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Telemetry based Quality Control and Directional Wave Information Improvement in Real Time

P. Ravichandran
Department of GMDSS, AMET University, Chennai, India

Abstract: The transmission of met-ocean data collected in real-time is essential for marine operations. Due to the high cost associated with satellite communication, the complete characterization of sea state is impaired. The moderns single boards computers, enables the development of dedicated modules for processing and quality control of the collected series, allowing to perform more complex tasks and transmitting additional information relevant to the characterization of sea states. The primary goals of this research is to increase the reliability of real-time data, transmitted by heave-pitch-roll buoys and verify the efficiency of a single board computer to execute the traditional wave processing by Longuet-Higgins and DAAT including automatic quality control. This new wave data processing system allows a deeper evaluation of the information that can characterize a sea state of a time series that was stored inside the buoy and was not transmitted in real-time.

Key words: Buoys, wave processing, DAAT, telemetry, board computer, India

INTRODUCTION

The satellite real-time telemetry of wave data main parameters, measured by met ocean buoys is an important issue that has been studied, aiming to improve the characterization of sea states. Buoys with software that performs internal processing of the data including quality control algorithms have the advantage of reducing inconsistent data to be transmitted and allowing greater attention to suspicious data which can provide valuable information.

The power consumption and the high cost associated with satellite data transmission are two factors that limit, somehow, the quantity and quality of information sent in real time. Low-power, low-cost and high performance embedded systems like the single boards computers, enables the development of dedicated modules for processing and quality control of the collected series, allowing to perform more complex tasks and transmitting additional information relevant to the characterization of sea states without significant battery consumption or processing time of the main CPU.

Aiming to increase a directional resolution of waves, Parente (1999) developed a method called Directional Analysis with Adaptive Techniques (DAAT). This method provides additional information using a wavelet data processing, in which time series are subject to an event-driven process that search and selects periods in which the wave directional parameters have stability. Two output variables are suggested to be sent in real time which provides two directions and two peaks per frequency band.

The primary goals of this work are to increase the reliability of real-time data, transmitted by heave-pitch-roll buoys and verify the efficiency of a single board computer to execute the traditional wave processing by Higgins *et al*. (1963) and DAAT including automatic quality control. To achieve these goals, routines for processing and quality control of wave data, using Python language have been developed and tested in an "Electrum 100" board from the micro mint. To perform the tests, time series of elevation and two orthogonal horizontal displacements from an axis technology buoy located at Rio Grande/RS-Brazil were used.

MATERIALS AND METHODS

Quality control and processing: Several sources can cause data inconsistencies collected by met ocean buoys such as failures in the sensors, transmission errors, computational errors, the influence of mooring line, the presence of marine animals, vandalism, among others. Three different sets of time series were selected: consistent, inconsistent and suspicion to verify the operation and flags applied for quality control routines.

The data quality control programs are divided into two modules: consistency of short-term series (elevation and horizontal displacements) and long-term series (Hs, Tp and Dp) derived from short-lived series. The short-lived series were processed in the time domain, using zero up-crossing methods and frequency with 16° of freedom using Welch smoothing and first direction obtained through the Fourier coefficients of the first order as described by Higgins *et al*. (1963).

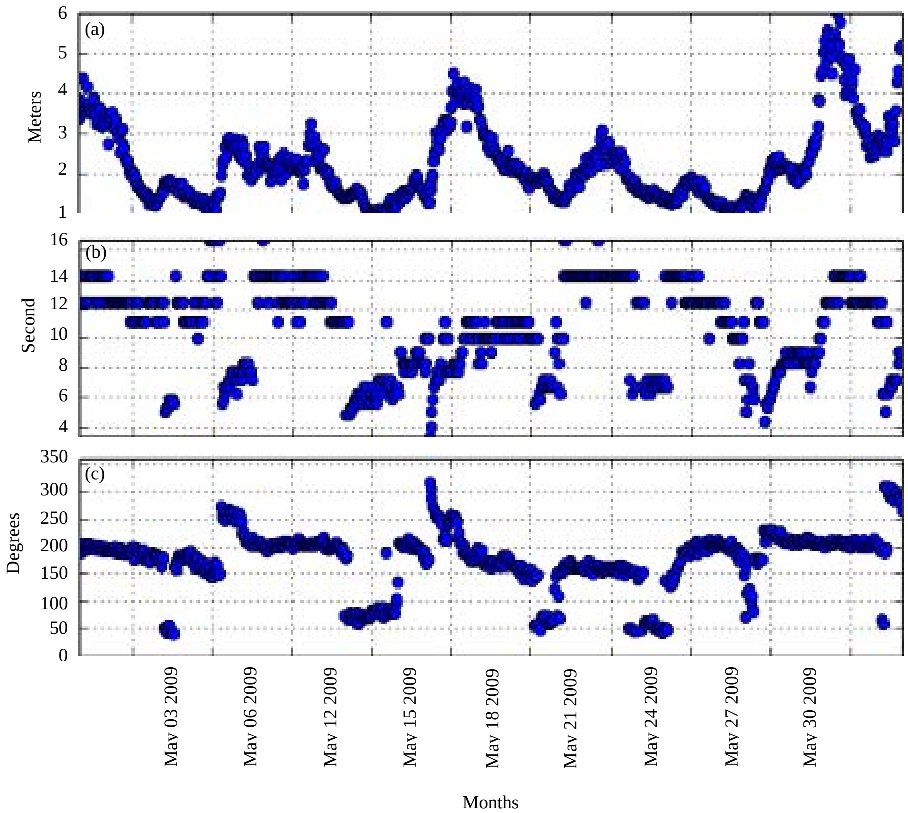

Fig. 1: Main wave parameters: a) Significant wave height (Hm0); b) Peak period (Tp) and c) Peak direction (Dp)

Figure 1 shows the main wave parameters (Hs, Tp and Dp) calculated during May 2009 at the Rio Grande. It's possible to observe that for high significant wave height, the peak period is large and the direction of wave is from the Southwest. Wave directions coming from East-Northeast is commonly associated with territorial seas with little time. This kind of sea states is prevalent at South Atlantic.

In the data quality control processing, each variable is subjected to a series of quality control tests and even if the variable flunked a test, it should make the whole proposal sequence to quantify the perturbations affecting the series, creating more support for the classification of the studied variable. The tests used in this study were recommended by agencies such as IOOS (2013), Barreira and Ribeiro (2011) and NDBC (2009).

The short-term evaluation include fifteen tests: checking the length of the series, gap, range, spike, null and equal consecutive values, mean shift, number of zero crossing, distribution of periods and nine tests of long-term: acceptable limits, peak, variability, consecutive equal values, check-ratio, wave steepness, wave band operating frequency and correlation of height and wave period. The parameters used as input for testing quality control (NDBC, 2009) were defined by evaluating series collected from four Axis buoys operated by PNBOIA (National Buoys Program) of Brazilian Navy, located in the states of Rio Grande do Sul, Santa Catarina, Sao Paulo and Pernambuco.

As output, the routines generate an array of flags from short and long term analysis, based on UNESCO (2013) where the results of each test for each variable are reported. The colors are divided in hard-flags which its information should not be transmitted and soft-flags where the descriptor of quality should be forwarded to the central, along with the calculated parameters. This study by Sagadevan and Podder (2015) tells about an investigation of structural, SEM, TEM and Dielectric Properties of $BaTiO_3$ nanoparticles. Group search optimization in deregulated electricity market based on reactive power pricing (Kannan *et al*., 2015). Investigation of the structural, optical and electrical properties of copper selenide thin films is described by Thirumavalavan *et al.* (2015).

DAAT: The simultaneous occurrence of different "sets" can produce non-stationarities in the process. Averaging through fixed segments will provide some weighted average. Even in the case of an incoming sea from a limited sector, the waves in a narrow frequency band are always combining constructively or destructively, producing high and low spectral values. The average tends to hide an isolated event, defined here as the occurrence of a wave occupying a very narrow band of frequency and direction.

The fundamental properties of DAAT are to obtain better information of directional waves by detection of short- duration events, allowing to identify for the same frequency band, the occurrence of waves coming from different directions (Parente, 1999). The highest directional resolution obtained by DAAT comes with the cost of a low-frequency resolution.

DAAT calculates the main parameters for each segment with one sample increment. These values are evaluated under several criteria and eventually, the section is considered with low noise, stable in direction and representative of the process and so selected to compose the averages. This technique allows the construction of df( ) the distribution of energy with direction for a given frequency band.

DAAT performs the calculations on m point segments with 1 sample increment the smaller the portion size, the bigger the chance to detect events along the record; on the other hand, the smaller the segment, the worst the frequency resolution however, it is possible to reach a trade-off, accepting a frequency band produced by this little segment size representative of the wave climate (Parente, 1999).

The parameters of the first direction, spectrum and directional spectrum for each frequency band are calculated using a Morlet wavelet function. The cardinal direction is obtained by Maximum Entropy Method (MEM). The limits defined for each frequency band was selected by previous analysis of power spectrum and associated wave parameters. These groups and corresponding values of segment sizes are shown in Table 1. The frequency bands seem adequate to represent the different combinations of sea and swell that occur in most situations at sea (Parente, 1999). In this case, Group 1 corresponds to long fetch swell, bands 2 and 3 to medium or small fetch swell or high seas and band 4 to tiny fetch swell or low seas showing an associated swell with 12.5 sec from the South and a local sea with 4.2 sec comings from East. Both methods estimated the same directions for the two peaks of the spectrum. The third frequency band of DAAT has used to detection the territorial sea.

The output of DAAT is represented by a technique developed by Parente (1999) called PEDS (Plotting the Evolution of the Directional Spectrum). This graph makes more visible the presence of associated seas and identifying the coming of swells (Fig. 2).

Table 1: Groups and corresponding values of segment size

Band (N°)	Frequency band (Hz)/sec
1	(0.046-0.078)/(21.3-12.8)
2	(0.078-0.14)/(12.8-4.00)
3	(0.14-0.25)/(7.11-4.00)
4	(0.25-0.50)/(4.00-2.00)

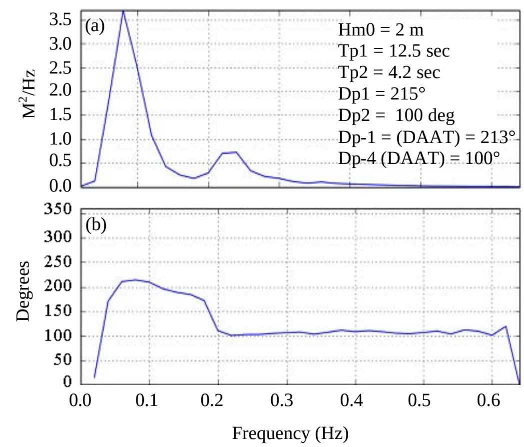

Fig. 2: a) Power spectrum Rio grande/RS-05-09-2009 06:00 h and b) Principal direction

RESULTS AND DISCUSSION

A set of 1 month of met-ocean wave data were analyzed to evaluate the quality of the data and plot the evolution of directional spectrum with the PEDS as an example of the figure that we can get by the DAAT output parameters, transmitted each hour.

Aiming to verify the feasibility of the use of the proposed modules in an "Electrum 100" board, CPU ARM 400 MHz, Debian Linux OS, 1.5 W and Power-Down Mode, time and consumption were quantified for one Axis file which contains a series of elevation and two orthogonal horizontal displacements. These values are shown in Table 2.

The system's startup and standby time were estimated at 30 sec. This represents an additional of 1.25e-05 kWh on the energy consumption for each tested module. This time can be reduced by optimizing the system startup.

The output variables calculated by DAAT provides information of two directions and two peaks per frequency band. Depending on the sea state, the transmission of all parameters may not be required. An evaluation of the multi-modal identification method can assist the decision of what information should be transmitted.

Figure 3 shows a comparison of Peak Direction (Dp) for each frequency band, calculated by Higgins *et al.* (1963) and DAAT (Parente, 1999) for May 2009 at Rio

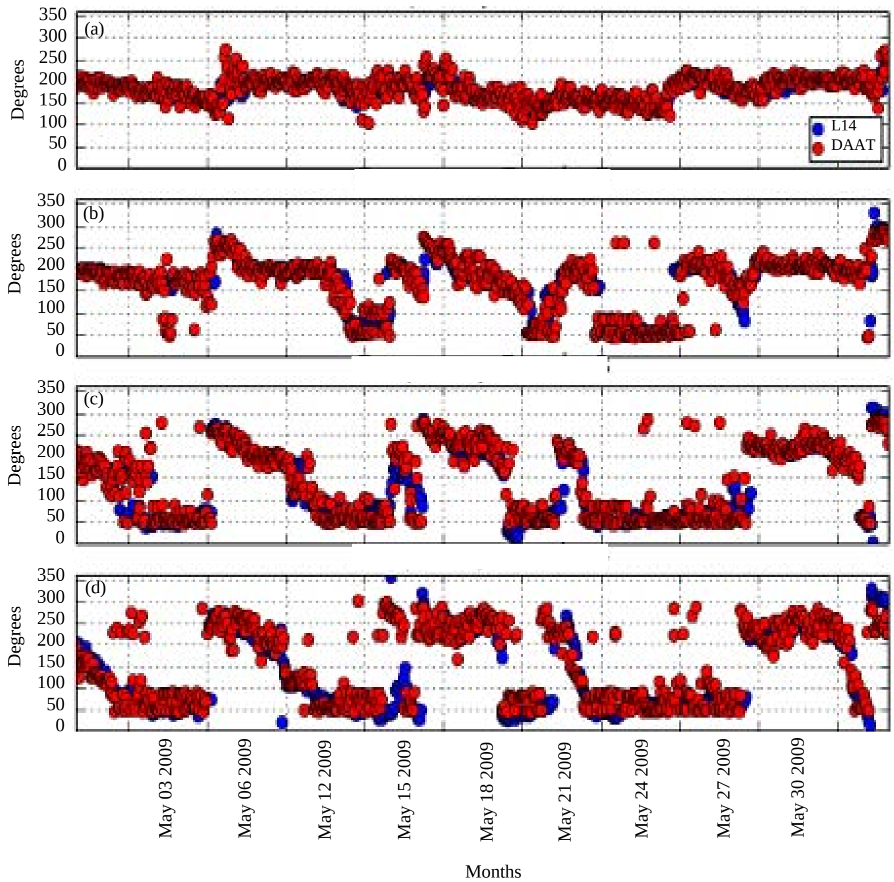

Fig. 3: Peak direction (Dp); a-d) Frequency band 1-4

Table 2: Orthogonal horizontal displacements

Electrum-100 (method)	Time (sec)	Energy consumption (kWh)
Long.Higg.	4.01	1.6707e-06
DAAT	40.96	1.7067e-05
Long.Higg.+DAAT	45.11	1.8796e-05

Grande/RS-Brazil. In both methods, the power spectrum was subdivided in the same frequency bands for calculating the waves directions. As expected when related to meteorological systems presents in South Atlantic, the band 1 (12.8-21.3 sec) normally represents waves coming from the Southwest, generated by extra-tropical cyclones. The Group 2 (7.11-12.8 sec) follows the band one most of the time, sometimes changing to the Northeast when the territorial sea gets more energy. The bands 3 and 4, represented by waves with the peak period smaller than 7.11 sec follow the same direction of the territorial sea which is predominant from the Northeast and varies to the Southwest in the presence of storms. Plotting the Evolution of Directional Spectrum (PEDS).

PEDS is a four-dimensional plot where the time is on the vertical axis, the colors represent the frequency band and the energy is proportional to the height of the hanging window plotted. Winds can also be plotted in this figure, represented by white rectangles.

As an example, Fig. 3 shows the directional spectrum evolution for the same data showed at Fig. 3 where we can see the presence of territorial seas (band 3-yellow) associated with swells (Band 1-red). In this month is clearly to see the presence of two systems more energetic coming from the Southwest. Figure 3 helps verify the importance of a good spectral partitioning and detection of isolated events in situations of mixed seas.

CONCLUSION

The “Electrum 100” single boards appear to be suitable for executing the proposed wave processing module which includes data quality control and treatment by Higgins *et al*. (1963) and DAAT (Parente, 1999) techniques.

The output variables calculated by DAAT can be less using another method that determines which wave parameters is critical to transmit in real-time to minimize the high costs associated with telemetry. The possibilities of dedicated embedded systems for processing and quality control of wave data, inside net ocean buoys, proved that this is a feasible option, due to the processing capacity and low power consumption of the modern boards. This new wave data processing system allows a deeper evaluation of the information that can characterize a sea state of a time series that was stored inside the buoy and was not transmitted in real time.

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