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Mind the Gap! Forward-Looking Sonar Fills in Missing Data From Nadir 'Holiday'

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Combining Forward-Look and Side Scan Imagery Provides 100 Percent Coverage, Saving Time in a Post-Tsunami Survey of Hawaii

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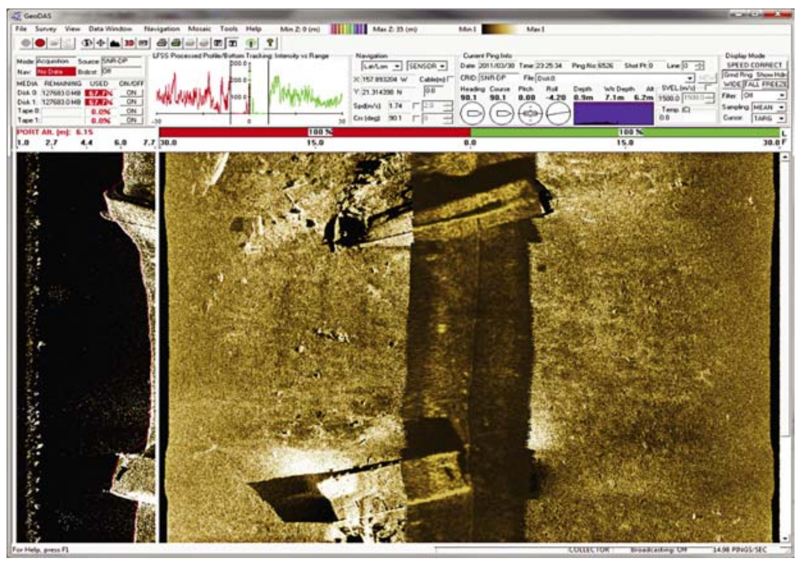
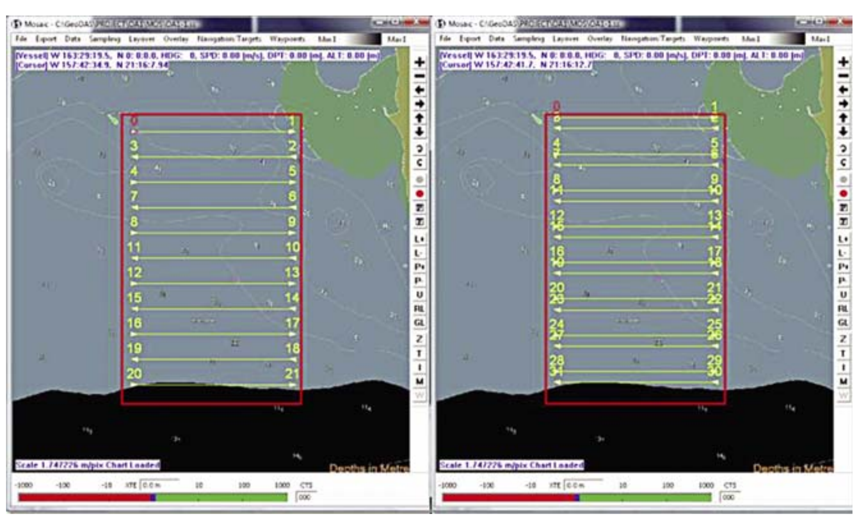
Significant progress has been made in the field of seafloor mapping since the era of lead lining and calling out "by the mark, twain!" Echosounders, multibeam and side scan sonars have made the job of mapping the seabed easier. As the name implies, side scan sonar systems produce narrow beams of acoustic imagery out to the side of the sensor. We tend to think of each "ping" of the sonar as illuminating, in a camera-like fashion, a swath of the seabed beneath the sonar. The reality is that coverage is a complex function of the beam pattern, the seabed geometry and the material properties. The results are often less than ideal.

It's no secret that the coverage and quality of data at nadir is generally poor. The side scan sonar's transducer mount angles, combined with each transducer's unique beam pattern, will dictate whether or not the seafloor at nadir is actually ensonified. If transducers are pointed downward, rather than sideways, it is possible to obtain acoustic returns from directly below the sensor. However, due to the vertical angle of incidence, acoustic shadows cannot be generated for near-nadir data, making object detection nearly impossible. Knowing this, surveyors will often choose to mount transducers to project more horizontally. Doing so will effectively expand the maximum range of usable data but will more often than not generate a gap in data coverage at nadir—a "holiday."



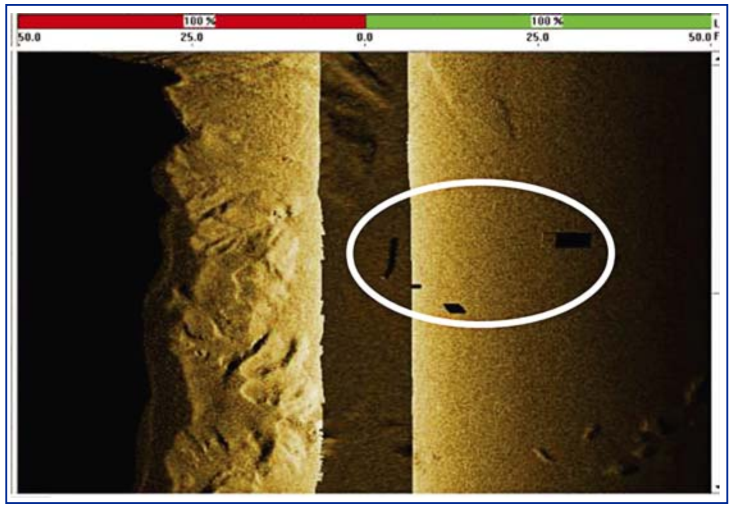
(Above) A typical result of merging forward-look data from BlueView's P450-45 2D imaging sonar with data from Falmouth Scientific's HMS-1400 side scan sonar. Shown here is a submerged dock and an overturned sailboat.

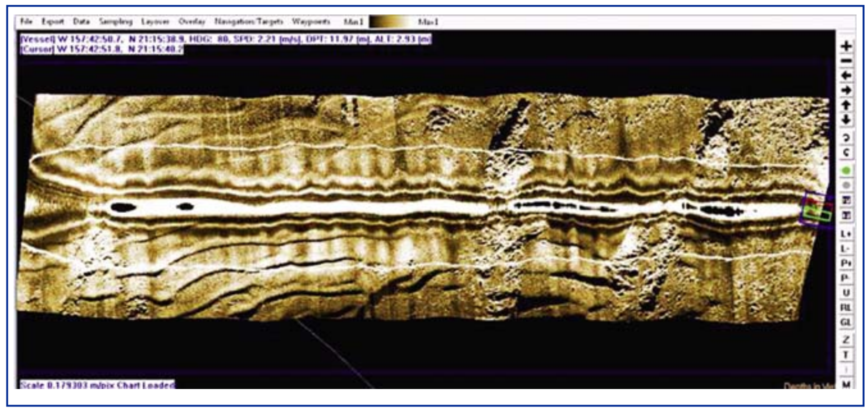


(Right) An overhead view showing an ideal survey pattern on the left, with uniformly spaced lines, compared to the gap-filling "15/45" survey pattern on the right. Note that the ideal survey pattern requires 11 track lines to complete the survey, whereas the 15/45 line pattern requires 16 track lines.

To compensate for this gap at nadir, the surveyor is required to run extra track lines in order to achieve full coverage of the survey area. A typical survey line plan is called the "15/45" pattern, in which spacing of adjacent survey lines alternates between 15 and 45 meters.

With the sonar at a range setting of 30 meters, lines could ideally be run at 45-meter line spacing, ensuring good overlap and rapid coverage. But because of the nadir gap, a different strategy is adopted. The first pair of lines are run with only a 15-meter line spacing, with the good data from the second pass filling the nadir gap of the first line, and the good data from the first line filling the nadir gap of the second line. The third line is then run at the usual 45-meter spacing, allowing good overlap, while extending the survey more rapidly. This type of survey plan allows the nadir gap of each line to be filled by data from the narrowly-spaced adjacent pass but increases the time required to cover the area by nearly 50 percent, costing more in acquisition and post-processing.





(Top) GeoDAS waterfall image of merged forward and side-looking imagery over a simulated terrain. Note that the forward-looking data have detected a target, which would have been missed in the nadir gap of the side scan.

(Above) A mosaic showing a typical side scan sonar swath exhibiting poor coverage at nadir.

Bridging the Nadir Gap

While not optimal in terms of survey time, this method of alternating closely spaced lines with widely spaced lines does offer the surveyor 100 percent coverage but at the cost of 50 percent more survey time. One alternative to this approach would be to use the data from a forward-looking sonar as a "gap-filler." Forward-looking sonars can provide imagery ahead of the vehicle and are often used for obstacle avoidance and interactive (man-in-the-loop feedback) navigation.

To test this gap-filling technique, Oceanic Imaging Consultants Inc. (OIC) developed ray-tracing simulators for both a side scan and a forward-looking sonar. With a terrain model and navigation path fed into the simulator, it was possible to test various merging strategies.

As the area covered by the forward-looking sonar corresponds well to the area of the side scan nadir gap, it was proposed to use data from a forward-looking sonar installed ahead of a side scan to fill the side scan nadir gap, thus giving both an alert to possible hazards ahead and eliminating the nadir gap. By eliminating the nadir gap, it's also possible to increase survey efficiency, by guaranteeing that targets at nadir were detected and eliminating the need to waste survey time running "gap-filling" lines.

Challenges in Combining Forward-Look, Side Scan

While using the data from a forward-looking sonar to fill in the nadir gap of a side scan in real-time seems reasonable, several issues make this less than straightforward. First, the forward-looking data are ahead of the side scan data and must be "delayed" in order to fill the gap. Second, the forward-looking imagery available to "fill the gap" is highly redundant. While the side scan will only image a target once as it passes, a forward-looking sonar will image a target along its path multiple times at different incidence angles, resulting in variable representation. Choosing the "best" data with which to fill the gap is nontrivial.

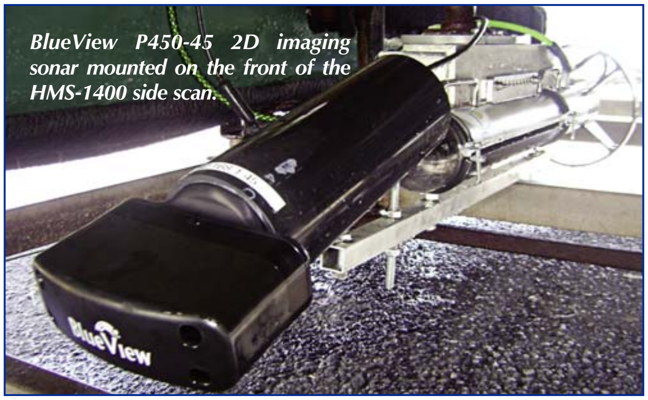
While mosaicking all the forward-looking data would definitely fill the gap, it would also result in averaging of multiple looks, resulting in degradation of target clarity even with perfect navigation. The approach settled on involves weighting the data from each frame as a function of position in the image and then filling the gap on a ping-by-ping basis from the best available data (the data with the highest weight).

The simulator was connected to a version of OIC's GeoDAS data acquisition software, which was modified to fill the nadir gap of the side scan with automatically chosen forward-looking data. While the shadows from the forward-looking and side-looking sonar are orthogonal, they are equally effective in indicating target presence and position to the operator.

Field Testing the System

For an actual test of forward-looking sonar's ability to effectively fill the nadir gap of a high-frequency side scan sonar, OIC executed a post-tsunami survey of Keehi Lagoon on the south shore of Oahu, Hawaii.

The side scan system utilized was a pole-mounted HMS-1400. The HMS-1400 is an economical, highly portable dual-frequency (400/1,250 kilohertz) digital system from Falmouth Scientific Inc. (Cataumet, Massachusetts). The system delivers excellent imagery in the mid- to outer ranges. However, the narrow system beam pattern, combined with the shallow nadir touchdown angle of the acoustic beam, provides weak



BlueView P450-45 2D imaging sonar mounted on the front of the HMS-1400 side scan.

or no return below the sensor, making it an ideal system for utilization of a forward-looking, gap-filling sonar.

The side scan sonar was modified to accommodate an updated BlueView Technologies Inc. (Seattle, Washington) P450-45 2D imaging sonar. The updated BlueView P450-45 was released this year and features upgraded electronics that improve image quality, range and signal levels. At 450 kilohertz, the P450-45 is an ideal system for gap-filling of a high-frequency side scan. With a 45º-by-15º field of view and expanded max range of 250 meters, the P450-45 provided more-than-adequate coverage of the predicted HMS-1400 nadir gap, as well as an added measure of security in avoiding obstacles.

Field Test Results

Following the March 11 earthquake in Japan, scientists at the Pacific Tsunami Warning Center had detected multiple surges during the tsunami, ranging in size from six to 17 feet in some of the harder hit harbors and coastal areas. Fortunately, no one in Hawaii was injured or killed as a result, but the many surges caused extensive damage to coastal property and infrastructure. On Hawaii's most populous island, Oahu, the destructive impact of the tsunami was confined to docking facilities in Haleiwa on the north shore and the small boat harbor area in Keehi Lagoon on the south shore.

While some boaters took their property out to sea during the tsunami warning, many did not. According to the U.S. Coast Guard, as many as 200 boats were damaged in Keehi Lagoon, and up to a dozen sank after docks broke free of their moorings (with boats still attached) and drifted around the harbor, slamming into other boats, docks and bridges. While unfortunate for the hapless owners, this event did make for a target-rich and challenging survey environment.

The integration of the BlueView P450-45 with the side scan worked admirably in aiding harbor clearance. Dozens of debris patches were mapped, and five missing boats were located, including a 30-foot sloop found upright and rigged on the bottom in the main channel.

The combination of forward-looking and side scan imagery allowed the surveyors to achieve 100 percent coverage without having to run wasteful "gap-filling" lines, thus saving time. This method also provided the added security of forward-looking obstacle avoidance, which was invaluable given the hazardous harbor conditions.

At Keehi Lagoon on the island of Oahu more than 200 boats were damaged, with a large number either being sunk or unaccounted for. (Photo credit: U.S. Coast Guard)

Acknowledgments

The author would like to thank BlueView Technologies for the loan of their P450-45 2D imaging sonar for this work, and Fred Hegg of Falmouth Scientific for the loan of the HMS-1400 side scan. The author would also like to dedicate this article to his mentor, program manager and true friend Vince Vigliotti, who passed away April 25. Fair winds and following seas. ■

Dr. Thomas B. Reed IV received his undergraduate degrees in economic geology from Harvard University and the Massachusetts Institute of Technology in 1982 and his Ph.D. in marine geology and geophysics from the University of Hawaii in 1987. He founded Oceanic Imaging Consultants Inc. in 1993 to answer the growing need for seafloor mapping software, services and systems.