Description
The University of Michigan OEL IWS is a +12V (+9 to +38Vdc) powered inertial wave sensor that reports heading, wave height, wave period, and wave direction via RS-232 communications. The on-board three-axis accelerometer (Analog Devices ADXL330) and digital compass (Honeywell HMR3300) provide 12bit measurements at a sample rate of 2Hz. Wave analysis is then computed via an integrated Rabbit RCM3600 embedded controller using a custom discrete Fast Fourier Transform algorithm.

Table 1. IWS Technical Specifications

<table>
<thead>
<tr>
<th>Sensor</th>
<th>A/D Bits</th>
<th>Record Length</th>
<th>Analog Filter</th>
<th>Sampling Rate</th>
<th>Digital Filter</th>
<th>Segment Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADXL330</td>
<td>12</td>
<td>1024 samples</td>
<td>1Hz Low-Pass</td>
<td>2Hz</td>
<td>Lang, 1987</td>
<td>1024</td>
</tr>
<tr>
<td>HMR3300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wave Analysis Overview
In order to perform non-directional and directional wave analysis, the follow processes are employed.

1. Acquire 1024 measurement samples at a rate of 2Hz, including heading, roll, pitch, and x,y,z accelerations.

2. Compute the discrete Fast Fourier Transform (FFT) of the 1024 sample spatio-temporal wave data to transform the record into the frequency domain.

3. Apply a digital filter to the data according to Lang’s (NDBC) 1987 paper where $C_{11}$ are the acceleration spectra at different frequencies and $f$ is a fixed frequency:

$$NC(f) = (13*0.5)^n[C_{11}(0.01) + C_{11}(0.02)]*(0.15-f)$$

4. Convert accelerations to displacements (in the frequency domain) and calculate directional properties. (See reverse side for directional calculation details)

5. Compute the inverse FFT on the Z-axis accelerations to determine significant wave height. Significant wave height, $H_s$, is defined as the average of the highest 1/3 waves. Here, $m_0$ is the area under the spectral density function, $f(x)$, where $R=8m_0$, and $x$ is the wave height.

$$H_s = 4.0043 \sqrt{m_0} \quad f(x) = \frac{2x}{R} e^{-\frac{x^2}{R}}$$

Output Message Specification
The IWS communicates via standard RS-232 communications with output data settings: RS232,115200,8,N,1, Flow:None

Output Format (Sensor sends output string at 1Hz):

A,B,C,D,F1,F2,F3,F4,G(CR+LF)

A = Heading in degrees (Used for wind sensor compensation)  
B = Wave height in meters  
C = Wave period in seconds  
D = Wave direction (from which waves originating) in degrees from North  
F1-F4 = Fourier Coefficients $a_1$, $b_1$, $a_2$, $b_2$  
G = Data age in seconds

CR+LF = Carriage Return + Line Feed (ASCII 10+13)
**Directional Analysis**

A spectral analysis is performed on the frequency data to determine directional properties of incident wave trains. This processing includes determining the first five Fourier coefficients, $a_0, a_1, b_1, a_2, b_2$ from the co-and quadrature spectra (as in Longuet-Higgins et al. 1963, and Steele et al. 1985).

The Fourier coefficients are defined as follows:

\[
\begin{align*}
a_0 &= \frac{C_{11}}{\pi} \\
a_1 &= \frac{Q_{12}}{k \pi} \\
b_1 &= \frac{Q_{13}}{k \pi} \\
a_2 &= \frac{(C_{22} - C_{33})}{k^2 \pi} \\
b_2 &= \frac{2C_{23}}{k^2 \pi}
\end{align*}
\]

Where $k = 2\pi$/wavelength. $C$ and $Q$ are the co- and quadrature spectra at each frequency.

Wave direction is defined by:

\[
\theta = \arctan(a_1, b_1)
\]

Wave period is defined as:

\[
T = 2\frac{\pi}{\Delta \omega_{\text{max}}}
\]

Comparison of NDBC 45002 and U-GLOS 45022
Through Storm Activity October 6-7, 2009