Abstract - Acoustic Doppler Velocimeters (ADV) have been used extensively for wave and current measurements. These pulse-to-pulse coherent systems are most commonly deployed using a pre-set velocity range that determines the maximum measured velocity (dynamic range) and velocity uncertainty (precision). As the velocity field energy can vary significantly (especially during storm events), this limitation requires tradeoffs between the precision and dynamic range of the measurements.

We describe the ADV Triton equipped with the auto velocity-range adjustment option that allows the sensor to dynamically select the measurement range based on the environmental state. This ensures that even during the most energetic conditions the velocity measurements are still valid, while still maintaining 1% velocity precision during calm seas. Field tests conducted off of the Scripps Institution of Oceanography Pier demonstrate the Triton’s ability to detect the wave-field of up to 0.5 Hz while maintaining 75% or higher coherence between pressure and velocity up to 0.3 Hz. This improved sensitivity allows the sensor to capture moderate storm events while still detecting a low energy background swell.

I. Background

In the past, the use of sophisticated acoustic water-velocity instruments was primarily the realm of acousticians. However, with the clear strengths of the acoustic Doppler method, many non-expert oceanographers have made acoustic Doppler instruments their primary tools for water-velocity measurement. This has increased the demand for instrumentation to become smaller, cheaper and easier to use without losing their functionality. SonTek has responded to these demands by developing a new Acoustic Doppler Velocimeter, the Triton.

II. The ADV-Triton

The Acoustic Doppler Velocimeter was invented by SonTek over 10 years ago [1, 2]. It has been the basis for breakthrough research in oceanography, hydrology and the laboratory. It uses a powerful pulse-to-pulse coherent method that allows for very high sample rates, while providing extraordinary precision at a given velocity range. The ADV was first developed as a laboratory tool, but was eventually developed for Oceanographic research. This breakthrough product is now the de-facto standard for point-source velocity measurement.
The ADV-Ocean was merged with multiple third-party sensors into the Hydra line [3]. This powerful package has been extremely successful with coastal oceanographers, but its capability comes at the expense of significant size, weight and price. Thus, the new ADV-Triton (Fig. 1) line has been developed.

The ADV-Triton is named after the mythological Greek god of water and the sea. He was the son of the Olympian Poseidon. Similarly, the ADV-Triton is the evolutionary-child of the ADV-Ocean/Hydra. It uses the same bi-static pulse-to-pulse coherent technology; however, the Triton is based on SonTek’s inexpensive Argonaut electronics and uses 10 MHz transducers. This allows the Triton to be smaller and much lower power than the ADV-Ocean. While it is not capable of the 25 Hz sampling frequency of the ADV-Ocean, it is more than capable of resolving all surface gravity waves. Thus, in tandem with the internal pressure gage, the Triton can function as a directional wave-gage by using the trusted PUV method.

The complete Triton package is only 13 cm × 70 cm in size and weights only 5 kgs in air. It includes an internal receiver and batteries that allow for autonomous deployments of up to two month. To ensure 1% accuracy of water velocity, the in-situ Sound Speed must be determined. This is accomplished by an internal thermistor and user defined salinity. Pressure gage, compass and tilt are also standard internal sensors.

A new development for the Argonaut line of ADVs is the auto velocity-range adjustment. All ADVs, like the Triton, uses the pulse-to-pulse coherent Doppler technique. This principle consists of transmitting a pair of pulses separated by a lag, \( T_l \), and computing the phase difference between the two. Doppler velocity is computed as [4]

\[
V = \frac{C \cdot \Delta \Phi}{4 \pi F_0 T_l} \tag{1}
\]

Where \( C \) is the speed of sound, \( \Delta \Phi \) is the phase difference between the pulses and \( F_0 \) is the system frequency. As the pulse coherent methods measures phase difference over short time it proves to be the most precise Doppler technique. As seen from Eq. (1) velocity uncertainty is inversely proportional to the pulse lag, \( \delta V \sim 1/T_l \).

Hence, longer lags produce lower uncertainty and vice versa and may appear to be preferred choice at a first glance. However since our ability to measure phase is limited to \( 2\pi \), longer lags have lower maximum measured velocity as [4, 5]

\[
V_{\text{max}} = \pm \frac{C}{4 F_0 T_l} \tag{2}
\]

Therefore, if very long lags are used then the corresponding maximum velocity of the system may be smaller than the velocities to be measured.

To help deal with this tradeoff of pulse-coherent processing, early developed ADVs offered users a choice of lags, that correspond to different velocity ranges (±5, ±15, ±50, ±200 and ±480 cm/s for the Triton). With past knowledge of the dominant flow regime, users could select appropriate lag, prior to their deployment so as to minimize velocity uncertainty while still maintaining enough dynamic range to capture the flow. This approach works well in lab environment where flow speeds are often predictable and/or controlled. Unfortunately, this is not the case when conducting oceanographic measurements, especially in the near-shore where the expected velocity range can be orders of magnitude apart between calm and storm conditions. To obtain good measurements in such demanding conditions, the ADV users were forced to use the largest (200 or 480 cm/s) velocity ranges which increased the velocity uncertainty.

To enable the ADV to operate in a variety of conditions, SonTek has developed a proprietary automatic velocity-scale adjustment processing option that allows ADV-Triton users to obtain precise velocity measurements regardless of the flow conditions. To achieve this, SonTek ADVs can be set to sense ambient flow regime and dynamically adjust velocity range based on the flow conditions. For example, when currents are on the order of 10 cm/s, the Triton-ADV would select 15 cm/s velocity range. If the currents increase to 100 cm/s the system would automatically adjust it’s setting to 200 cm/s range. Thus, the user gets the best of both worlds – the ability to measure the most energetic conditions while being able to resolve the most quiescent seas without changing any configurations.

III. Deployment and Results

To experimentally verify the performance of the ADV-Triton, a series of field test were conducted off the Scripps Institution of Oceanography Pier, La Jolla, California (Fig. 2). The first test was in the summer of
2001 and the second was in the fall of 2002. Both were at about 7 m water depth and both lasted for about 2 hours.

Data was collected in various modes from the ADV and the standard internal sensors. A short time series of the velocity and pressure anomaly is shown in Fig. 3. No external sensors were added for these deployments. As can be seen from Fig. 2, the mounting hardware and frame for the deployment could be very simple because of the small size of the Triton. Hardware requirements were a flat plate and an orthogonal pipe onto which the Triton was mounted in an upward configuration.

The Triton’s velocity and pressure signals resolved all of the surface-gravity wind-wave band. The respective Power Spectral Densities, Fig. 4, show complete resolution of all scales of motion up to 0.5 Hz, with no flattening that would be attributed to the electronic noise. The velocity and the pressure series show a high degree of coherence. Within the wind-wave frequency band of 0.05 Hz to 0.30 Hz, we see that as a first order check, the pressure and velocity signals are better than 75% coherent. This matches with what would be expected by linear gravity wave theory.

During the deployment, the Triton was set to measure the directional wave-field (Fig 6). The powerful Triton was able to resolve a complex sea, with waves of different length scales approaching from different angle. Fig. 6 shows the predominant wind-waves approached the beach in an easterly direction while a lower-energy swell was moving towards the north-east. This is the same capability one might expect from a more complex instrument or an array of instruments.
During the second deployment, the Triton was set in a custom dual-mode for testing. It was possible to use the auto velocity-range adjustment mode, and concurrently run four different velocity ranges. This special-mode shows the impact of the auto velocity-range adjustment in Fig. 7. The Triton resolved the velocities up to only 0.25 Hz with the largest velocity ranges, ±480 cm/s. By using a lower velocity range, ±50 cm/s, the velocity resolution was improved and the flattening of the high-frequency spectra, that is due to quantization noise, has been removed. This is clear because the lowest velocity range of ±15 cm/s, which has the best velocity resolution, has the same high frequency spectra as the ±50 cm/s case.

Resolving the complete velocity-field with a single user defined velocity-range would have been problematic. The user would have required prior knowledge of the velocity field and would still need to be conservative with the range, or else risk recording ambiguous large velocities. Typically, ±200 cm/s would have been the chosen velocity-range. For our case, that choice of velocity range would have resulted in all of the low-energy high-frequencies motions being contaminated by noise.

IV. Conclusions

SonTek has developed the ADV-Triton as a full-function, small, affordable, acoustic current-wave-tide sensor. It is a complete solution, with the capability of measuring not only mean currents but also the wave-field by using the tested PUV method. With the auto velocity-range adjustment, SonTek has added functionality that is not normally seen in Acoustic Doppler Velocimeters. The Triton is able to maintain 1% accuracy of the dynamic range while maintaining its maximum resolvable range, ±480 cm/s. This user-friendly design allows for greater simplicity in deployments where seas are expected be quiescent at times and stormy at others.

References


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