Results from a Small Synthetic Aperture Sonar

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Abstract— **A Synthetic Aperture Sonar (SAS) is capable of producing range-independent high-resolution imagery from an array which is small in length. The ability of these systems to operate at lower frequencies while maintaining high resolution has made them useful for mapping and searching large areas. The US Navy is now focusing on developing SAS systems into a form robust enough for deployment. Here, we will show results from several sea tests and describe one such system known as the Small Synthetic Aperture Minehunter (SSAM).**

I. Introduction

The US Navy through the Office of Naval Research has a history of developing SAS systems for minehunting. Recently their attention has turned to these sonars on autonomous underwater vehicle (AUV) based SAS systems. One such system is SSAM. In order to demonstrate the robustness of this system, SSAM has participated in seven sea tests between April 2005 and July 2006. These locations have included Panama City, FL; Keyport, WA; Buzzard's Bay, MA; La Spezia, Italy; and Jervis Bay, Australia. Approximately 300 km of track have been surveyed in these tests. SSAM has mapped areas with bottoms such as sand, mud, layered sand and mud, rock, posidonia (seagrass), and coral with varying levels of clutter. Throughout these tests SSAM has provided a robust solution for bottom mapping and object detection.

II. System Description

SSAM is a dual frequency band SAS system where the high frequency and low frequency bands have the potential for imaging resolutions of 2.54 cm x 2.54 cm (1 in x 1 in) and 7.62 cm x 7.62 cm (3 in x 3 in), respectively. With its dual frequency bands, the SSAM design provides detection and classification capabilities against proud and shallow buried targets with an area coverage rate of 0.28 square nautical miles per hour. Although SSAM in its current configuration does not have the embedded processing computing power required to perform onboard SAS imaging and automated target detection and classification, some basic data reduction and processing is done using its analog-to-digital conversion (ADC) boards. Each ADC board provides signal conditioning and ADC for eight-channels and was designed with an integrated field programmable gate array (FPGA). In addition to some control and interface functions, the FPGA is programmed to perform filtering, complex demodulation and decimation of the received signals. This provides a reduction in the data rate and subsequent computational load.

A key feature of the transition from early feasibility tests to current SAS systems has been the reduction of vehicle size. SSAM's primary test and operational platform is the REMUS600 AUV designed and built by the Woods Hole Oceanographic Institution. The REMUS600 is a payload reconfigurable 12.75-inch hull diameter AUV with a maximum depth rating of 600 meters on the NSWC-PC variant. The REMUS600 system possesses a variety of subsystems powered by a 4.8 kWh rechargeable lithium ion battery pack that is also used to power the SSAM payload. For positioning and navigation REMUS600 uses measurement estimates from various instruments; a Global Positioning System (GPS) receiver, an RD Instruments Workhorse Navigator Doppler Velocity Log (DVL), a Kearfott T-24 Inertial Measurement Unit (IMU) and a Long Base Line (LBL) acoustic navigation unit. While REMUS600 is on the surface, GPS information is used for positioning and IMU alignment. When submerged, the instrumentation provides REMUS600 with three modes of navigation: long base line transponder navigation, acoustic homing to a transponder and dead reckoning using the Kearfotts IMU data and velocity estimates from the DVL. SSAM uses forward and aft fins to improve the stability of the vehicle and to provide crab angle control in the harsh conditions found in shallow water. As the sonar platform has changed from towed platforms to 21-inch AUVs to 12.75-inch AUVs, unwanted platform motion has increased. However, the forward fins of the REMUS600 provide good stability for a system of this size.

Real-time SAS processing has been an interest at NSWC-PC for several years [1], [2]. In the past, this was accomplished using a large number of DSP boards placed either in a conventional rack or in a section mounted on a towbody. This system has not been used since the transition to autonomous underwater vehicles. SSAM is scheduled to receive embedded real time processing within the next year. This system will not be based on DSP boards, but instead on eight Pentium M class chips. The current SAS processing code, which is developed in MATLAB, is being ported to C in order to optimize its performance. This C code runs as a network distributed application over an arbitrary number of heterogeneous nodes. This allows for the processing solution to be easily scaled for embedded or off-line processing of a host of systems.

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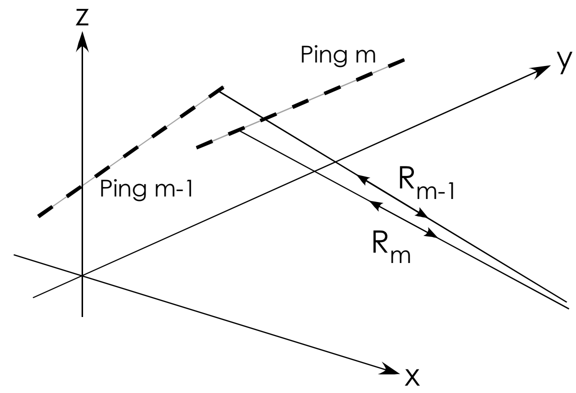
III. MOTION ESTIMATION

For any synthetic aperture imaging system, the array should translate along a path which is perfectly straight to within a fraction of a wavelength. This is not possible in a dynamic littoral environment, so the unwanted vehicle motions must be estimated and compensated. For SSAM this is accomplished by combining redundant phase center motion estimation and onboard vehicle navigation [3].

SSAM has eight receive elements, and for typical operation two of those are overlapped leaving six for imaging. It is possible to estimate the array rotation from the differential delay between channels [4]; however, a single pair of overlapping elements provides only a single estimate of yaw. This is not sufficient to provide a robust yaw estimate. Consequently, the IMU is used to provide an estimate of the angular motion of the vehicle. Using these estimates the measured delays from the redundant phase center elements are then reduced to sway estimates. Schematically this is shown in Fig. 1. In Fig. 1(a), the array is shown on two successive pings where the unwanted motion consists of both yaw and sway. By using angular estimates from the IMU the yaw is compensated producing the orientation in Fig. 1(b). The redundant phase center estimates are then used to account for and compensate the residual sway. After these two steps the data are ready for beamforming.



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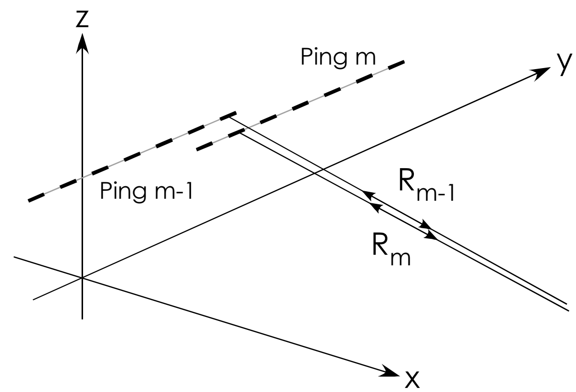


(b)

Fig. 1. The motion estimation and compensation routine used for SSAM combines angular estimates from the vehicle IMU and sway estimates from redundant phase centers. In 1(a), the array is both yawed and swayed. Using the IMU estimates we correct the array to 1(b) and then apply a sway correction based on redundant phase center delays.

IV. RESULTS

In the past eighteen months SSAM has participated in seven sea tests around the world. In the course of these tests, SSAM has surveyed nearly 300 km (180 mi) of sonar track covering approximately 31 km^2 (12 mi^2). The system has proven to be a reliable and robust platform for collection of high resolution imagery of the sea floor. Below are details of the recent tests of SSAM.

A. San Diego, CA (SMCM UUV Phase VII, April 2005)

In April of 2005 SSAM tested in the Pacific Ocean off the coast of San Diego to demonstrate the future capability of autonomous underwater vehicle borne SAS. This test served as an initial shakedown for the newly integrated payload and vehicle. The environment in which SSAM operated was moderately difficult due to the large amount of flora and fauna in the area. In Fig. 2 some of these difficulties are apparent. A large fish school is at 25 m along track and 15 m range. Additionally, in the water column through 10 m range it appears that there may be kelp present.

B. Buzzards Bay, MA (May 2005)

Buzzards Bay, Massachusetts, near Woods Hole Oceanographic Institution (WHOI), features a generally flat bottom with some clutter including rocks and lobster pots. One interesting image of a SB2C Helldiver, which crashed in 1947, is shown in Fig. 6. A great deal of detail is visible in the spars and ribs of the starboard wing.

C. Keyport, WA (AUVFEST2005, June 2005)

AUVFEST2005 was held in Keyport, Washington. The goal of this test was to provide a major in-water demonstration of unmanned and autonomous under water vehicles and related technologies. SSAM was invited to demonstrate the acquisition of high resolution imagery from an autonomous underwater vehicle. The majority of the fields in which SSAM operated were fairly benign with respect to the environmental conditions (current, sea state, bottom type). The exception was Hood Canal. This area was typified by high currents induced by tidal changes and bathymetry. This is the first time SSAM operated in an area with significant topographical variation. An example image from this test is shown in Fig. 5.

D. Panama City, FL (September 2005 and April 2006)

The testing areas in Panama City, Florida are generally low clutter with either smooth or rippled sandy bottoms. This is nearly ideal for testing SAS because of the high reflectivity of the bottom. Recently, some test areas have changed significantly due to hurricane activity in the area. A test conducted in September 2005 following hurricanes Dennis and Katrina found severe disruptions in target fields planted only a few months before. The original fields consisted of smooth bottoms and coarse sand. The hurricanes produced a long wavelength ripple as well as some ridging exposing both mixed and layered mud and sand. In Fig. 3(b), the variation in reflectivity is due to changes in the composition of the bottom that is most likely layered mud and sand.

While testing off the coast of Panama City in April 2006, a large area of exposed coral was found. An example of this area is shown in Fig. 4 where both the upper and lower bands of SSAM have strong returns from the coral and relatively low returns from the surrounding sand.

E. La Spezia, Italy (MX3 Trial, November 2005)

In the MX3 trials, SSAM operated in three different fields. The first was in the Gulf of La Spezia adjacent to the Nato Undersea Research Center. This field has a muddy flat bottom with a large amount of clutter. The reduced SNR of the returns used for motion estimation degraded the overall image quality for this area. The second field surveyed consisted mainly of smooth and rippled sand and was very similar to conditions in Panama City. The final field in this area was the most interesting with mixed sand, mud and posidonia. The presence of the seagrass was expected to hamper motion estimation, but this turned out not to be true. In Fig 7(a), a large area of rippled sand is surrounded by a thick coat of seagrass. It is interesting that the surface of the seagrass is well focused.

F. Jervis Bay, Australia, July 2006

In July 2006, SSAM participated in a joint exercise with the Australian Navy. The purpose of this exercise was to demonstrate the robustness of the REMUS600 platform for minehunting with a SAS payload. The facilities provided by HMAS Creswell permitted deployment of the vehicle in seas states ranging from one to five with water depths ranging from fifteen to twenty meters. The extreme sea states combined with shallow water produced a large amount of unwanted vehicle motion. The bottom in Jervis Bay consists of a mix of mud, sand and rock. Fig 8, shows an area typical of Jervis Bay.

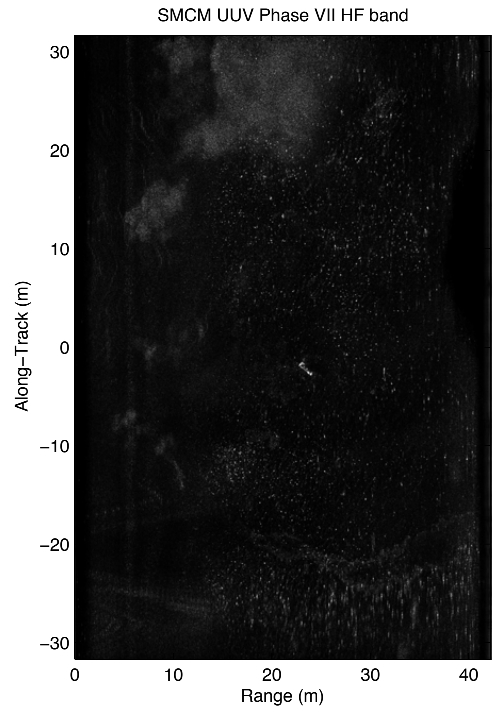
REFERENCES

[1] G. S. Sammelmann, J. E. Fernandez, and J. T. Christoff, “High frequency/low frequency synthetic aperture sonar,” in *SPIE*, 1997.

[2] R. W. Sheriff, T. C. Montgomery, J. E. Fernandez, and J. T. Christoff, “High resolution synthetic aperture sonar,” in *UUV Showcase 98 Conference*, 1998.

[3] D. A. Cook, J. S. Stroud, J. E. Fernandez, and J. D. Lathrop, “Results from a hybrid synthetic aperture sonar motion estimation scheme,” in *Oceans 2005*, June 2005.

[4] A. Bellettini and M. A. Pinto, “Theoretical accuracy of synthetic aperture sonar micronavigation using a displaced phase centre antenna,” *IEEE J. Oceanic Engineering*, vol. 27, no. 4, pp. 780–789, October 2002.



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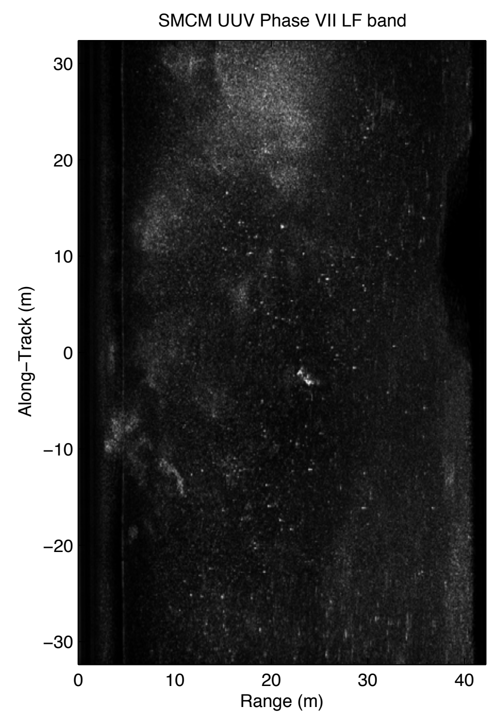
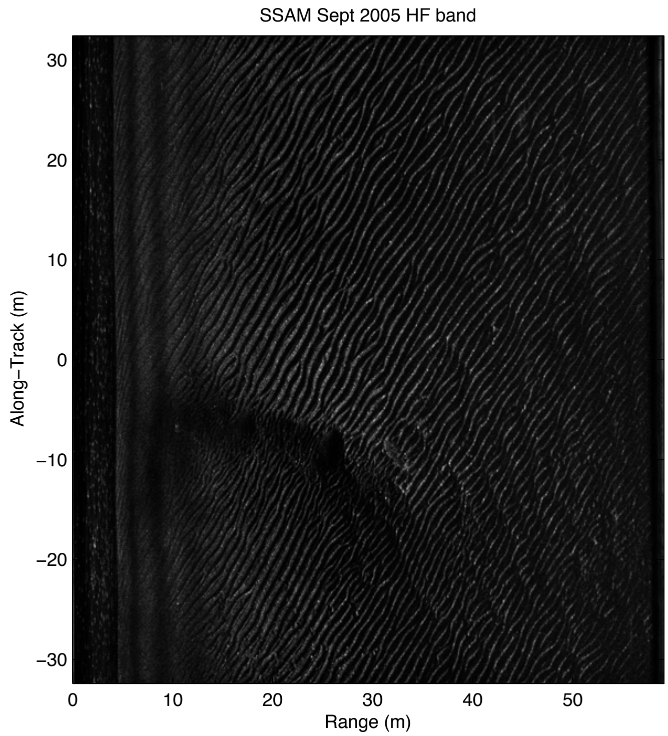


(b)

Fig. 2. A cylindrical object off the coast of San Diego. Notice the large area of low contrast at 15 m range and 25 m along track caused by a school of fish. This scene also shows an interesting pattern at -10 m along track most likely due to vegetation such as kelp.



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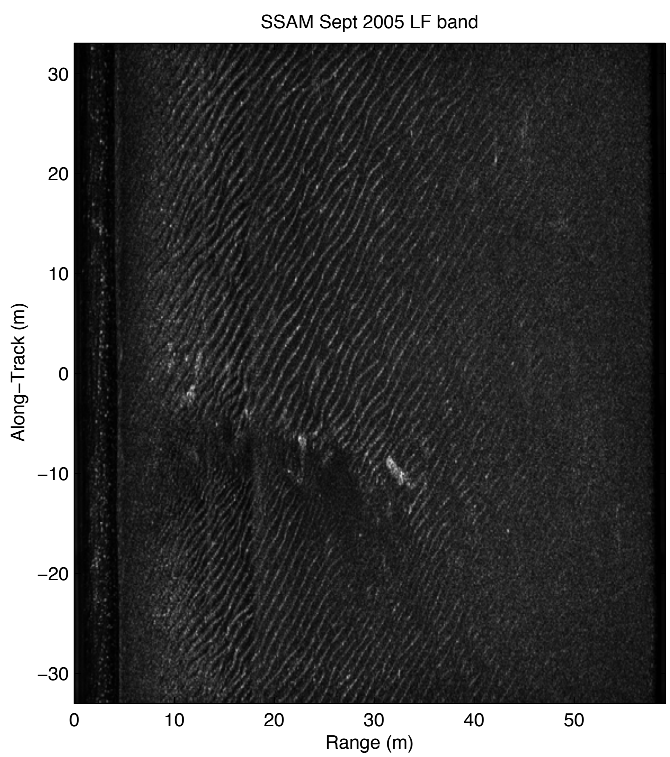
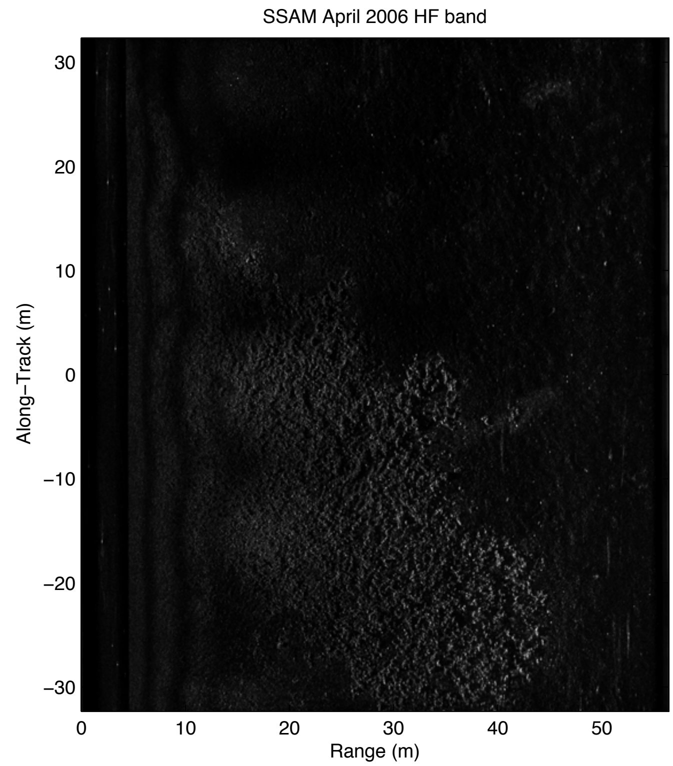


(b)

Fig. 3. Rippled sand and layed mud and sand from the Panama City, Florida Whiskey field



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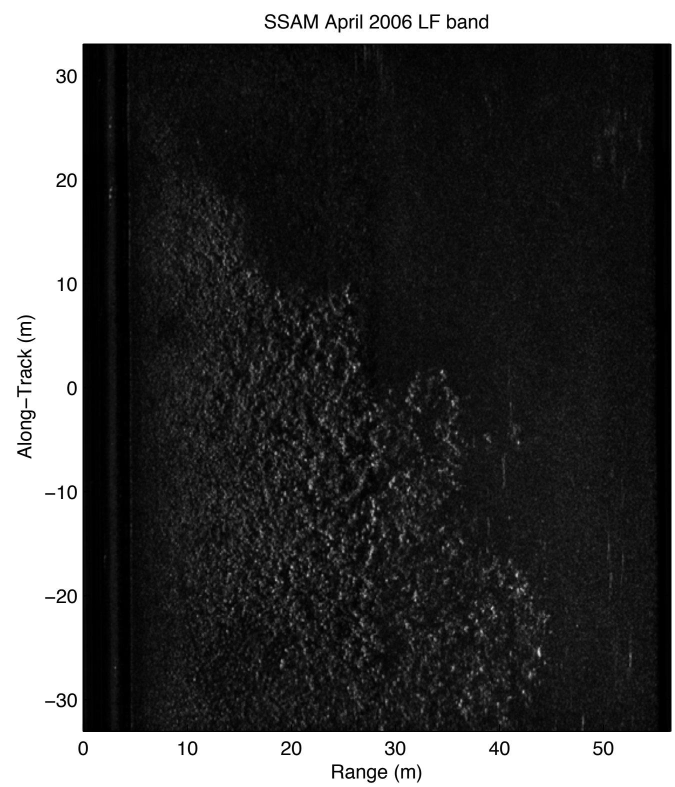

(b)

Fig. 4. Exposed coral from the Panama City, Florida Bravo field.

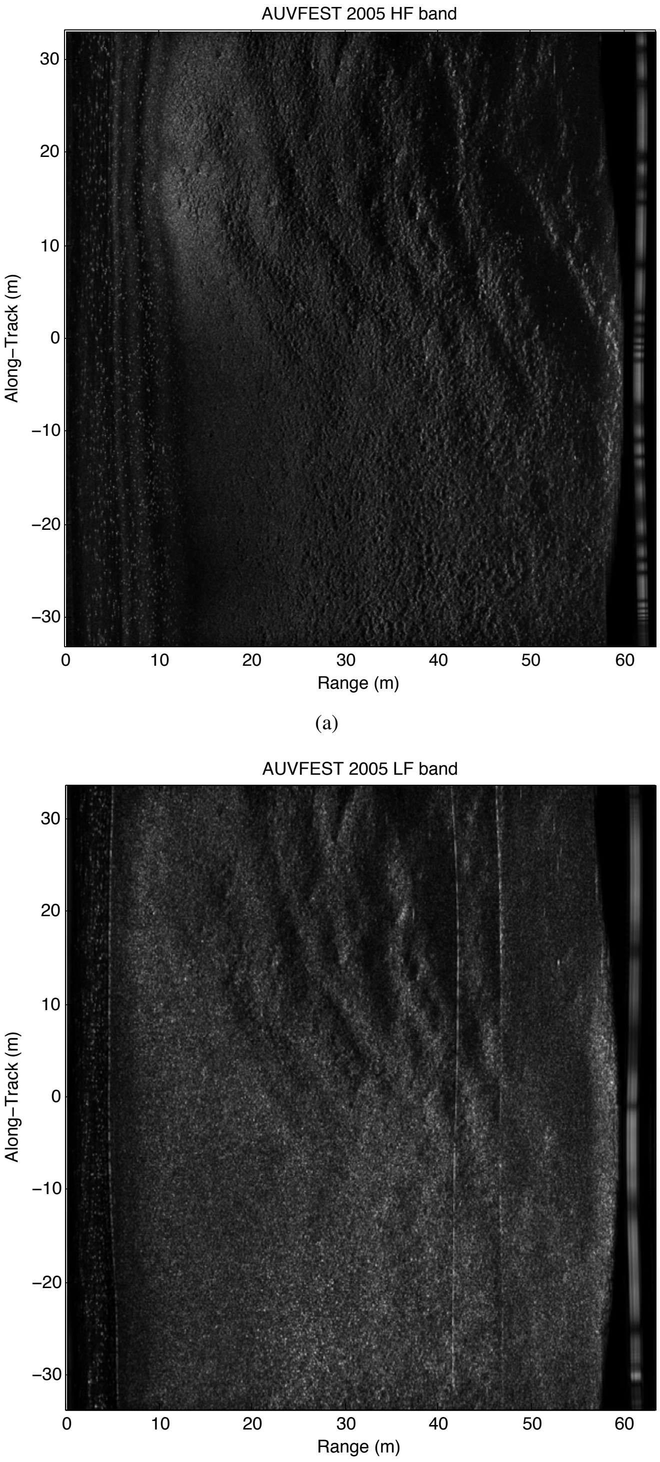

Fig. 5. Bathymetry variation in Hood Canal from AUVFEST2005.

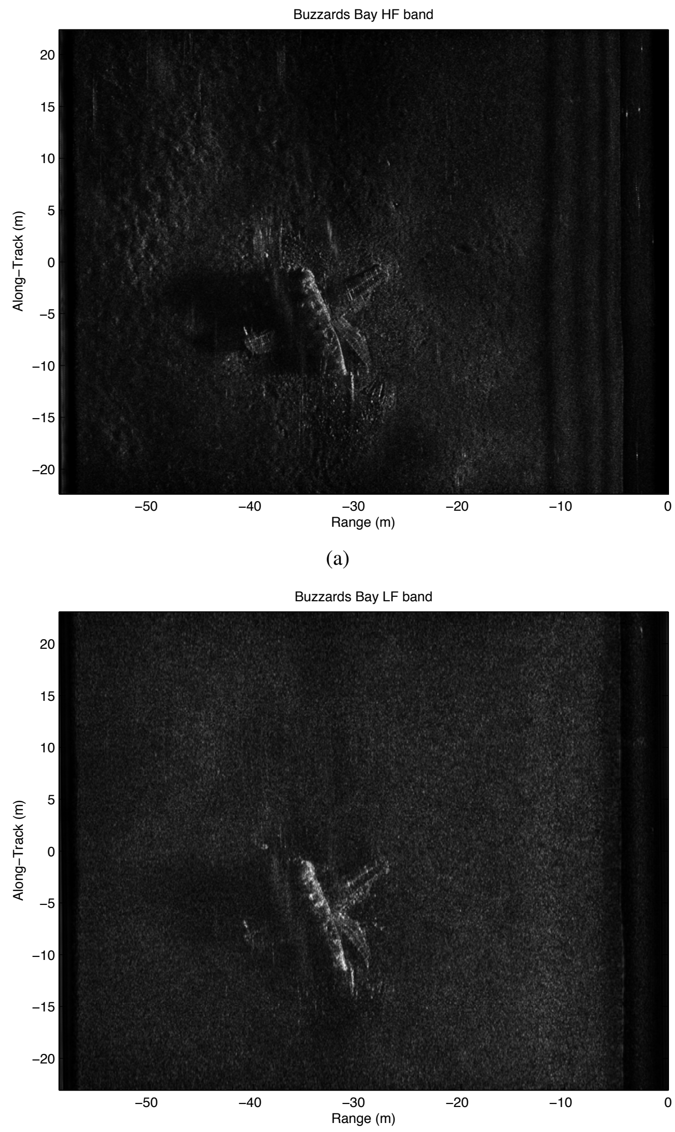

Fig. 6. SB2C Helldiver in Buzzards Bay, Massachusetts.

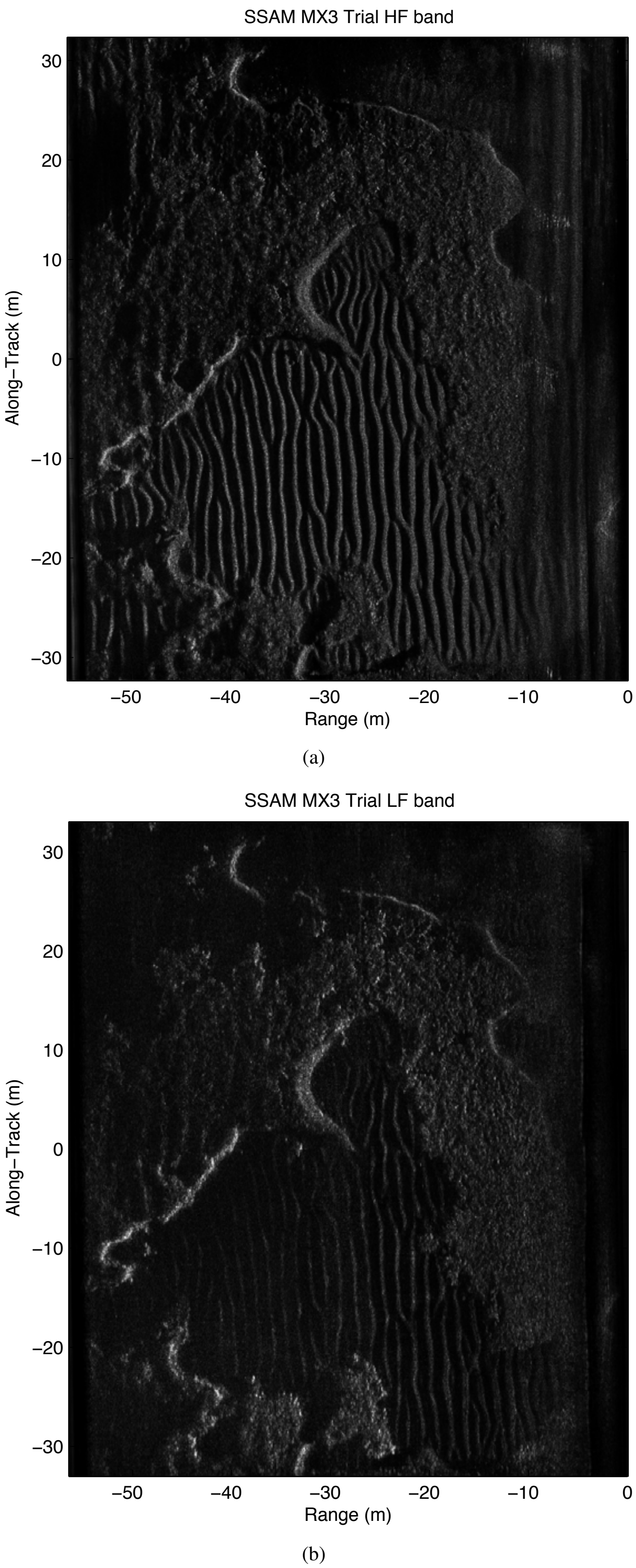

Fig. 7. Mixed posidonia, sand and mud from the Ligurian Sea

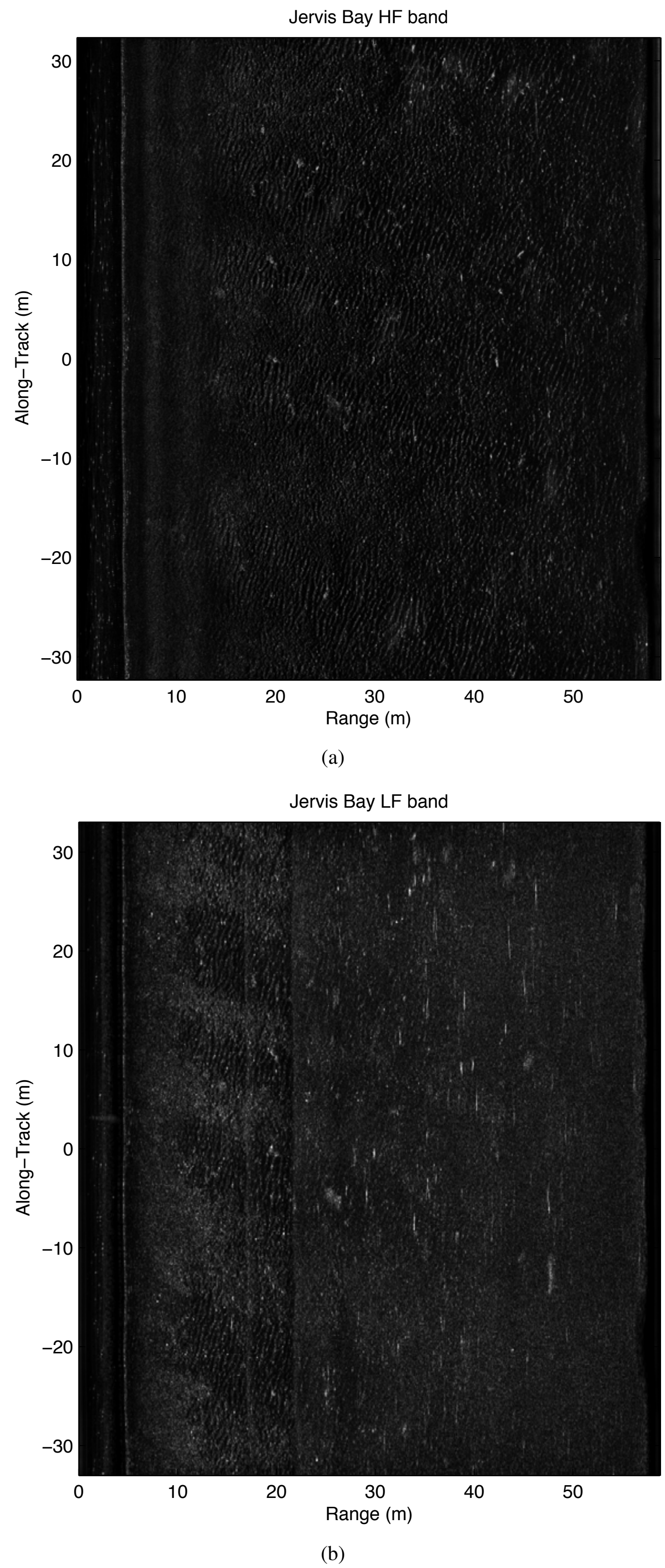

Fig. 8. Mixed sand and rock in Jervis Bay, Australia