

USING ELECTRIC SIGNATURES FOR EXTRACTING TARGET NAVIGATION PARAMETERS

Fco. Javier Rodrigo, Antonio Sánchez

Sociedad Anónima de Electrónica Submarina (SAES)

Advanced Studies and DSP Technical Area

Carretera de la Algameca, s/n, 30205 Cartagena, Spain

Tif. 34 968 508214 Fax: 34 968507713

f.rodrido@electronica-submarina.com, asanchez@electronica-submarina.com

Abstract

Underwater detection systems are increasingly incorporating non-acoustic sensors to counteract the significant levels of noise reduction achieved by modern vessels during the last years. Electric field sensors represent an effective way for detecting, in a concealed way, the static (UEP) and alternating (ELFE) electric signature of the targets. Besides, the detection of a number of target navigation parameters can be estimated. The goal of this paper is to present a PCA (Principal Component Analysis) electric field algorithm for calculating the target heading, size/velocity rate and port/starboard location in relation to the electric sensor axis. This PCA algorithm is based on the simultaneous analysis of the three components (longitudinal, athwartship and vertical) of the electric signature in order to compare the time evolution of their waveforms as a way to determine the target parameters. The degree of accuracy of this PCA is evaluated through the use of simulated signals based on BEM (Boundary Element Method) modelling and signals from real ships.

Keywords: UEP, ELFE, Electric Signature, BEM, Target Parameters, Passive Localization.

1. INTRODUCTION

All vessels emit electromagnetic fields, which are propagated through the water and, therefore, are susceptible of being detected by means of appropriate underwater sensors. In the past, the emphasis was centred in magnetic and acoustic detection; nowadays the ever-increasing reduction in the emission level of these influences has originated the necessity of using sensors based on other influences for detecting vessels. Among these new considered influences it is found the electric field (static and alternating).

The static electric field is also referred as Underwater Electric Potential (UEP) and it is characterized by an amplitude, observed from the sensor, almost constant (really the electric field magnitude remains constant, but the effect of the variable distance between the vessel in movement and the static sensor implies that the magnitude of the electric field measured by the sensor varies slightly in time). The range of considered frequencies are typically lower than 2.0 Hz.

The alternating electric field is also known as Extremely Low Frequency Electric (ELFE) field and it is characterized by a fluctuating electric field with frequencies up to at least 3 kHz, although in practice the useful frequencies extend up to 1 kHz.

Some factors are helping to extend the use of electric sensors for detecting and classifying vessels, as are their characteristic of passive sensor (with the associated advantages derived of hiding their presence to the possible targets), the progressive reduction in their size and consumption that permits to build detection systems progressively of smaller size, their increasing performance implying higher capacity of detection from shorter distances and also their cost production is decreasing, helping to extend their use to entities with more limited resources.

Electric sensors can be placed individually, making part of a multi-influence system or configured in an array that permits to implement a trip-wire barrier for protecting a specific area.

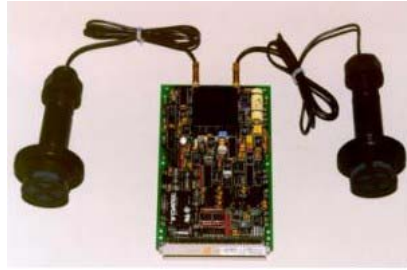


Fig 1. UEP sensor developed by SAES

This paper takes advantage of the SAES experience in working with the underwater electric field including its capacity for estimating the electric field signature and recording and analyzing real data. Based on this experience a method is proposed to calculate the target heading, size/velocity rate and port/starboard location in relation to the electric sensor axis.



Fig 2. Multi-influence mine (MINEA) developed by SAES

2. BACKGROUND

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

2.1 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, composed by the components below related, 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.

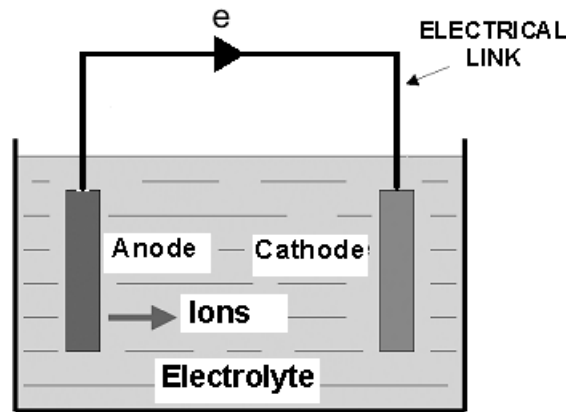


Fig 3. Galvanic corrosion cell

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 sea water. Due to electrochemical reactions of reduction (into the cathode) and oxidation (into the 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.

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

2.2 Extremely Low Frequency Electric sources

The underwater alternating electric field or ELFE is originated by the following sources:

- a) 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.
- b) Power supply ripple in the machinery of the target. A frequency corresponding to the power supply frequency appears.
- c) Ripple in degaussing systems and active cathodic protection systems.
- d) Modulation that experiments the ICCP current caused by the variation of the resistance between the axis and the target hull.

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.

The PCA algorithm described on this paper is based on the UEP waveform of both simulated and real vessels.

3. PRINCIPAL COMPONENTS ANALYSIS METHOD

The proposed method to obtain the target heading, size/velocity rate and port/starboard location in relation to the electric sensor axis is based on Principal electric field Components Analysis. This algorithm has been developed in SAES and it is based on the study of the propagation in the seawater of the three electric field components. The idea of the algorithm is that the electric current is generated by the existence of sources and sinks. The current always flows from the sources to the sinks through the seawater. The computation of the directions of each component and the comparison with each other permit us to calculate the cinematic target parameters.

Let us denote the measured electric field by a triaxial sensor as follows:

$$\bar{E} = E(x, y, z)$$

The meaning of each component depends on the sensor localization in the 3-Dimensional geographic space. Usually, for us, the x component is the athwartship influence, the y and z components are the longitudinal and vertical influences respectively.

Firstly, the algorithm makes a positive levels conditioning. This process is computed with the following equation:

$$\bar{E}_c = \bar{E} - \min(\bar{E})$$

This step is necessary because subsequent steps work with positive signal levels in order to eliminate the ambiguities that appear when sign discernment is used.

Then, the first order derivate of the three conditioned signal components is computed:

$$\nabla \bar{E}_c = \left\{ \frac{\partial \bar{E}_c(x)}{\partial x}, \frac{\partial \bar{E}_c(y)}{\partial y}, \frac{\partial \bar{E}_c(z)}{\partial z} \right\}$$

The derivative signal must be filtered with a low pass FIR filter in the time domain with the convolution operation as follows:

$$\varepsilon = \nabla \bar{E}_c * h$$

Now, we will threshold each component of the signal obtained in the filter process. The threshold function is:

$$\varepsilon_i(x) = \begin{cases} \varepsilon(x_i) & \text{if } \varepsilon(x_i) \geq \lambda_x \\ \varepsilon(x_i) = 0 & \text{if } \varepsilon(x_i) < \lambda_x \end{cases}$$

$$\varepsilon_i(y) = \begin{cases} \varepsilon(y_i) & \text{if } \varepsilon(y_i) \geq \lambda_y \\ \varepsilon(y_i) = 0 & \text{if } \varepsilon(y_i) < \lambda_y \end{cases}$$

$$\varepsilon_i(z) = \begin{cases} \varepsilon(z_i) & \text{if } \varepsilon(z_i) \geq \lambda_z \\ \varepsilon(z_i) = 0 & \text{if } \varepsilon(z_i) < \lambda_z \end{cases}$$

where i takes the values $[1, 2, \dots, N]$, being N the number of samples in the signal. The λ parameter is a positive constant and it is computed with the following equation:

$$\lambda_{x,y,z} = \kappa_{x,y,z} \times \bar{\varepsilon}_{x,y,z}$$

where κ is a constant with $0 < \kappa \leq 1$ values and $\bar{\varepsilon}_{x,y,z}$ is the mean value of each electric field component. Through this method we are eliminating the samples with a low derivate value, that means, the samples providing low information.

The thresholded derivative signal is used as the input to a ‘Flank Detection’ algorithm. This algorithm will be divided into the following steps:

- Firstly, a clipping of the input signal is done.
- The clipped signal is used to detect the different rise and fall flanks.

Finally, the flanks sign discernment of the athwartship and vertical components is used to estimate port/starboard location in relation to the electric sensor axis. The classification method is:

- If the first flanks signs of each component are not equal, then the location in relation to the electric sensor axis is port.
- Otherwise, the target navigates on the starboard side if the first flanks signs of each component are equal.
- The target navigates through the keel line if $\varepsilon_t(x) = 0$.

To compute the heading and size / velocity rate we will assume that the target navigates through a straight line with a constant velocity. The target model is the following:

$$\bar{x}_T(t) = (r_{Tx}(t), r_{Ty}(t), r_{Tz}(t), \dot{r}_{Tx}, \dot{r}_{Ty}, \dot{r}_{Tz})$$

where $r_{Tx}(t), r_{Ty}(t), r_{Tz}(t)$ denotes the target position at each time on the geographic coordinates system and $\dot{r}_{Tx}, \dot{r}_{Ty}, \dot{r}_{Tz}$ are the velocity vector components.

To compute the size / velocity rate, the time length τ_T of the longitudinal electric influence is evaluated as follows:

$$\tau_T = \zeta \times t_s$$

where ζ is the amount of samples between the first and the last detected flanks and t_s is the sampled time.

The size / velocity rate will be obtained with the τ_T value and the cinematic equation to compute the velocity of a rectilinear uniform movement:

$$\dot{r}_T = \frac{\ell_T}{\tau_T}$$

To obtain the heading we know:

- The sensor position in relation to the true north.
- The target location in relation to the sensor axis.

An inverse modelled with a 2-Dimensional space projection of the athwartship and longitudinal components is done. This way, we rotate the horizontal components (athwartship and longitudinal components) and evaluate them at different distances in order to search the value that minimizes the athwartship electric field and maximizes the longitudinal and vertical electric fields. The searching is based on the electric field attenuation in relation to the distance.

$$\hat{\theta} = \{\arg \min(E(x, \theta)), \arg \max(E(y, \theta)), \arg \max(E(z, \theta))\}$$

To find a minimum and a maximum values a numerical iterative search algorithm is needed. Suitable algorithms are e.g., the Gauss – Newton and the Levenberg – Marquardt methods [1], [2]. These methods are easy to implement, but to avoid a possibly large number of time consuming iteration steps, good starting values are usually necessary.

4. EXPERIMENTS

Electric field signatures obtained with a boundary elements software is used to evaluate the algorithm accuracy. This software computes the galvanic currents of each active element of the ship. All areas of the ship are modelled. A potentiodynamic curve (polarization diagram) for each material type is used to solve the model. These curves depend on the ship velocity. The seawater is modelled as a box with minimum length ten times the maximum length of the ship.

The target to emulate is a ship of 50 meters long. The potentiodynamic curve of the different active materials corresponding to a ship velocity of 4,74 knots is used. The seawater is modelled as a box of 500 x 500 meters with 16 meters deep. We suppose that the model centre and the target bow are on the origin geographic coordinate system.

With the electric signatures computed, the boundary elements model is reduced to a dipole model. This is necessary in order to reduce dramatically the computer time.

The result obtained with the reduction is a ‘three poles model’, which poles are located 10, 19 and 50 meters under keel position at 1 meter deep. The current intensities are -1200 mA, 2000 mA and -800 mA respectively.

The x axes corresponds to the athwartship influence, while the y and z axis correspond to the longitudinal and vertical influences. We suppose an acquisition system of 4 Hz sampling frequency. The measured points are located in a longitudinal line [-125,125] meters at 15 meters deep. In these conditions, the target navigates in the same direction as the longitudinal axes. In the following figure the three electric field components under keel are shown:

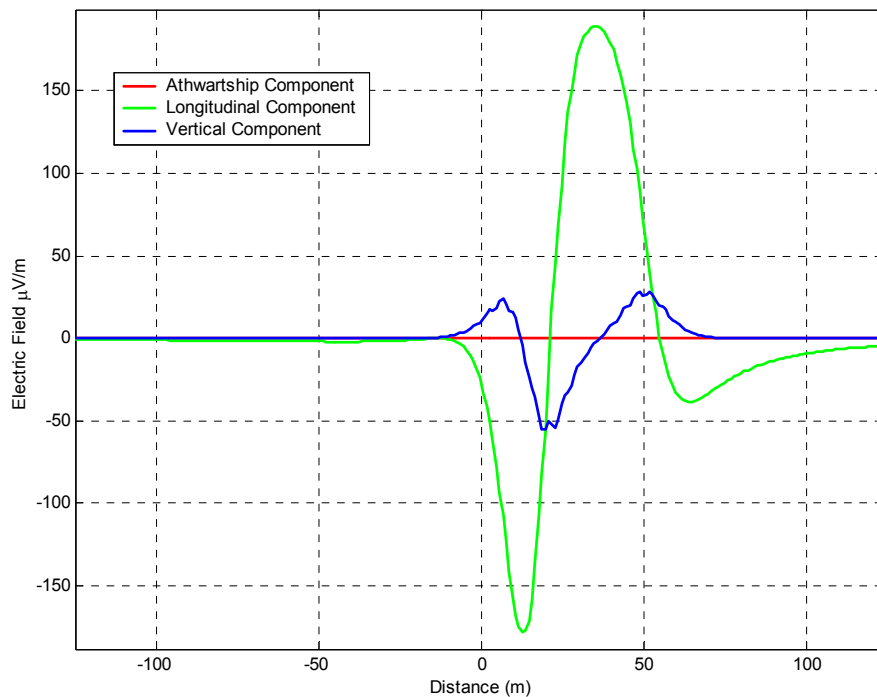


Fig 4. Electric field signatures under keel.

With the propose of studying the propagation direction of the electric field lines we are showing the three electric field components at different distances between the target keel line and the sensor:

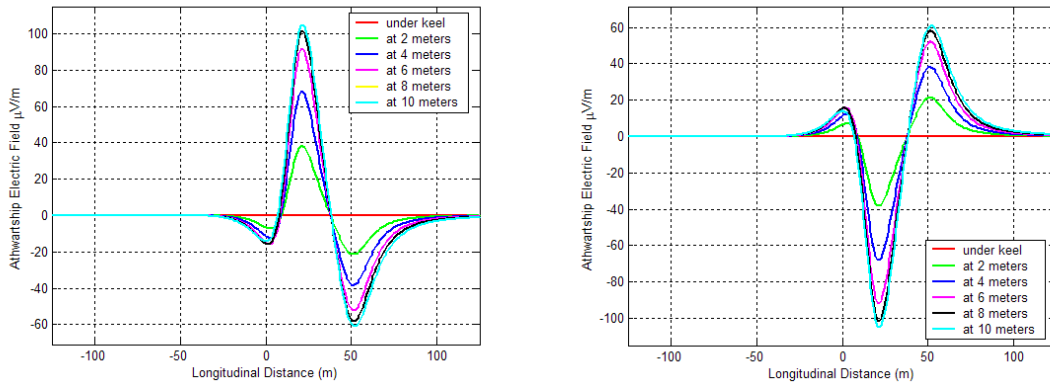


Fig 5. Athwartship Electric field at different distances between the target keel line and the sensor located on the port side (left) and on the starboard side (right) from the target.

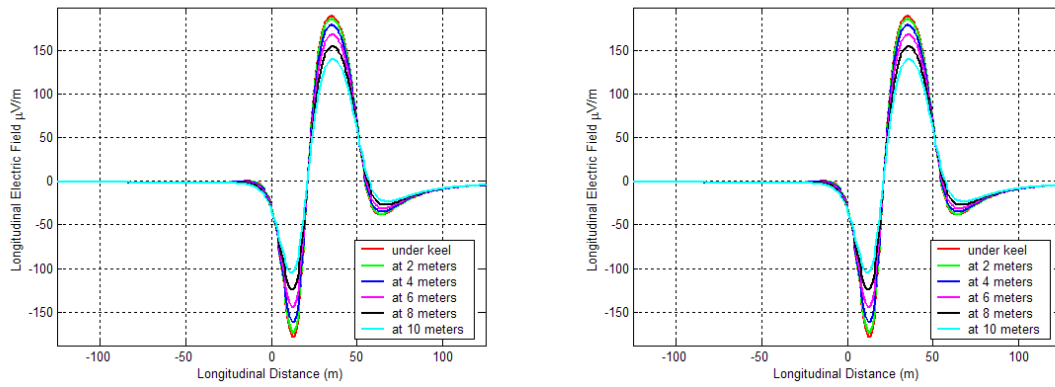


Fig 6. Longitudinal Electric field at different distances between the target keel line and the sensor located on the port side (left) and on the starboard side (right) from the target.

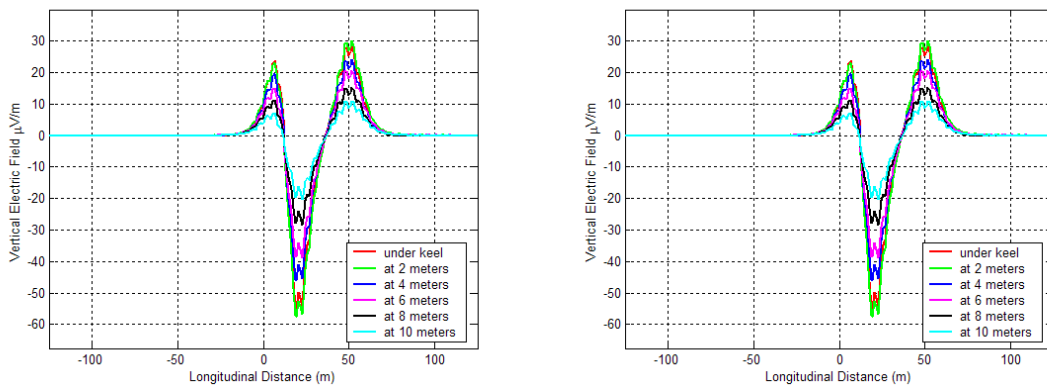


Fig 7. Vertical Electric field at different distances between the target keel line and the sensor located on the port side (left) and on the starboard side (right) from the target.

Through the analysis of the three previous figures, we will prove the sign discernment, that means, if the first flank sign of the athwartship and vertical components are not equal, then the location in relation to the electric sensor axis is port, otherwise, the target navigates on the starboard side if the first flank sign of the athwartship and vertical components are equal.

We take the case when the target navigates at a distance of 6 meters between its keel line and the sensor located on its port side. In the following figures we show the computed \bar{E}_C (electric field component), $\nabla \bar{E}_C$ (derivative of the electric field component), ε_i (filtering of the derivative of the electric field component) signals and the output of the 'Flank Detection' algorithm for each component.

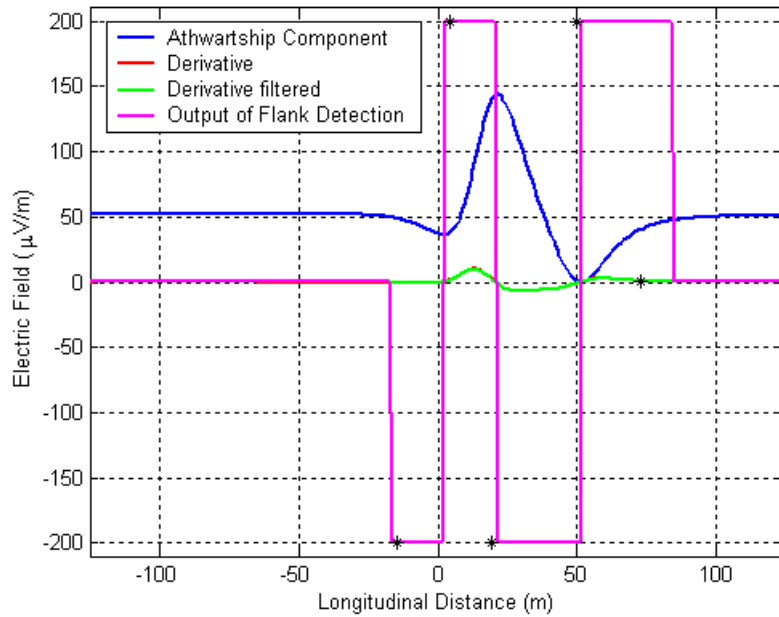


Fig 8. Athwartship Electric field analysis.

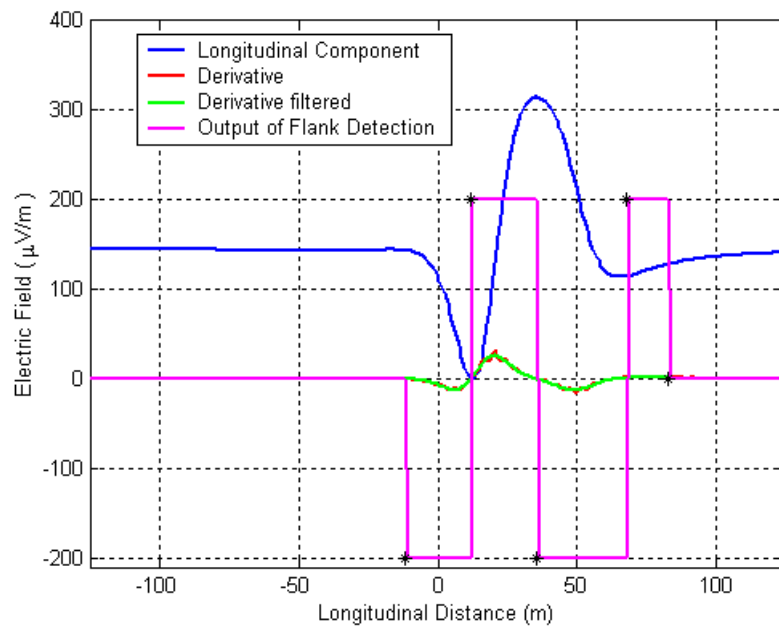


Fig 9. Longitudinal Electric field analysis.

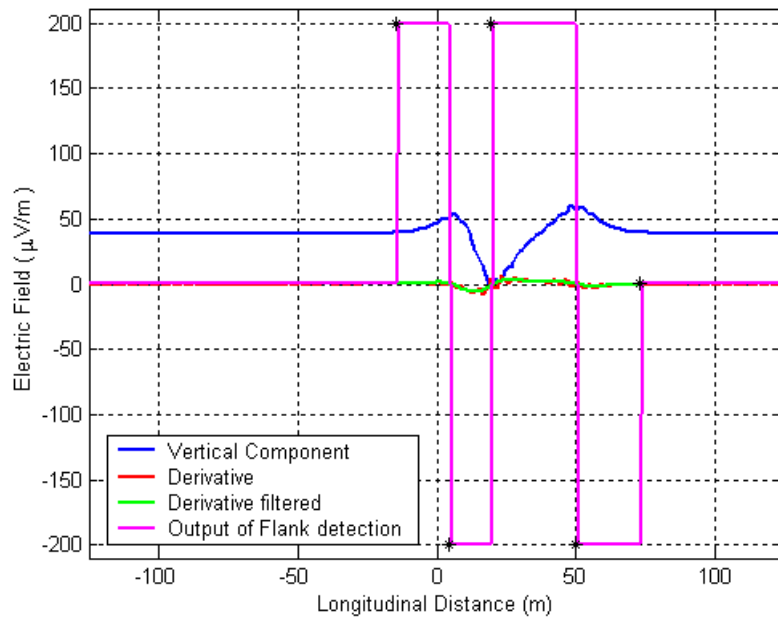


Fig 10. Vertical Electric field analysis.

The analysis denotes that when the sign of the first flank of the athwartship and vertical electric influences are not equal, then, the target localization in relation to the sensor axis is port.

In this case, the obtained value for the τ_T parameter is 21.75 seconds. The target velocity \dot{r}_T for different target lengths are shown in the following figure:

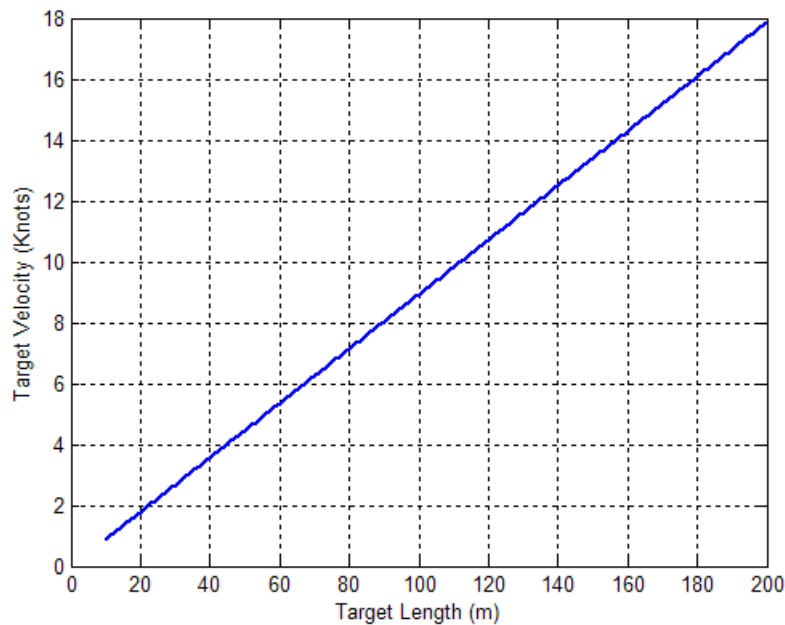


Fig 11. Size/velocity rate.

In this example, the real target velocity is 4.74 knots. The estimated target velocity for a 50 meters long ship is 4.47 knots. The absolute error is lower than 6 per cent of the real value.

The heading computation algorithm output corresponds to a target heading in the same direction than the longitudinal sensor axes.

5. DISCUSSION AND FUTURE WORKS

A new algorithm to extract navigating parameters has been developed. The cinematic parameters computed are heading, size / velocity rate and port/starboard location in relation to the electric sensor axis. The algorithm is based on Principal underwater electric field Components Analysis.

Simulated and real signals have been used to validate the algorithm, though the real results are not presented on this paper because they are restricted.

The great advantage of this passive method is that it is based on a physic reality (underwater electric field lines), that is, it can be used in all propagation conditions, meanwhile, there are not possible countermeasures that avoid its accuracy.

This method can be used in both classification and localization techniques, besides we can do a target identification with a database of the electric field signatures.

The future works are oriented to optimize the heading detection algorithm and its implementation in real time systems.

References

- [1] P. E. Gill, W. Murray and M. H. Wright, *Practical Optimization*, Academic Press, New York, 1981.
- [2] J. E. Dennis and R. B. Schnabel, *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, Prentice Hall, Englewood Cliffs, NJ, 1983.
- [3] D. J. De Renzo. *Corrosion Resistant Materials Handbook*, Noyes Data Corporation. 1985. ISBN: 0-8155-1023-3.
- [4] Pierre R. Roberge, *Handbook of Corrosion Engineering*, McGraw-Hill. 1999. ISBN: 0-07-076516-2.
- [5] Enrique Otero Huerta, *Corrosión y Degradación de Materiales*, Editorial Sintesis S.A. 1997. ISBN: 8477385181.