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# Current State of Wave Measuring Technology from Buoys (Extended Abstract)

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## 1. History of Wave Analysis

Historically, ocean wave measurement beginnings can date back to the first time humans encountered large open water bodies and decided to navigate in and around these. The development of wave analysis dates back to circa 550 BCE when Pythagoras experimented with Vibrating Strings and Sound. Around 250 BCE Archimedes studied the value π (22/7) and Buoyancy (Hydrostatics) and Sphere making and gave a foundation for buoy making. Archimedes and his associates also worked with what we would now call Calculus, however, this knowledge was lost through the ages.

Much later, around 1670 Newton and Leibniz rediscovered calculus and invented dynamical physics. Relevant to modern wave analysis, Joseph Fourier in 1822 discovered what is now called the Fourier series and used to analyze a time series of measurements. In 1903, C. Runge described the Fast Fourier Transform (FFT) algorithm. The FFT transforms time domain waveforms into the frequency domain, which is now an important format for studying ocean waves.

During World War II, Sverdrup and Munk, using pressure transducers at 40 feet and visual observations from marine vessels developed the wave statistics of Significant Wave Height and Period. After World War II, MM.S. Longuet-Higgens in 1952 introduced us to the wave statistics of Wave Root Mean Square of Amplitude and $H_{avg}$, $H_{1/3}$ and $H_{1/10}$ and in 1956 further developed wave statistic analysis with D.E Cartwright.

The analysis of ocean waves in near real time was finally possible owing to developments of mainframe computers, the J. Cooley and J. Tukey FFT algorithm in 1965 and by the Personal Computer in the 1970's.

## 2. History of Wave Measurement

The first practical wave measurements were done by mariners and fishers. These measurements were Qualitative in terms like big, small, high, calm and rough. In 1853, M.F Maury (USN), initiated the beginnings of the International Meteorological Organization (IMO, 1873–1953) which has subsequently become the WMO, World Meteorological Organization. With the beginnings of the IMO. Wave observations began being catalogued by the world shipping industry. In 1891, Lord Kelvin, built a Tide Gauge which measured the wave cycle of the tides. As mentioned previously the first quantitative measurements of ocean waves were done during World War II with pressure gauges at 40 feet (12m) and combined with qualitative measurements to produce the first wave statistics. During the 1950's there is an unclear history of the use of wave staffs for measurement. The real advancement came in the 1960's with the use of accelerometers for wave measurement. In the 1980's and 1990's data acquisition system became powerful enough that the wave analysis can be done in real time on a buoy.

## 3. Wave Analysis with Accelerometers

The practical measurements of waves using accelerometers were developed in the Netherlands by Datawell BV who produced the first Waverider™ buoy in 1968. They further developed a directional wave measuring buoy, the WAVEC™ in 1983 then the Directional Waverider™ in 1988. Similar buoys were developed in the U.S.A by Endeco Inc. called the WAVE-TRAK™, in Norway by Bergen Ocean Data called the NORWAV™ and in France by CNE-OX and Néréides called the WADIBUOY™. In the 1980's and 1990's the use of strap down accelerometers came into common use by NOAA/NDBC and Environment Canada/Canadian Meteorological Service. In 1997 AXYS Technologies Inc. began a partnership with Canadian Hydraulic Centre (CHC) of the National Research Council (NRC) who independently had been developing its own software for measuring waves using accelerometers with other motion sensors. This led to the development of the TRIAXYS™ Directional Wave Buoy.

## 4. Time Domain and Frequency Domain Analysis

In order to determine wave height time series the accelerometer signal must be double integrated, once to transform into velocity and again to determine displacement (distance). The Datawell Waverider™ and Strap down accelerometers buoys developed prior to 1997 use electronic integration which is a feedback type circuit. The resulting data is a time series of heave as generated by the electronic circuit. Wave Analysis is then carried out on this time domain series. The TRIAXYS™ buoy with the 1997 CHC-NRC software collects the accelerometer time series then does a FFT analysis on the acceleration data. The accelerometer time series data is thereby transformed into the Frequency domain. This transformed data is then double integrated in the Frequency Domain. Much of the Ocean Wave analysis can then be done directly on this data. An Inverse Fourier Transform is then done which produces a Time Domain series from which zero crossing or time series analysis can be done. A further discussion and comparison of these methods will be done.