# ID 19- BARES 2.0 WAVE BUOY AND SUSTAINABLE BUOY NETWORK

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*Abstract – The aim of this article is to show the operation of the Bares 2.0 wave buoy and the Bares network developed by HCTech. In the marine sector it is highly important to know the state of the sea for applications such as the construction of ports, the study of the impact of waves in coastal areas, the development and calibration of forecasting wave models, the knowledge of the state of the maritime navigation channels, etc. Some of the great difficulties that exist in order to obtain the information of ocean waves is the high cost of the buoys, installation and maintenance. The Bares network aims to cover areas of high oceanographic interest, the target is a sustainable network of buoys that facilitate the access to wave data. The features of this network are the optimized cost, high reliability and reduced maintenance.*

*Keywords - buoy, waves, network, swell, Bares, Triaxys, oceanography, comparative.*

**1 INTRODUCTION**

The Bares 2.0 wave buoy and the Bares network allow analyzing the behavior of the sea at an optimal cost, with high precision and high robustness in order to obtain long temporal series with high quality. In the following sections the most important aspects of hardware and software are explained, we talk about the Bares network project and finally we will see a brief comparative between the Bares 2.0 and the Triaxys sensors.

**2 HARWARE AND SOFTWARE**

***2.1 Energy Module***

The buoy includes three rechargeable batteries and four solar panels, this elements provide an autonomous operation for a long time. Thanks to the optimal consumption of electronics it is possible to guarantee the operation in adverse conditions, that is, with very low solar energy. This buoy has different states of operation, if the available energy is too low the buoy works in a low consumption state in order to ensure the operation of the system.

***2.2 Inertial Sensors***

The buoy has a cutting-edge and cost-effective IMU/AHRS (Inertial Measurement Unit/Attitude Heading Reference System) based in MEMS (Micro Electro Mechanical System) technology. This unit has a three axis accelerometer, a three axis gyroscope, a three axis magnetometer and a temperature sensor. The most relevant characteristics of the IMU/AHRS are:

· MEMS sensors with high linearity and low noise.
· Sensors calibrated and tested in the range of -40 to 85 ° C.
· Efficient microprocessor running the Kalman [1] algorithm at 1KHz. This algorithm implements the sensor fusion and rejects spurious vibrations.
· 0.2º pitch and roll accuracy.
· 0.8º heading accuracy.
· Very low consumption.

***2.3 Control Module***

This module controls, synchronizes and monitors all subsystems in the buoy. For guarantee a robust and an efficient operation, we made a great effort in the development of both software and hardware. The control module software is based on the state machine concept, the most relevant characteristics are:

· In function of battery charge it automatically adjusts the operation mode. If it is too low for the processing, the software stores raw data and only processes when the battery charge has the correct level. The system has FIFO queues for the pending raw data, thus this data will be processed in the same order that they were stored.
· In the case of critical errors in the processing and communication module, the system stores the raw data. Thus raw data can be recovered and processed later.
· A solid state memory to store the raw data for more than two years. The raw data that were processed and transmitted are removed.
· In the case of critical errors as errors in the inertial sensors, the system will send alert messages to the servers.
· In the case of GPS errors due to malfunction or buoy drifting, the system will send alert messages to the servers.

**2.4 Processing and Communication Module**

The processing of raw data and the communications with the servers are performed in this module. The more relevant characteristics are:

· Powerful and efficient ARM microprocessor that runs the C++ applications.
· GPRS/3G modem. Due to modular design it is also possible to use other interface types as satellite communication.
· The integration of the communication module in the Bares 2.0 sensor allows increasing energy efficiency and reliability.
· A solid state memory allows storing the processed data for more than seven years. This memory is independent of control module memory and when the communication interface is broken or when there are not enough battery for transmit the processed data it stores the processed data. The system has FIFO queues for the pending processed data, thus this data will be sent in the same order that they were stored.
· The wave processing software was completely developed by HCTech. This software was validated comparing our sensor with Triaxys and Datawell sensors.
· The communication software was completely developed by HCTech. This software is highly reliable and efficient and is based on the AMQP protocol described in [2]. The integrity and the confidentiality of the data in the transmission toward our servers is ensured by our software.

The wave processing software is an improvement of the Bares 1.0 software. Initially the software was developed in Matlab platform and in order to validate the correct operation of the mathematical model we develop a wave simulator based on Simulink. Then in order to perform an on-board processing in the ARM microprocessor all the software was implemented in C++.

As can be seen in the comparative section of this paper, we show the comparison of both Bares 2.0 and Triaxys sensors, but previously a comparison between the Bares 1.0 and the Triaxys was made. In this we saw that non directional parameters of the Bares 1.0 are comparable with the Triaxys parameters, however due to the noise and the nonlinearity of the IMU/AHRS we saw that the directional parameters were not accurate enough. For this reason Bares 2.0 includes a cutting-edge and cost-effective IMU/AHRS for assuring the accuracy.

Generally, the operating of the software is the following:

1. Transformation of accelerations in to a fixed coordinate system.
2. Digital integration and high pass filtering of accelerations in order to obtain velocities and displacements according to [3].
3. Non directional processing as shown by Earle [4]: statistical-temporal processing and spectral processing of vertical displacement.
4. Directional processing as shown by Benoit [5]: spectral processing of vertical and horizontal displacements.

An advanced protocol between the buoy and the servers is performed by the communication software. This is based on AMQP protocol which allows sending a very high quantity of messages, always ensuring the integrity and confidentiality of the data. The main advantages of this protocol are:

· Message-oriented protocol.
· Redundancy and availability. If the application of the server fails on processing the messages, these are not lost because the protocol insists until they are fully processed.
· Asynchronous communication that allows processing the messages one by one or for groups.
· Delivery guarantee of messages in the order in that they were sent.

· Scalability.
· Multicasting between the server and the buoys with the possibility of actualizations of the wave processing software.
· Remote configuration of the buoys.

**3 THE BARES NETWORK**

The knowledge of the sea state is highly important for applications such as the port construction, the study of wave impact in coastal areas, the development and calibration of forecasting wave models, the knowledge of the state of the marine navigation channels, the recreational navigation, the aquatic sports, the study of the climate change, etc.

At present it is difficult to obtain a quality ocean wave data because the buoys are expensive and difficult to install and to maintain. This implies that the number of ocean wave buoys is small and that in order to cover an extensive marine area it is very frequent to install only one wave buoy.

The Bares network aims to contribute to reduce these lacks in the oceanographic physics. The main objective is to promote in the creation of a stable and sustainable coastal wave buoy network that allow increasing the number of sample points. In fact this is the principal philosophy of the project, because increasing the number of sample points provides the next advantages:

· Allows increasing the accuracy in the characterization of ocean waves and allows improving the forecasting models.
· Allows ensuring the wave data of the marine area because there are not a single point of failure.
· Allows installing wave buoys near the coastal area. Thus it is possible to study in great detail the waves affected by the underwater topography.

This is possible because the Bares 2.0 is a cost-effective buoy with low maintenance requirements and highly robust.

HCTech will contribute to generating the wave buoy network in places where interest for the ocean wave data is high. Interested entities will be able to access the data contractually. Betting for this sustainable solution, you do not need to make large investments for buying buoys and neither no need to worry about maintenance.

**4 COMPARATIVE**

The next figures show real data from the Bares 2.0 and the Triaxys, both sensors in the same buoy during ten days in June 2016. Figures 1, 3 and 5 are comparative plots, upper subplots show the Bares signal under the Triaxys signal and lower subplots show the Bares signal above the the Triaxys signal. Figures 2, 4 and 6 are scatter plots.

In figures 1 and 2 we can see the significant wave height, in figures 3 and 4 the mean spectral period and finally in figures 5 and 6 the average mean direction of the ocean waves. For define these parameters, previously we need to know the next concepts and equations:

· Spectral moments where S(f) is the spectrum of the vertical displacement and f is the frequency:

$$m_k=\int_0^\infty f^k S(f)df$$

· Directional spreading function that models the directional spreading of the wave energy at each frequency:

$$\int_0^{2\pi} D(f,\theta)d\theta=1\ ;\ D(f,\theta)\geq 0$$

· Directional spectrum:

$$S(f,\theta)=S(f)D(f,\theta)$$

· Fourier coefficients a0, a1, b1, a2 and b2 that are determined from the cross-spectral data. With this we can obtain the wave direction and directional spreading function as showed in [4].

Thus the parameters in the comparison are defined as follows:

· Significant wave height:

$$Hm0=4\sqrt{m_0}$$

· Mean spectral period:

$$Tz=\sqrt{m_0/m_2}$$

· Mean wave direction:

$$\theta_0=Arg(a_1+ib_1)$$

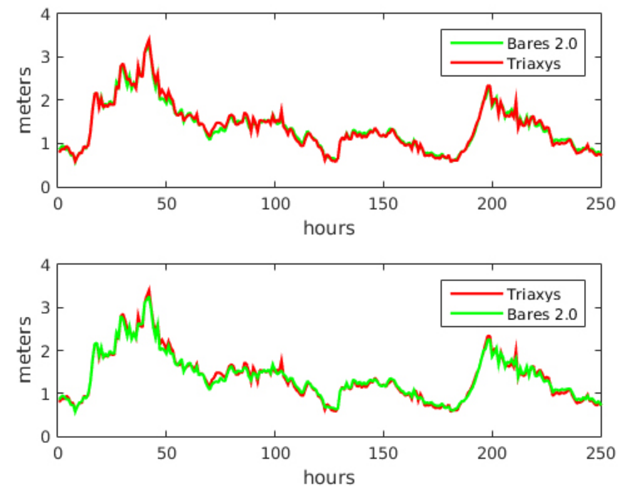


***Fig. 1 Comparative plot of significant wave height (spectral), Hm0.***

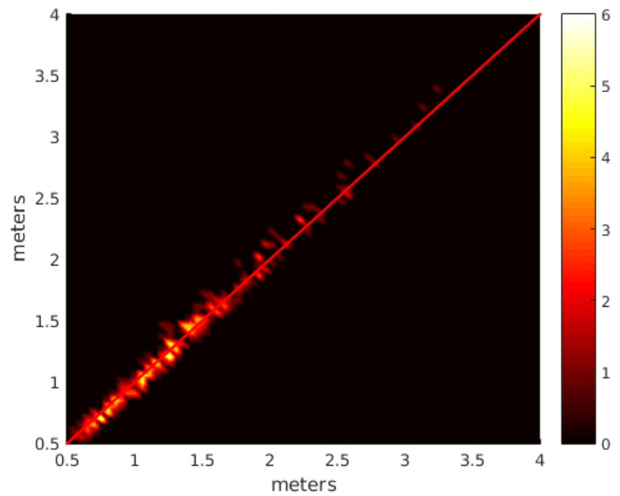


***Fig. 2 Scatter plot of significant wave height (spectral), Hm0.***

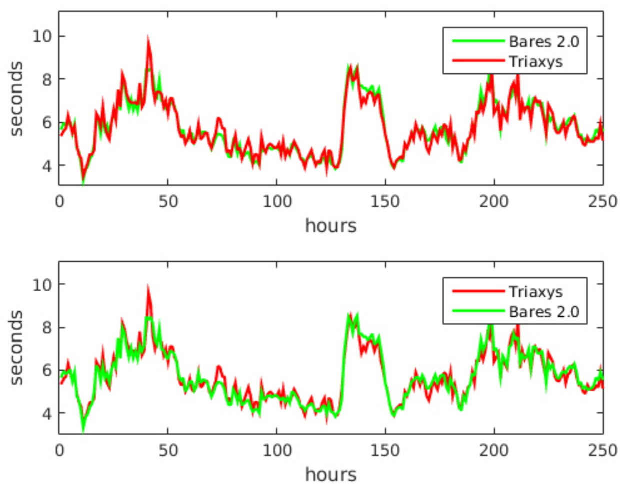


***Fig. 3 Comparative plot of mean spectral period, Tz.***

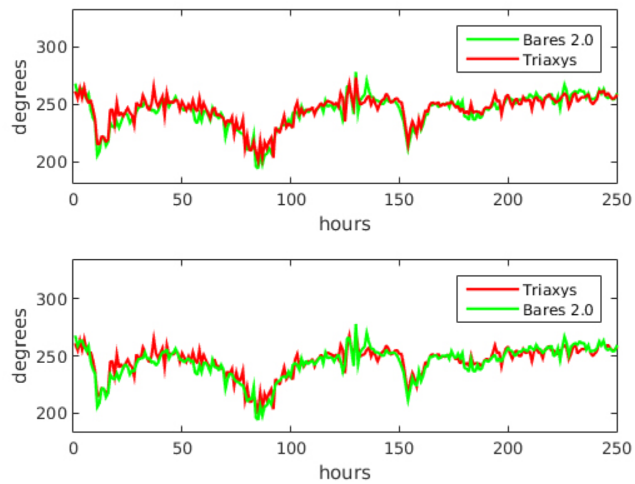


***Fig. 5 Comparative plot of mean wave direction, θ0.***

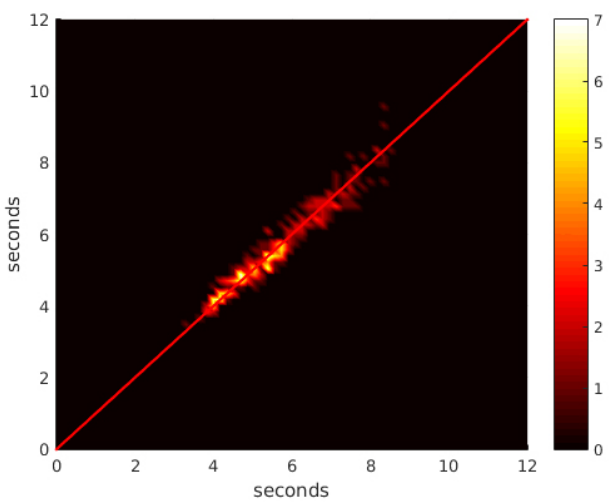


***Fig. 4 Scatter plot of mean spectral period, Tz***

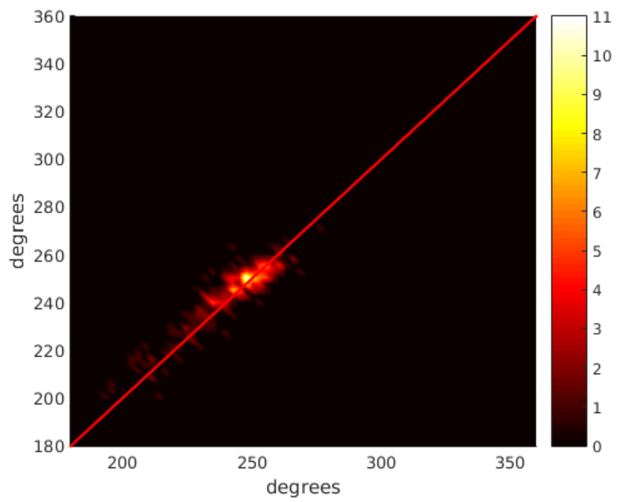


***Fig. 6 Scatter plot of mean wave direction, θ0.***

**5 CONCLUSIONS**

In the previous section can be seen the good performance of the Bares 2.0 directional wave sensor. In the comparative plots (figures 1, 3 and 5) and in the scatter plots (figures 2, 4 and 6) the high similarity and correlation between the sensors can be seen.

The most critical parameter is the mean wave direction because the noise and nonlinearity of the IMU/AHRS should be optimal, if both are high it is not possible to obtain an accurate wave direction. Bares 2.0 has a cutting-edge and cost-effective IMU/AHRS that allows to obtain an accurate wave direction.

These results and the characteristics of the wave buoy allow us to ensure that the Bares 2.0 will contribute to create a permanent and sustainable buoy network that will provide high quality wave data.

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