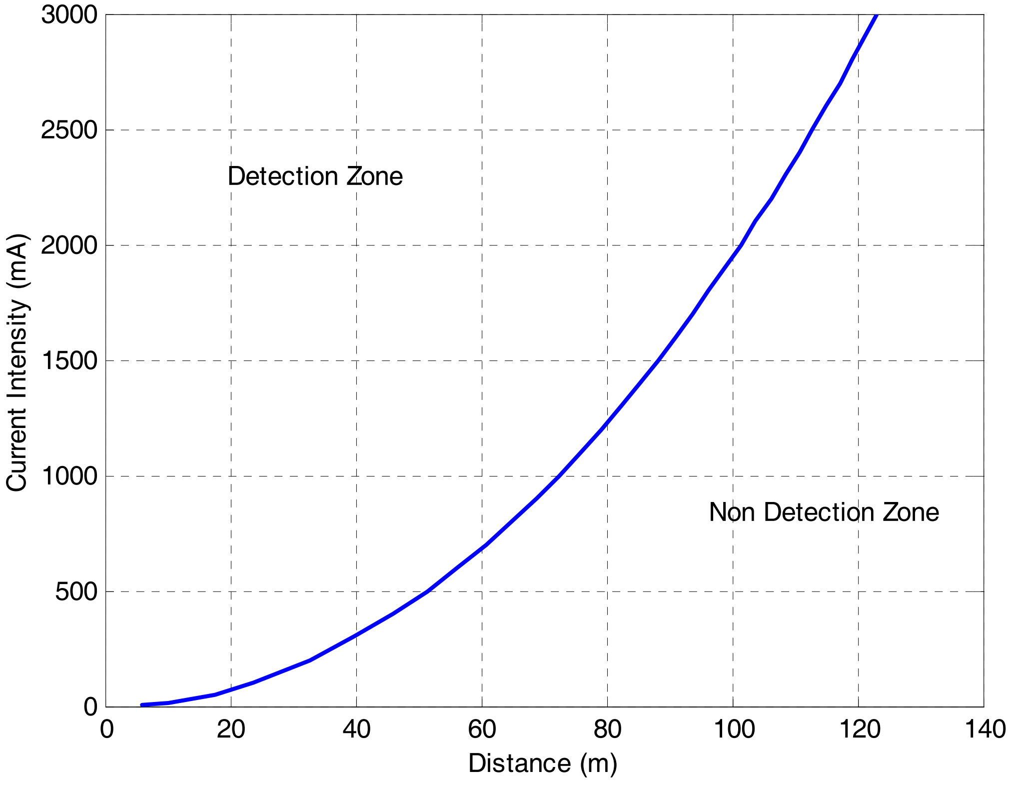


Figure 9. Detection distance versus source strength for a notional electric field sensor.

4.2 Detection distance of an unmanned underwater vehicle (UUV)

A model of the UUV (shown in Figure 10) has been built in order to estimate the detection distance based on electric field simulations. The model is a cylinder of 1.5 m length and 0.6 m diameter. It is considered that the UUV includes 1131 cm^2 of steel in the bow. Alto it is supposed that the propeller is located in the stern and has 1131 cm^2 of NAB. The assumed measurement device depth is 10 m and the bottom depth 20 m. The conductivity of the seawater is set to 5 mS/m.

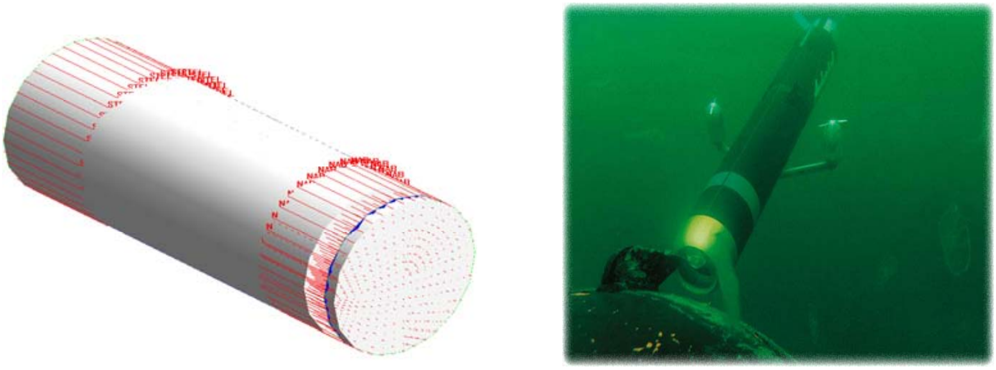


Figure 10. UUV Model of an actual UUV.

The intensity of the electrical current generated by the modelled vehicle is 120 mA. The obtained detection distance for an electric field sensor with 300 nV/m of resolution ranges between 27 and 32 m. The horizontal component of the electric field computed at a set of horizontal distances and at a depth of 10 m is presented in Figure 11.

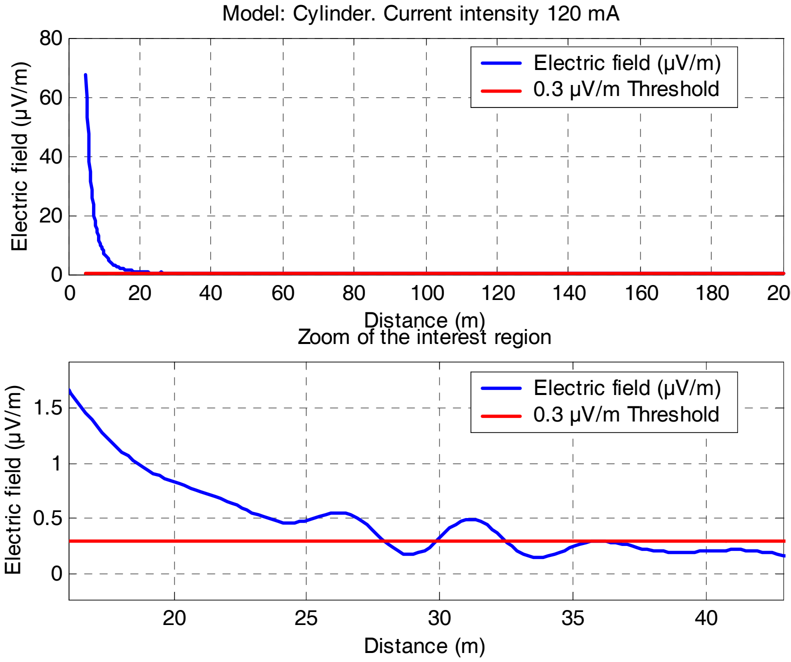


Figure 11. Electric field versus distance for the UUV model.

4.3 Detection distance of a swimmer delivery vehicle (SDV)

The next study presented is the detection distance of a SDV based on the electric field influence using an electric model. The model (shown in Figure 12) is a cylinder of 5 m length and 1.5 m diameter. It is considered that the SDV includes 4418 cm^2 of steel in the bow. Alto it is supposed that the propeller is located in the stern and has 1963 cm^2 of NAB. The assumed measurement device depth is 10 m and the bottom depth 20 m. The conductivity of the seawater is set to 5 mS/m.

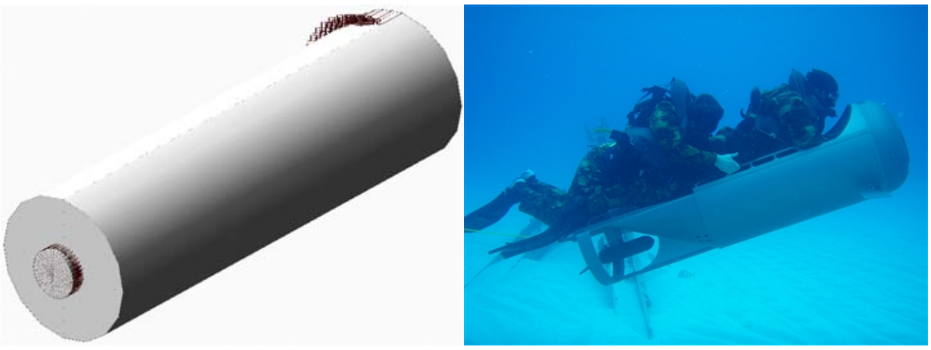


Figure 12. SDV model (left) and real SDV (right).

The intensity of the electrical current generated by the modelled vehicle is 90 mA. The obtained detection distance for an electric field sensor with 300 nV/m of resolution ranges in this case between 50 and 55 m. The horizontal component of the electric field computed at a set of horizontal distances and at a depth of 10 m is presented in Figure 13.

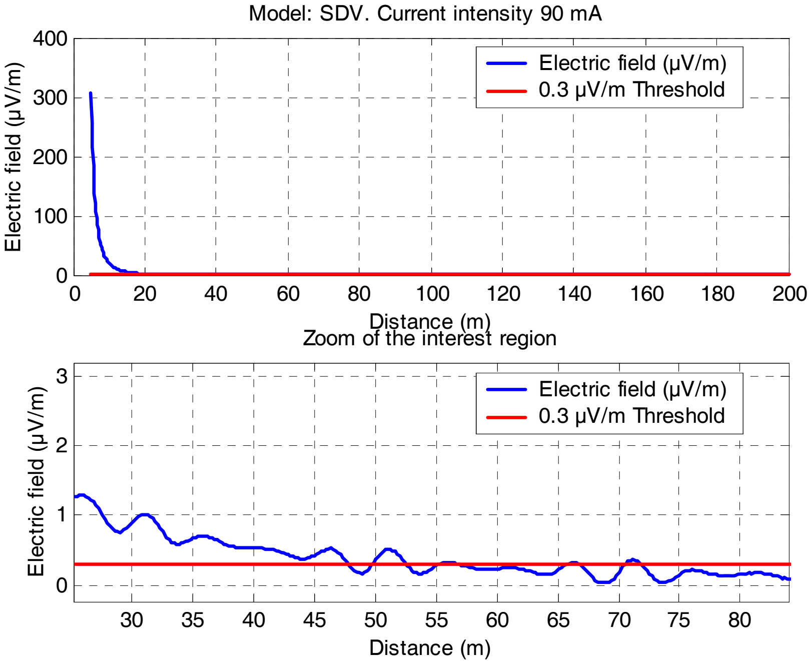


Figure 13. Electric field versus distance for the SDV model.

5 PESMR DESCRIPTION

PESMR (Portable Electric Signature Measurement Range) is a measurement system of the static electric field (UEP) and the alternating electric field (ELFE). It is shown in Figure 14 and consists of:

- Two SET-200/P electric field sensors manufactured by SAES.
- Amplifying card for sensor signals.
- Casing and support for the fixation of the sensors and the card.
- NI-DAQ-516 acquisition cards. 12-bit multifunction I/O devices able to get more than 50 kS/s. Each card has a 4-bit input and a 4-bit output digital port and 8-bit input and 8-bit output analog channels. The digital I/O ports are 5V/TTL compatible and they area able to bear 4 mA on each line. Digital ports are used for data acquisition.
- Laptop computer for measurements control, visualization and analysis.

Figure 14. PESMR of one axis developed by SAES.

One axis PESMR on its support has the following characteristics:

- Weight: 20 Kg
- Maximum Length: 1 meter.
- Maximum Heigth: 1 meter.
- Four configurable sensitivities: 8560 μV/m, 856 μV/m, 85.6 μV/m and 8.56 μV/m.
- Two channels: UEP channel with a bandwidth of 0.005 Hz- 10 Hz and ELFE channel with a bandwidth of 0.5 Hz- 1 kHz.
- Some characteristics of the electric sensor are the following:

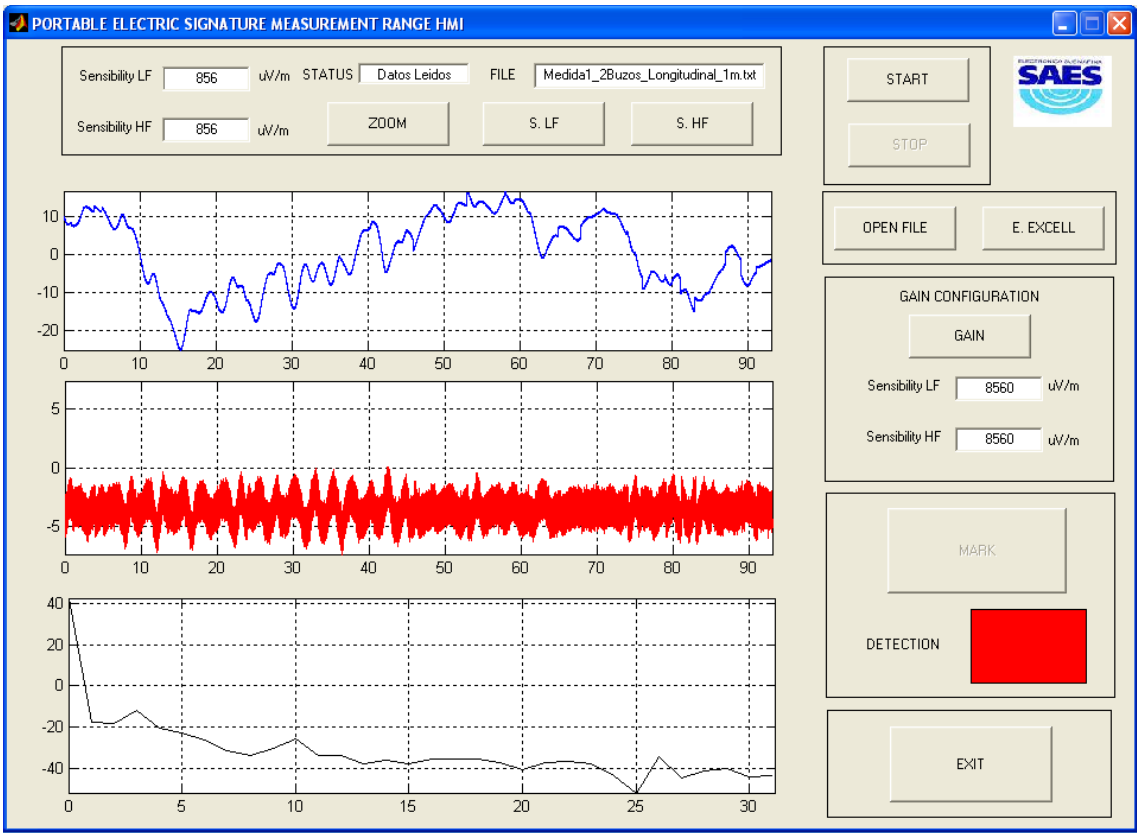
- Power supply voltage: ±15V ±10%
- Power consumption (outputs unloaded): <1500 mW
- Frequency response (cut-off at –2.5 dB ±0.5dB):
    - Low Band (LB) from 0.005 Hz to 10 Hz
    - High Band (HB) from 0.5 Hz to 1 KHz
- Linearity and distortion (Full Scale output signal): < -50 dB
- Amplifier noise:
    - Low Band (LB):
        - < 2 nV/√Hz @ 1 Hz
        - <10 nV/√Hz [typ. 3 nV/√Hz] @ 0.1 Hz
        - <200 nV/√Hz @ 0.005 Hz
    - High Band (HB):
        - < 2 nV/√Hz [typ. 0.7 nV/√Hz] from 1 Hz to 1 KHz
- Sensor noise:
    - Low Band (LB):
        - < 2 nV/√Hz @ 1 Hz
        - <15 nV/√Hz [typ. 4 nV/√Hz] @ 0.1 Hz
        - <200 nV/√Hz @ 0.005 Hz
    - High Band (HB):
        - < 2 nV/√Hz [typ. 1 nV/√Hz] from 1 Hz to 1 KHz
- Sensitivity and gain (Electrodes separation = 1000 mm.):
    - Range A (Full Scale sensitivity = 8.56 μV/m): 61.35 dB ±0.2 dB
    - Range B (Full Scale sensitivity = 85.6 μV/m): 81.35 dB ±0.2 dB
    - Range C (Full Scale sensitivity = 856 μV/m): 101.35 dB ±0.2 dB
    - Range D (Full Scale sensitivity = 8560 μV/m): 121.35 dB ±0.2 dB
- Gain stability: ±200 ppm/ºC
- Pressure resistance in seawater (electrodes): 20 bar
- Electrode case material: black polyester
- Weight:
    - Amplifier (without front panel): 185 g.
    - Pair of electrodes (without protective cap): 310 g.
    - Pair of electrodes (with protective cap): 630 g.
- Operating temperature:

- Amplifier: 0ºC to +40ºC
- Electrode: 0ºC to +28ºC

It is used a man-machine interface for control, visualization and analysis. With PESMR and HMI the user is able to:

- Display the UEP (time) and the ELFE (time and frequency) components.
- Configure the sensor gain.
- Save and open measurements files.
- Calculate and visualize the spectogram of UEP and ELFE components.
- Set target marks.
- Determine if there is detection or not by using an integrated detection algorithm.

Figure 15 shows the graphical output of the PESMR - HMI:



Sensibility LF 856 uV/m STATUS Datos Leidos FILE Medida1_2Buzos_Longitudinal_1m.txt

Sensibility HF 856 uV/m

Sensibility LF 8560 uV/m

Sensibility HF 8560 uV/m

Figure 15. PESMR Human - Machine Interface (HMI).

6 SEA TRIALS

The goals of the sea trials are the following:

- To determine the detection distance for a metallic device, with a similar level of generated electric field to that originated by an UUV or a SDV, by means of an electric field-based passive system,
- To determine the diver detection capability using an electric field-based passive system.

A PESRM system with only one axis was developed in order to be able of carrying out underwater electric field measurements. This system was placed 1 m distance from the sea bottom by means of a nom-metallic support. An only axis is enough in order to conduct the required measurements due to the dipole is symmetric regarding its horizontal plane and therefore the vertical component is null when the diver passes longitudinally above the PESRM system. Based on this, we have to consider that detection is expected when the diver passes longitudinally above the PESR system. As it was noted during the sea trials, it is difficult that the diver passes right above the PESRM system and as a consequence unexpected results were obtained in some measurements.

A passive dipole (shown in Figure 16) was developed in order to emulate an electric field signature with a similar level to that generated by an UUV or a SDV. This dipole has cylindrical shape and 1 m length and 30 cm radius and it is composed by two different materials. Half of it is composed of zinc (anode) and the other half of iron (cathode). In Figure 16 it is shown this passive dipole.

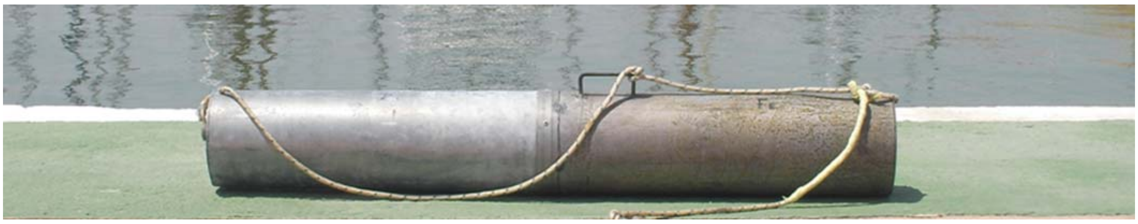


Figure 16. Passive Dipole. Zinc (Left side) and Steel (Right side).

A diver longitudinally towed the passive dipole, as shown in Figure 17, in order to emulate the passage of an underwater vehicle above the PESRM system. The part of the dipole made of iron was the closest to the diver. In the next figure it is shown a diver towing the dipole during the sea trials.

Figure 17. Diver towing the passive dipole.

An important aspect was the location of the appropriate place to carry out the measurement campaigns. With the aim of obtaining measurements with a low level of underwater electric field noise, an open sea area close to San Pedro del Pinatar (Murcia) was chosen (shown in Figure 18). A zodiac boat was employed to translate into the operational area the PESRM system and the associated equipment needed for the control, visualization and analysis of the underwater electric field measurements. In Figure 18 it is shown the geographic location of the sea trials area.

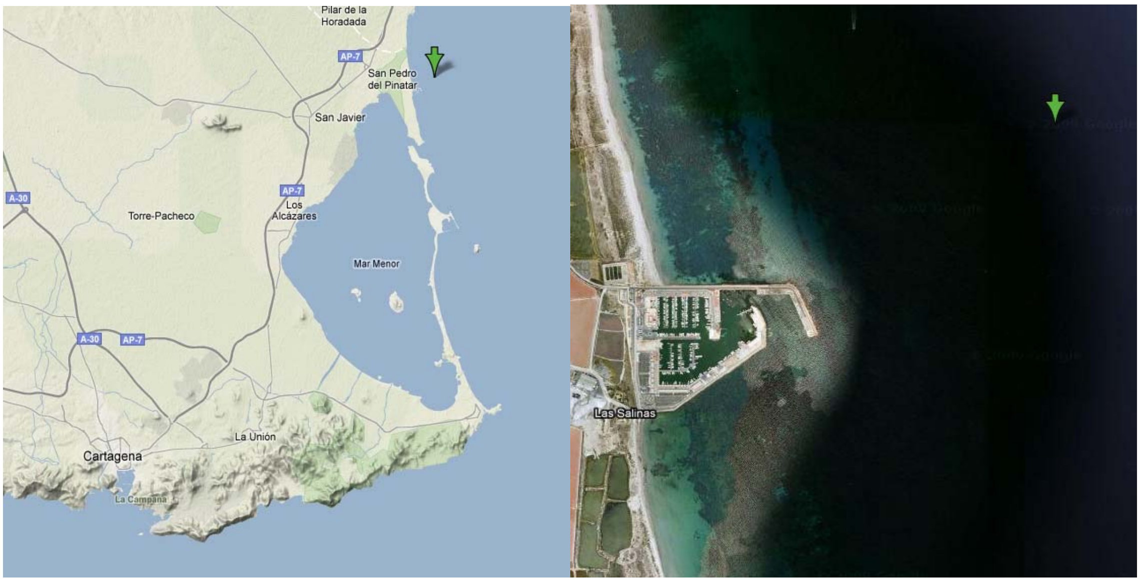


Figure 18. Geographic zone for sea trials.

A total of two measurements campaigns have been performed. Both of them took place in the area referenced above and using the same equipments. The deployment depth of the PESRM system was 14 m during the first campaign and 9 m during the second one. The sea state was 0 in both occasions and the sea bottom of the sea trials area is sandy with abundant presence of posidonia oceánica. The deployment process is shown in Figure 19.

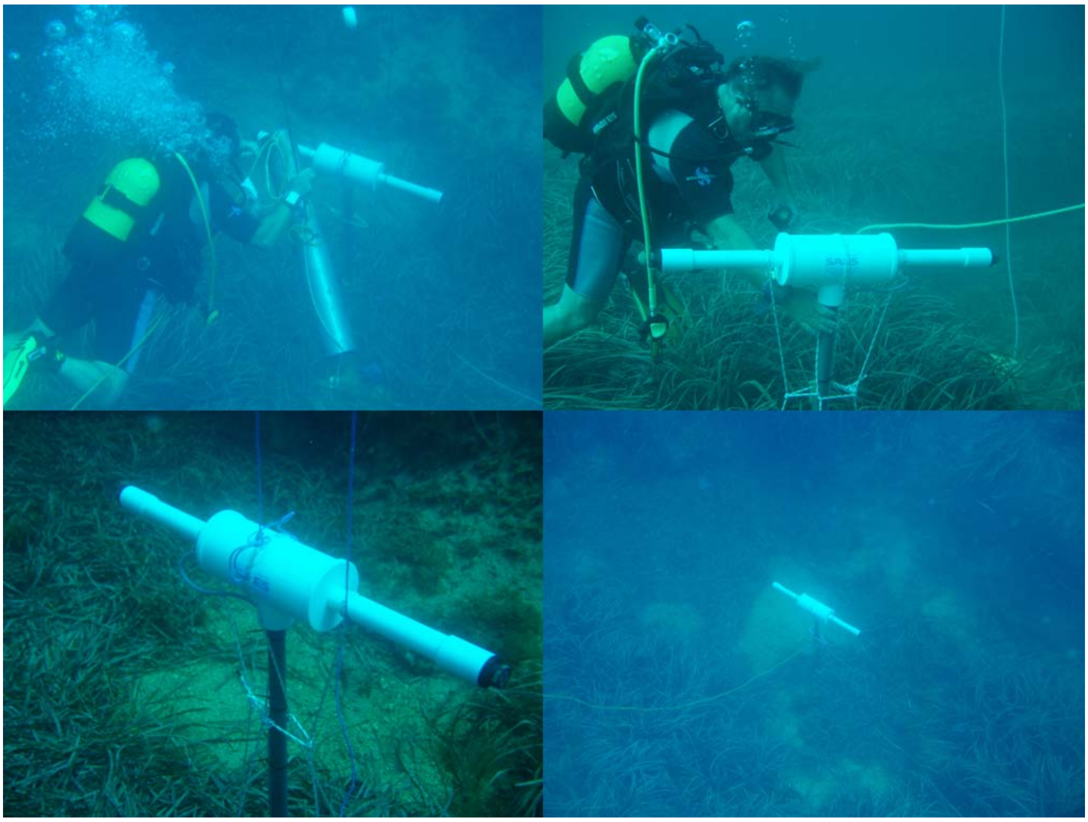


Figure 19. Deployment of the PESMR system.

In the following table are shown the detection distance for the passive dipole, the number of the measurement campaign, the depth at which the dipole was towed and the direction of passage of the dipole above the PESRM system.

Detection Distance	**Campaign number**	**Passive Dipole Depth (from bottom)**	**Direction of the dipole from the sensor**
28 m	1	2	longitudinal
22 m	1	2	longitudinal
5 m	1	2	athwartship
5 m	1	2	athwartship
35 m	2	2	longitudinal
7 m	2	2	athwartship
21 m	2	Surface (9 m)	longitudinal
34 m	2	Surface (9 m)	longitudinal

Table 1. Detection Distance of the passive dipole.

An average detection distance of 28 m has been obtained for the longitudinal passage in the case of 2 m dipole depth, and of 22 m in the case of 9 m dipole depth. Additionally, as it can be expected, the detection distance when the dipole passes athwartship above the PESRM system is very small. Theoretically this value should be null. In this case the obtained small value is due to the diver did not pass exactly longitudinally above the PESRM system.

Regarding the diver detection, the currently available measured data do not permit us to determine a specific detection distance due to their variability and even the lack of detection in some cases. New measurement campaigns will be programmed in the future in order to increase the set of recorded data and be able to provide more accurate results.

7 CONCLUSIONS

This paper introduces the Portable Electric Signature Measurement Range (PESMR) developed by SAES. This System has the capability of measuring the static component (UEP) and the alternating component (ELFE) of the electric field generated by a ship, vehicle or any object generating electric influence. A significant advantage of this passive system is that is based on a physical influence (underwater electric field lines) against which there is no possible countermeasures.

In the present paper the PESRM system is intended to protect harbours against several intruders as UUVs, SDVs or divers. A set of PESMR systems can be deployed to define a protection barrier and a security area against underwater threats. These PESRM systems can be integrated with other sensors in order to create an Integrated Harbour Protection System (IHPS).

Studies of the detection distance for a modelled UUV and a modelled SDV have been carried out in order to define the optimal number of PESRM systems needed to protect a Harbour. Detections distances have been estimated from models that simulate the electrical behaviour of the real vehicles. As a conclusion of these studies we can state that UUVs and SDVs could be detected at distances of 30 m and 50 m respectively.

Two campaigns of sea trial have been conducted in order to obtain realistic at sea measurements concerning the detection of divers and UUVs and SDVs. The goal has been the detection of divers and a passive dipole built to emulate the electrical influences of the UUV and the SDV. As a result, we can state a detection distance for the passive dipole in the range 22 to 28 m. In relation with diver detection the set of measurements currently available do not permit us to establish a specific detection distance due to it is highly variable and not always exist.

In the future, it is planned to perform measurements with real UUV and SDV in order to confirm the estimated distance values. Also it is planned to build a barrier from PESRM systems and to operate with real intruders.

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