Applications of an Acoustic Current Measurement Technique

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Introduction

Both the scientific and the commercial community have a great interest in measuring current and wave parameters. The parameters of interest are direction, velocity and, in the case of waves, directional and point spectra. Falmouth Scientific Inc. has a full range of instruments for measuring the above parameters. These are the 3D-ACM, the 3D-ACM Wave, and the 2D-ACM. All three instruments use Falmouth Scientific's acoustic current measurement technique, which is based on measuring and comparing direct path acoustic phase shifts along multiple paths. The technique has proven to provide high accuracy current measurements and its hardware implementation requires very low power.

Measuring Current Direction and Velocity

The current measurement technique used by FSI was invented by Neil Brown [1]. An outline of an instrument using this technique is shown in Figure 1. The instrument has four "fingers". Each finger houses two acoustic transceivers. The transceivers are used to create four acoustic paths. The flow velocity is measured by comparing phase shifts of sound pulses traveling along three of the four acoustic paths. One path is always disregarded - this is the path that is contaminated by the wake from the center support strut.

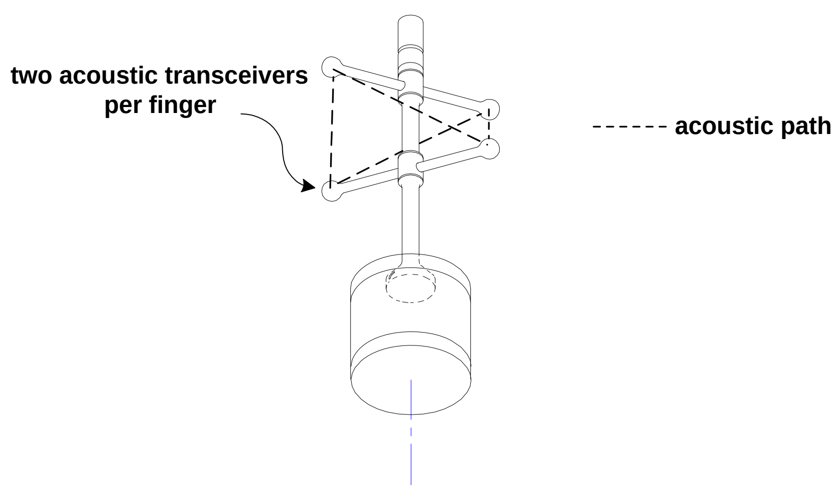

Figure 1 *Acoustic current meter outline*

In order to be able to deploy the instrument for several months using battery power only, the power consumption of the instrument needs to be very low (on the order of ten mA). Two features of the measurement technique described above help to reduce the instrument's power consumption. First, the measurement technique uses direct acoustic paths and not reflected sound. This reduces the power dissipated into the water and thus the power required to operate the instrument. Second, the instrument measures phase shifts of the acoustic signals along the paths, not the time of travel along the individual paths. The advantage of measuring phase shift is that it can be accomplished with slower circuits than measuring time of travel. Slower circuits in turn require less power to operate.

Three FSI instruments use the above described current measurement technique. Let us now take a look at them in a little more detail.

The 3D-ACM Acoustic Current Meter

The first acoustic current meter developed by FSI is the 3D-ACM. The 3D-ACM is a three dimensional acoustic current meter. The instrument also includes a 3-axis fluxgate compass which measures the Earth's magnetic field and a 2-axis electrolytic tilt sensor which measures the instrument's angle to the vertical. Using the compass and the tilt sensor we can estimate the heading of the instrument, and consequently the flow direction in Earth-coordinates.

The sample volume of the 3D-ACM is small - it is a sphere with a radius of roughly 13 cm. Individual measurements take a very short time - about 32 ms, and the single ping uncertainty is only 0.01 cm/s. Figure 2 shows data collected at a deployment of a 3D-ACM in the sea of Japan. This graph shows tidal currents in the direction of east. Notice that the instrument produced extremely clean current measurements at very low current velocities.

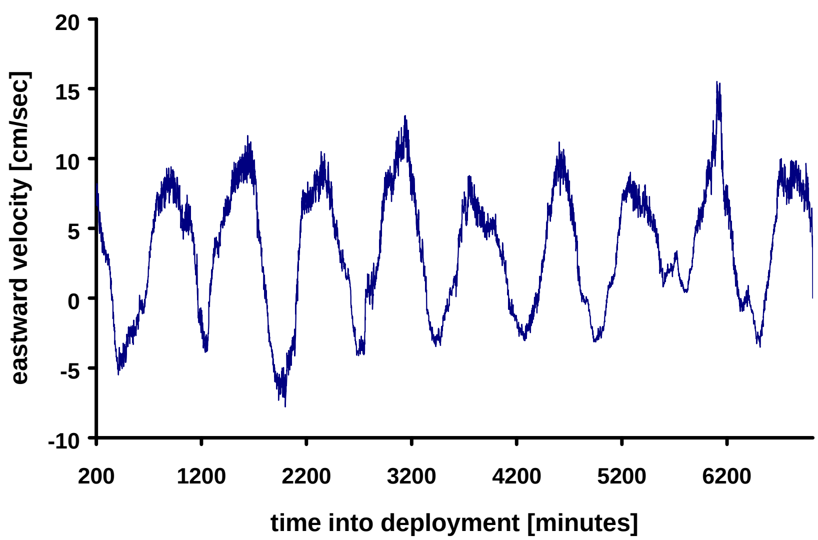

Figure 2 *Sea of Japan deployment*

Measuring Wave Parameters with the 3D-ACM Wave

The 3D-ACM Wave is a shallow water version of the 3D-ACM equipped with a 0.01% full-scale precision micro-machined pressure sensor [2]. The pressure sensor data in combination with the current meter data is used to determine the wave spectrum, based on readily available spectral analysis techniques [3]. The sampling rate of the 3D-ACM Wave is 5.36 Hz, allowing a wide spectral range for wave characterization. The instrument is fixed in a frame and the frame is mounted on the ocean floor, as shown in Figure 3. Note that, since the instrument has a tilt sensor, it does not have to be mounted in a vertical position, since tilt can be measured and corrected for.

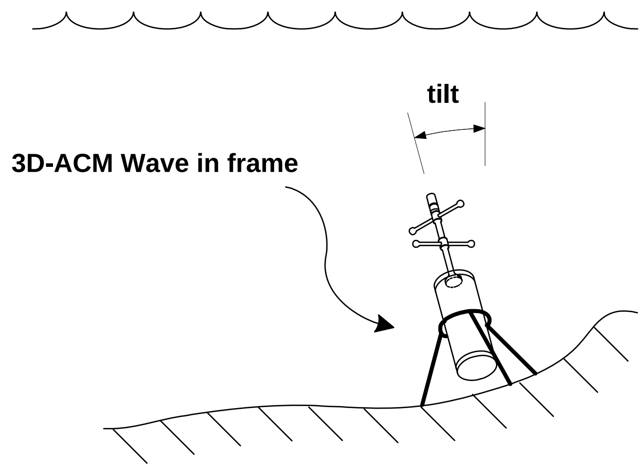

Figure 3 *3D-ACM Wave positioning*

A Closer Look at the New 2D-ACM

The latest result of FSI's efforts is the 2D-ACM, a very low cost acoustic current meter priced under $4000.00, which provides two dimensional current readings. The 2D-ACM evolved from the proven acoustic current meter design of the 3D-ACM. Figure 4 shows the instrument.

Figure 4 *The 2D-ACM instrument with the protective frame*

The 2D-ACM electronics is shown in Figure 5 in block diagram form. It is built around an 8051 derivative microcontroller. The microcontroller has a built-in real-time clock. Using this clock the instrument can be programmed to periodically take data and shut itself off while not taking data. The microcontroller manages the acoustic current meter measurements. It also collects information from a 3-axis solid state compass which measures the Earth's magnetic field, and a 2-axis solid state accelerometer which is used to measure the instrument's angle to the vertical. Using the compass and the accelerometer we can estimate the heading of the instrument, and consequently the current flow direction in Earth-coordinates. The microcontroller also collects sea temperature information from a solid state thermometer, and takes care of logging the sampled data into nonvolatile flash memory.

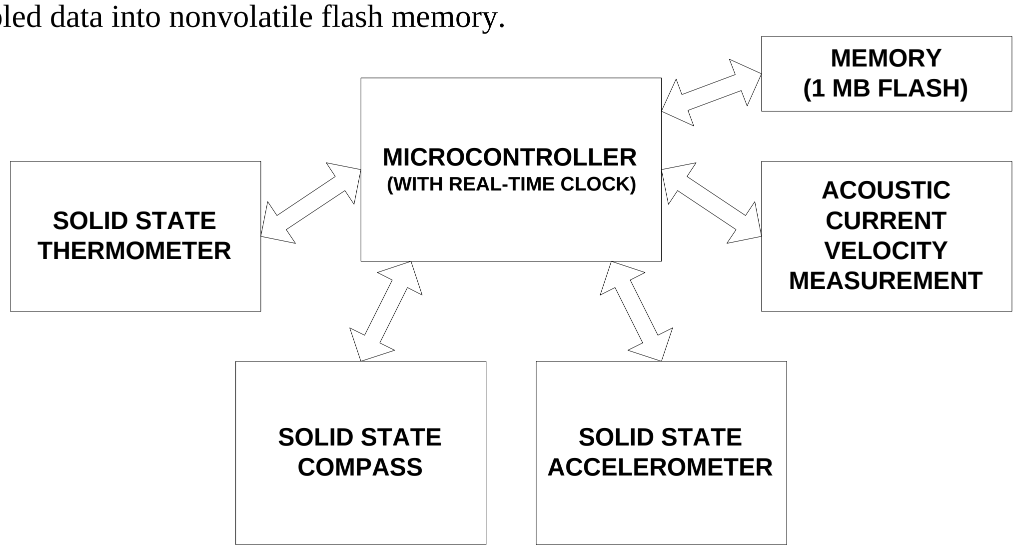

Figure 5 *2D-ACM hardware outline*

Solid state compasses and accelerometers used in the 2D-ACM are surface mount components with small form factors. Furthermore, the 2D-ACM uses surface mount components almost exclusively. This reduces the overall size of the instrument: the 2D-ACM measures 12.1 cm in diameter, 57.4 cm in length, and weighs approximately 3.5 kg. Another result of this approach is that the instrument uses approximately 10 mA while it is taking data.

The 2D-ACM was designed to satisfy users who require high accuracy measurements of variables with wide dynamic ranges. Let us first look at current measurements. The accuracy of the current measurement is ±2% of reading (up to ±1 cm/sec), while the dynamic range of the measured flow is ±600 cm/sec. Note that this dynamic range is double the range of the 3D-ACM. The accuracy of the directional measurement is specified to be ±2°. This allows for high accuracy estimation of actual current flow direction. The temperature readings are accurate to within ±0.5°C. The instrument has a fixed sampling rate of 2 Hz, while the duration of vector averaging intervals can be programmed by the user.

Conclusion

The acoustic current measurement technique invented by Neil Brown, and described in this article, is used in three instruments by Falmouth Scientific Inc. Two of these instruments, the 3D-ACM and the 3D-ACM Wave, are successfully being used in the field. The latest development, the 2D-ACM, is a two-dimensional current meter. It promises to improve the ability of users to acquire high accuracy current data by reducing the price of performing such measurements, while not sacrificing their accuracy. The new instrument consumes around 10 mA while taking data. This allows it to operate continuously for approximately 60 days. If the instrument is programmed to periodically take data and shut itself off while not taking data, it can operate and for up to two years.

Bibliography

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