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Wayfinder DVL

Verifying Performance, Integration of DVL for Small ROVs, AUVs

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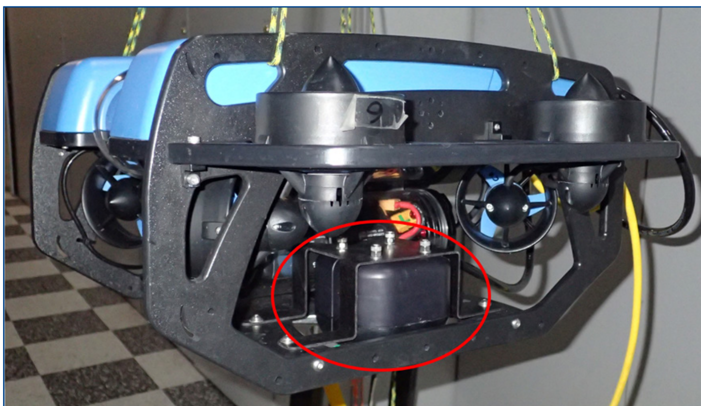
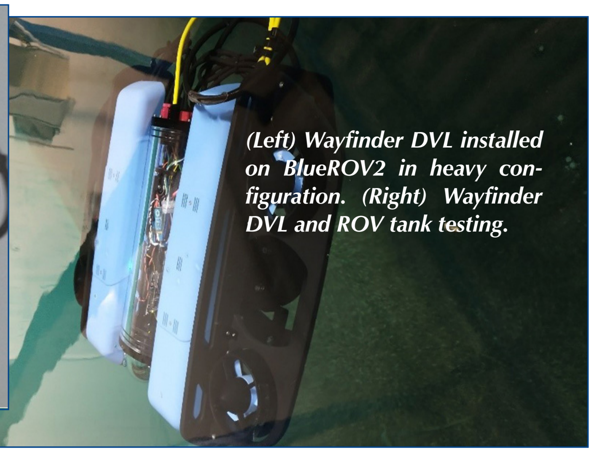

(Left) Wayfinder DVL installed on BlueROV2 in heavy configuration. (Right) Wayfinder DVL and ROV tank testing.

Teledyne RDI (TRDI) has been manufacturing high-quality Doppler velocity logs (DVLs) for over 25 years. Thousands of these DVLs are on ROVs and AUVs, including Hydroid REMUS, Teledyne Gavia SeaRaptor, Kongsberg HUGIN, Bluefin Knifefish, ISE Explorer and SOC Autosub, to help provide both positioning and navigation.

On larger vehicles, which have been using DVLs for years, tightly controlled autonomous functions such as station-keeping (holding position) are possible using the high-resolution velocity-over-bottom feedback from the DVL. In many vehicles, the DVL also provides navigation (location) using dead reckoning. The DVL is combined with accurate heading, attitude and inertial sensors to achieve very high location accuracy over long underwater deployments.

Like larger vehicles, the newest classes of small ROVs and AUVs have a much easier time doing their job if they (and their operators) know where they are and can control their motion well. Wayfinder is Teledyne RDI's smallest DVL to date (at 10-by-10-by-7 cm), and it provides the fast, high-quality velocity measurement needed to keep small vehicles on track. Wayfinder uses a 600-kHz phased-array transducer to create four acoustic beams that together provide 3D vehicle velocity and altitude over bottom. Its new Proteus electronics platform provides high-performance in a small package, and it uses proven bottom-tracking algorithms developed and improved over several decades.

For less advanced users, the Wayfinder DVL needed to be easier to integrate onto vehicles, so user interface and integration utilities were developed and included. The DVL comes with Wayfinder Tools, a Python-based GUI that provides all the necessary utilities. It also comes with a Python open-source driver intended to run on vehicle platforms to handle setup, commands, data extraction and other interactions.

This article will cover the verification of the Wayfinder DVL performance and ability to integrate on a vehicle.

Performance

The core functionality of a DVL is its ability to measure velocity over the bottom reliably and accurately. This performance is verified during testing in a few major categories: velocity accuracy, zero-velocity performance, single-ping standard deviation and dynamic range tracking.

Wayfinder DVL.

Wayfinder DVL specifications.

Parameter	Value	Units
Size	10 x 10 x 7	cm
Accuracy (offset)	± 1.15% (±0.1)	cm/s
Single-ping standard deviation	10	mm/s

Accuracy. Scale-factor error is defined as relative error in distance traveled compared to a known reference. This specification is important in navigation solutions, or when accurate velocity is required for control or pilot feedback. These tests are performed via tank accuracy testing versus a known distance traveled, and lake and ocean testing versus GPS. Wayfinder DVL's accuracy, with "base accuracy" enabled, was measured to be within ±1.15 percent as specified.

Accuracy Offset. Bias offset (zero-velocity error) is defined as the velocities measured when the unit is not moving. This is important for positioning, with the DVL providing the vehicle control system with high-resolution, real-time velocity over bottom at or near zero velocity so that it can stay on location. Additionally, in navigation applications where a vehicle stays still often or for long periods, the accuracy offset can add significant error to the overall position.

The test is performed by taking DVL measurements at multiple locations at different altitudes while completely stationary in a large test tank. Accuracy offset was measured to be within ±1 mm/sec in the test tank (but was 0 in greater than 90 percent of samples).

Single-Ping Standard Deviation. This is the standard deviation of the bottom velocity measurement for a given velocity over bottom. This varies somewhat with altitude and velocity. The standard deviation was measured to be 10 mm/s at a velocity of 1.5 m/s.

Dynamic Range Tracking. Dynamic range tracking is a series of tests where the DVL is exposed to increasing and decreasing altitude, tilted mounting and sloping bottom in simulated and real-world situations. The tests are used to verify that the DVL can detect and track the bottom in dynamic and non-ideal situations, and that the algorithms that filter bad data and/or provide partial (three-beam solution) velocities are working properly. These tests are used to tune the algorithm during development and to verify that Wayfinder bottom tracking meets the high expectations established by TRDI's existing DVL products.

Vehicle Integration

As mentioned earlier, DVLs are commonly integrated on ROVs and AUVs to aid in positioning and navigation. Thus, demonstrating the ease with which Wayfinder DVL can be integrated with a vehicle is critical to enabling a new set of users to do custom integrations. Since the target application is small underwater vehicles, we opted to demonstrate this integration on the Blue Robotics BlueROV2.

The Blue Robotics BlueROV2 is a low-cost ROV aimed at the inspection and research communities. In its base configuration, it provides 5° of freedom (three axes of lateral movement, plus roll and yaw) with 100-m depth rating. However, in order to successfully integrate the Wayfinder DVL, the full 6° of freedom was required for proper control, so the Blue Robotics heavy configuration retrofit was added.

This ROV is controlled by an onboard Pixhawk flight controller running ArduSub firmware, paired with a single-board Linux companion computer (Raspberry Pi). The onboard flight controller is responsible for all the sensor fusion and low-level motor controls, while the companion computer is responsible for providing high-level communications between the flight controller, external sensors and the topside control station.

As an ROV, the BlueROV2 is connected to the surface via tether. On the BlueROV2, this provides Ethernet connectivity between the companion computer and the topside control station. On the topside control station, the end-user can interface with the flight controller using mission control software such as QGroundControl.

Integration Architecture. The BlueROV2 is a modular ROV that can be configured to meet a wide variety of mission profiles, and it provides several modular interfaces to which Wayfinder DVL can be attached. In the heavy configuration, there is available space immediately to the left and right of the battery container. Placing the DVL in these locations is ideal, as the ROV frame protects the DVL from accidental impacts, while still providing it with enough clearance for the transducer face to see the seafloor.

The BlueROV2 also provides several penetrator positions in the rear endcap on the electronics container. These allow the Wayfinder DVL cable to be potted into a cable penetrator and easily installed onto the rear endcap. From there, the DVL cable splits into two sets of wires: power and communications. The power wires attach to the BlueROV2-provided screw terminal block within the electronics housing that distributes raw battery voltage (14 to 17 V). The communications wires are soldered to a USB-to-RS232 adapter (FTDI USB-RS232), which plugs into the Raspberry Pi.

Integration Script. In order to integrate with the BlueROV2, the Pixhawk flight controller needs to be provided with the velocity data from the Wayfinder DVL. The visual odometry capability in the ArduSub firmware was leveraged for this purpose. Visual odometry sensors measure the translational and rotational velocities of a vehicle by measuring the change of speed at which an image is taken from a camera fixed on the vehicle. A DVL does

"DVLs are commonly integrated on ROVs and AUVs to aid in positioning and navigation."

essentially the same thing, providing the translational velocities. The rotational velocity can then be provided by another sensor to provide the full translational and rotational velocities desired by the visual odometry libraries.

Interfacing with the Wayfinder DVL is significantly simpler than in previous Teledyne RDI DVLs due to the availability of the Python driver, as well as the binary structure of the data stream. The Python driver provides a callback function with updated velocity and beam range data every time the Wayfinder has completed a ping. The velocity data are then transformed from the instrument coordinate frame to the vehicle coordinate frame, then fed into the Pixhawk flight controller as visual odometry inputs.

Integration Testing and Performance, Tuning. In order to leverage the improvements afforded by integrating a DVL, the baseline vehicle performance must be very tight. Station-keeping using DVL inputs requires that the vehicle be able to react to and precisely counter small velocities and perturbations to reliably hit the programmed setpoint. This is accomplished by a pose controller for rotational stability.

Once the vehicle is reliably stable, the position-hold control loops can be tuned. The ArduSub firmware has a three-layered position control loop: position-controlling velocity, velocity-controlling acceleration and acceleration-controlling motor setpoint. These need to be individually tuned to ensure maximum performance. This is commonly done starting from the acceleration loop, which ensures that the vehicle can utilize the full extent of its performance envelope.

Station-Keeping Performance. To test the performance of the position-hold controller, the vehicle was placed in a test tank and allowed to hold its position for several minutes. The position of the vehicle was monitored by placing a plumb bob just above a known position on the hull of the vehicle. During testing, the vehicle exhibited the expected performance.

Tests verifying the ability of the position-hold controller to react to external perturbations were also performed. The vehicle was placed in a larger test tank, then pushed and pulled using poles and the tether. The vehicle returned to its original orientation and position quickly and reliably.

Notes on Waypoint Navigation. A further extension of position-hold in ArduSub is waypoint navigation. In ArduSub, position-hold is implemented by having the vehicle attempt to hold at a global setpoint. This setpoint can then be moved around to move the vehicle to a new position. Waypoint navigation is then simply setting the setpoint to the next waypoint.

This was not possible in the test tank due to structural steel members affecting the compass on the vehicle. Tests at Miramar Lake showed that the vehicle can roughly follow a waypoint mission; however, it was unable to accurately perform turns, most likely again due to the compass being buried inside the vehicle near the motor controllers. This functionality has not been fully vetted by ArduSub developers and can be resolved by future end-users.

Conclusion

The goal of the Wayfinder project was to provide a small, high-performance DVL that could easily be integrated into small ROV, and eventually AUV, platforms. By leveraging a new small electronics platform, an updated transducer design and proven bottom-tracking algorithms, the Wayfinder DVL was able to achieve the performance and reliability targets. To prove the ease of integration, the first integration was performed in house, using the new tools provided. The Wayfinder DVL has been put through its paces by a team who knows DVLs and integration. With many upgrades already in the works, this is only the beginning. Find out more at: https://teledynerdi.myshopify.com. **ST**

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