Bares Wave Sensor

Pablo González Cerredelo, Xulio Fernandez Hermida.
Departamento de Teoría de la Señal y Comunicaciones. Universidad de Vigo.
E.E.T. Ciudad Universitaria S/N. Phone: +34-986-812131.
E-Mail: xulio@tsc.uvigo.es, pablooogonz@gmail.com

Abstract - *The aim of this article is to show how the Bares sensor works. This sensor has a microcontroller, an accelerometer, a gyroscope, a magnetometer and a communication board. It is designed to measure the displacements of the marine free surface for finally obtain the ocean parameters that describe the state of the sea. Currently these sensors are very expensive and it is necessary to reduce the costs. We made the Bares sensor with modern low costs components but with good features.*

Keywords - *Wave sensor, low cost wave sensor, monitoring of the ocean, wave height, wave period.*

I. INTRODUCTION

The sensor emerges from the need to analyze the behavior of the sea in order to improve statistical prediction models, measuring the waves energy, and provide information on the impact of waves in coastal areas. Currently these systems are expensive so there is a need to make them cheaper to enable them to be acquired more easily by administrative institutions, universities, port authorities, etc.

In order to measure the series of accelerations, velocities and displacements we use three sensors with three degrees of freedom each, in total we have nine degrees of freedom. The sensors are a MEMS three-axis accelerometer, MEMS three-axis gyroscope and three-axis magnetometer. We explain the workings of our software in three parts. First we show how to get the Euler angles and how to use them to transform the accelerations to a fixed coordinate system. In the second step we explain how to make the integration of the accelerations to obtain the series of displacement and speed. The third and final step is to obtain the wave parameters.

In short, we will see the hardware, the software development platform, the way the software operates and the comparative results of our “Bares” sensor against Triaxys.

II. SYSTEM DESCRIPTION

General description of operation

The Bares sensor has an IMU (Inertial Measurement Unit) board with nine degrees of freedom. The IMU provides the accelerations and the Euler angles (also known as navigation angles, yaw, pitch and roll). As a first step, we transform the accelerations from a moving coordinate system to a fixed coordinate system [1] and we record the accelerations (twenty minutes time series). In the second step, we perform a double digital integration of accelerations [6] to obtain velocities and displacements. In the last step we obtain the time domain parameters and the spectral domain parameters of the free marine surface [4][2].

Hardware and software overview

We use open hardware compatible with Arduino. Our IMU board has a digital MEMS accelerometer, a digital MEMS gyroscope, a digital magnetometer and an Atmega328 microcontroller. This board is connected to an Arduino Mega ADK board that records the accelerations and the angles series and sends through a communication shield.

The software of the Bares sensor has two different parts. The first part works in the Atmega328 microcontroller. This part corrects the sensors values, merges data from the sensors to obtain Euler angles and transforms the accelerations from the moving coordinate system to the fixed coordinate system [1]. The second part of the software performs digital integration [6] and calculate the free marine surface parameters [4][1] works in ours servers. Initially the software of the second part was developed and tested in Matlab, then it was migrated to C/C++.

Coordinate system transformations

Many applications need to describe the movements of an object in space. In this kind of applications it is necessary to use fixed coordinate systems with a fixed coordinate origin. Frequently, the sensors of this kind of applications measure the accelerations in a moving coordinate system (because the measurement axes are moving) and it is necessary to transform the accelerations. To perform this transformation we multiply the accelerations with a matrix [1] composed with sines and cosines of the Euler angles.

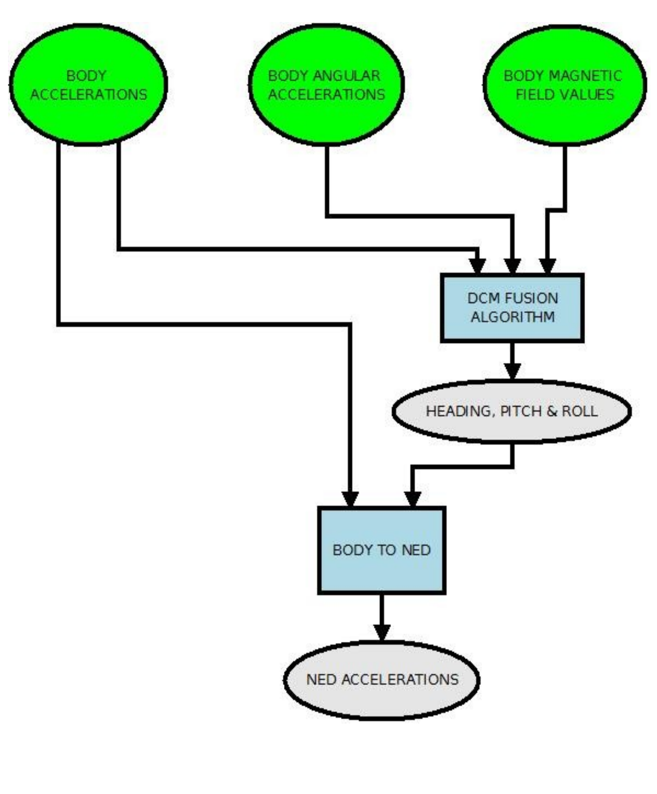

Fig. 1: Step 1, obtaining Euler angles and transforming coordinate system.

Digital integration

This is the second step and most critical part of the software. As already said, to obtain the velocities and the displacements we need to perform a double digital integration. Theoretically it seems simple but actually many problems appear: unknown initial conditions of the differential equations, low frequency noise and drift of the MEMS accelerometer, sampling errors, digital integration errors, etc. These errors affect the lower frequencies and the solution is to filter these frequencies. We perform the following steps [6]: filter the accelerations, integrate the accelerations to obtain the velocities, filter the velocities, integrate the velocities to obtain the positions and finally we filter the positions. Is necessary to indicate that the choice of the cut-off frequency of the filter is not trivial.

$$v(t) = v(t_0) + \int_{t_0}^{t} a(t')\,dt'$$

$$x(t) = x(t_0) + \int_{t_0}^{t} v(t')\,dt'$$

Calculation of the parameters of free marine surface

Once the displacements of free marine surface are obtained we can calculate the parameters that describe the state of sea. On one hand we calculate the time domain parameters simply applying the statistical theory of this field [2]. In the other hand we calculate the spectral domain parameters which are not trivial [2][4]. The most important issue to do this with success is to perform a correct power spectral density (PSD) estimation and cross power spectral density estimation.

To do this we use two different methods. Welch's method works well and is sufficient to calculate Tz and Hm0 parameters. However this method is not at all suitable to calculate the peak period Tp and the fifth peak period TP5 as discussed below. The parameter Tp is the inverse of the peak frequency fp that is defined as the frequency of the spectrum where there is more energy, i.e. fp is the frequency where the amplitude of PSD is maximum. Due to the high variance of the Welch method in the PSD it appears thin energy peaks with high amplitude but these peaks do not correspond to the frequency around which there is more energy. This causes some times the calculated value of fp to be incorrect and therefore Tp. To solve this problem, the autoregressive Yule-Walker method with a suitable order is used. This provides a much smoother PSD in which there are no such thin energy peaks, thus correctly calculation of Tp is achieved as can be seen in the comparative charts.

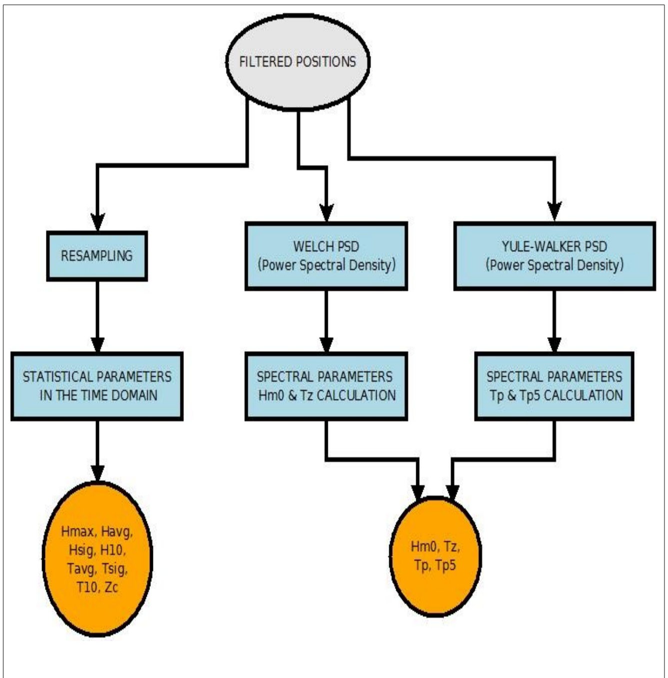

Fig. 2: Step 3-a, non directional parameters.

III. DIRECTIONAL PARAMETERS

The directional parameters are currently obtained in the spectrum domain, ie, using the PSD. We have developed our own method for directional parameters in the time domain. This method is patent pending so we can not talk about it. The traditional method for the estimation of the directional parameters is described in [3]. This method is to calculate the auto-spectra and cross-spectra, for example, for movements in X, Y and Z. Once calculated the auto-spectra and cross-spectra we obtain the mean direction and the mean directional spreading from the Fourier coefficients of first and second order described in [3]. In our case as we use a medium characteristics sensor we need additional filtering in order these values to be correct. This is due to the low frequency response and noise of the used sensors. We use the one-dimensional Kalman filtering, very useful to see what a noisy signal "hides".

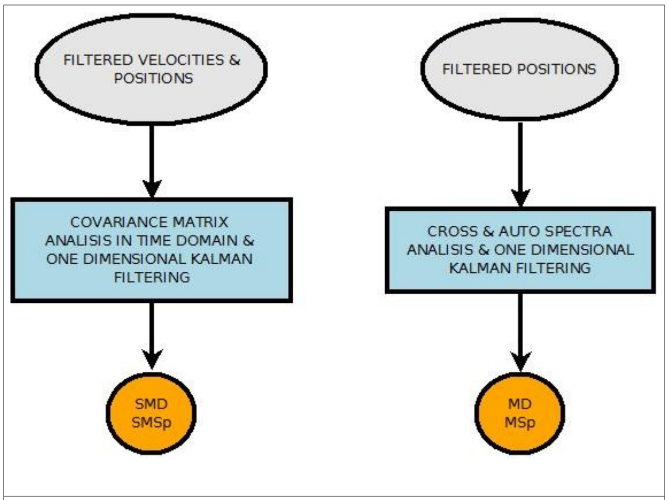

Fig. 3: Step 3-b, directional parameters.

III. LOCATION AND COMPARATIVE RESULTS

In this last section we will see the results when comparing our "Bares" swell sensor with Triaxys. Both sensors were mounted on the same buoy also called "Bares". This wave buoy was moored in the north of Galicia, Spain, during the winter 2013/2014. The graphs of Figures 4 to 8 show the comparative data obtained from Triaxys and our sensor. It is important to indicate that the Triaxys has ten years and is not the latest version they have on the market. In the following lines we will compare some results of both sensors.

As shown in the comparative graphs there is a high correlation between the data provided by both sensors. In all graphs Triaxys data are represented in red. The green color corresponds to our sensor "Bares" and blue and black colors shown in two graphs also correspond to data of the "Bares" sensor.

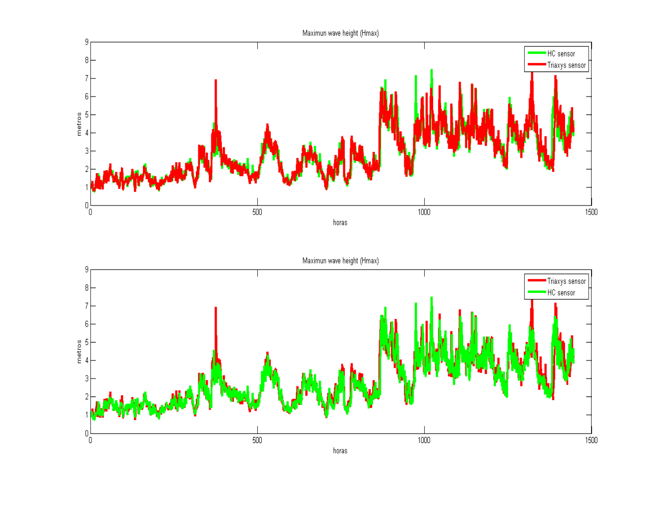

Fig. 4: Hmax. Maximum height.

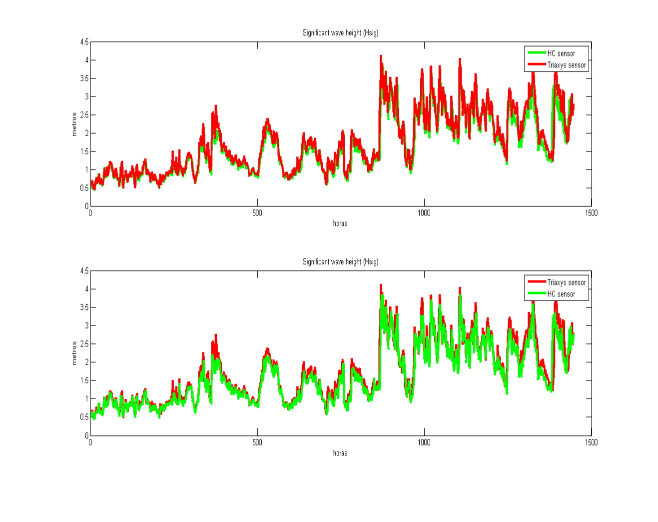

Fig. 5: Hsig. Temporal significant height.

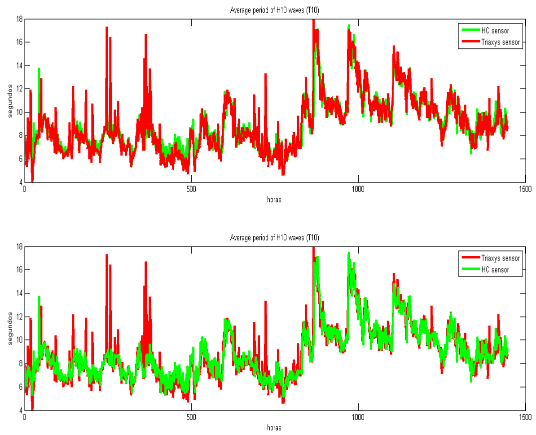

Fig. 6: T10. Mean period of N / 10 largest waves.

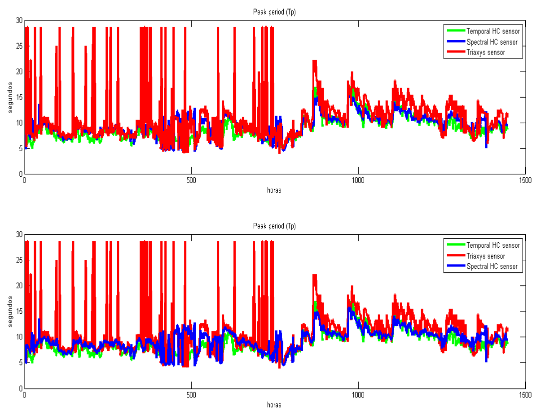

Fig. 7: Tp. Peak period.

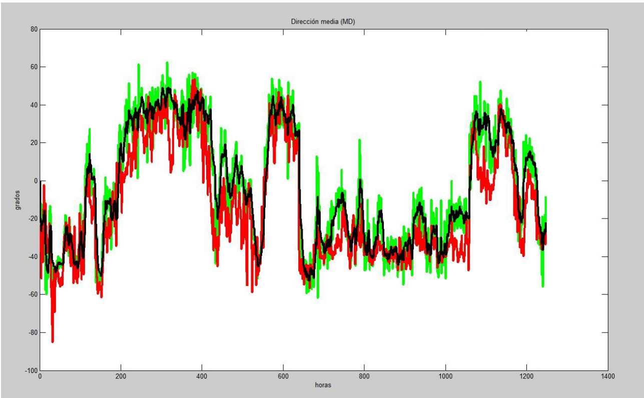

Fig. 8: MD. Mean direction.

III. CONCLUSIONS

In our research we install the Bares sensor and the Triaxys wave sensor in the same buoy. The comparative results are very good and show us that we go in the right direction. We conclude that today it is possible to access to this technologies with a lower cost and with very accurate results.

IV. ACKNOWLEDGEMENTS

The Bares Wave Sensor has been developed partially under the ECODRAGA project. ECODRAGA project has received the financial aid of national government by a CDTI project in 2011, code ITC-20113086 and title DISEÑO Y DESARROLLO, ESTRUCTURAL Y DE SISTEMAS, MEDIANTE EL USO DE HERRAMIENTAS CAD, FEA Y CFD, DE UN PROTOTIPO DE DRAGA ECOLÓGICA PARA LA LIMPIEZA POR SUCCIÓN DE FONDOS MARINOS (ECODRAGA).

V. REFERENCES

[1] Sangbo, H., J. W. Chung. 2002. Retrieving displacement signal from measured acceleration signal. In: SPIE proceedings series, 4753 (2):1178-1184.

[2] Slifka, L. D. 2004. An accelerometer based approach to measuring displacement of a vehicle body. Master of Science in Engineering. University of Michigan, 66pp.

[3] Benoit, M., P. Frigaard, H. A. Schaffer. 1997. Analysing multidirectional wave spectra: A tentative classification of available methods. In: Proc IAHR Sem Multidirectional Waves Interact Struct. 27th IAHR Congress, 131-158. San Francisco, USA.

[4] Cai, G., B. M. Cheng, Ben M., T. H. Lee. 2011. Coordinate systems and transformations. In: Unmanned Rotorcraft Systems. Ed. Springer, 23-34.

[5] Earle, M. D. 1996. Nondirectional and Directional Wave Data Analysis Procedures. Louisiana: U.S. Department of commerce. 43pp.

[6] Premerlani, W. and P. Bizard. 2009. Direction Cosine Matrix IMU Theory.