

Chapter 1.—EAARL: An Airborne LiDAR System for Mapping Coastal and Riverine Environments

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Abstract

LiDAR, an acronym for Light Detection and Ranging, is an active remote sensing technique that determines the distance between the sensor and the target by accurately measuring the round-trip time of a pulse of laser energy (Wehr and Lohr, 1999). The Experimental Advanced Airborne Research Lidar (EAARL) is an airborne LiDAR system that provides unique capabilities to survey coral reefs, nearshore benthic habitats, coastal vegetation, and sandy beaches (Wright and Brock, 2002). Operating in the blue-green portion of the electromagnetic spectrum, the EAARL is specifically

designed to measure submerged topography and adjacent coastal land altitudes in a single scan of transmitted laser pulses (fig. 1). Four main features separate the EAARL from traditional airborne bathymetric LiDAR: (1) a relatively short (1.3 ns) laser pulse, (2) a radically narrowed receiver field-of-view (FOV)(1.5–2 mrad), (3) digitized signal temporal backscatter amplitude waveforms, and (4) software as opposed to hardware implementation of real-time signal-processing elements. The short pulse and narrow FOV are beneficial in coastal environments to determine bare-Earth topography under short vegetation, as well as in riverine environments where large changes in topography occur over a very small area. The small receiver FOV rejects ambient light and

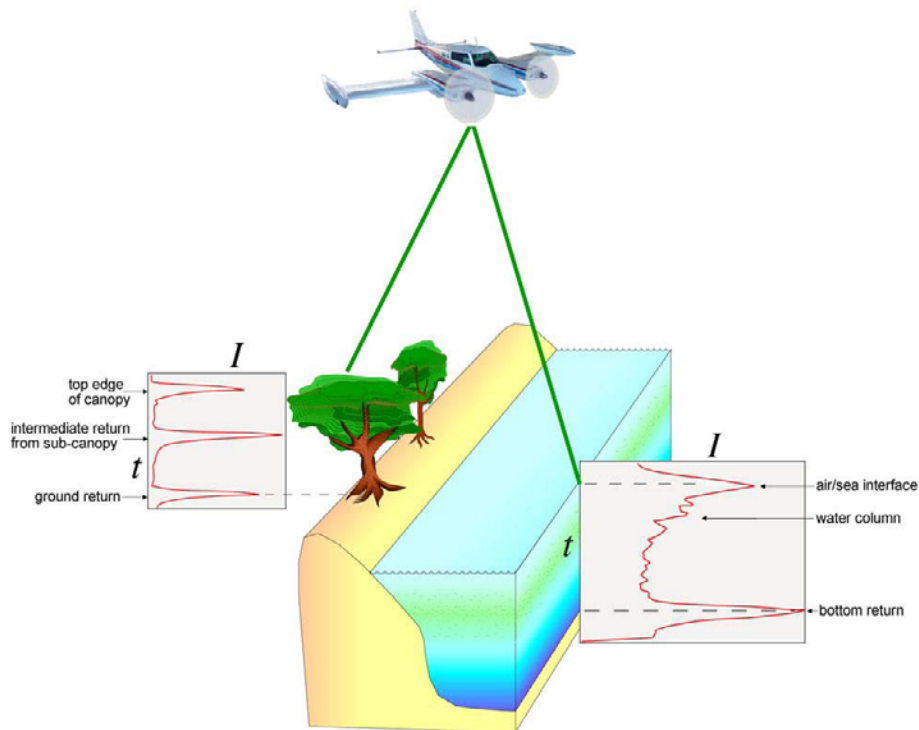


Figure 1. The EAARL system senses and records LiDAR backscatter returned to the sensor (I) in a series of equal time intervals (t) at 1 nanosecond resolution, thereby enabling the seamless characterization of sub-aerial and submerged topography.

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multiplies scattered photons from the water column and bottom-reflected backscatter (Feygels et al., 2003), thereby ensuring relatively high contrast and short duration of the bottom return signal. The EAARL system can accommodate a large signal dynamic range, thereby making it suited to mapping topography over a variety of reflective surfaces in the coastal zone, ranging from bright sand to dark submerged sea-bottom.

EAARL uses a very low-power, eye-safe laser pulse, in comparison to a traditional bathymetric LiDAR system that allows for a much higher pulse-repetition frequency (PRF) and significantly less laser energy per pulse (approximately 1/70th) than do most bathymetric LiDARs. The laser transmitter produces up to 10,000 short-duration (1.3 ns), low-power (70 μ J), 532-nm-wavelength pulses each second. The energy of each laser pulse is focused in an area roughly 20 cm in diameter when operating at a 300-m altitude. Based on test flights over typical Caribbean coral reef environments, EAARL has demonstrated penetration to greater than 25 m, and can routinely map coral reefs ranging in depth from 0.5 to 20 m below the water surface.

The EAARL system uses a “digitizer only” design, which eliminates all hardware-based high-speed front-end electronics, start/stop detectors, time-interval units, range gates, etc., typically found in LiDAR systems. The EAARL system instead uses an array of four high-speed waveform digitizers connected to an array of four sub-nanosecond photo-detectors. Real-time software is used to implement the system functions normally done in hardware. Each photo-detector receives a fraction of the returning laser backscattered photons. The most sensitive channel receives 90% of the photons, the least sensitive receives 0.9%, and the middle channel receives 9%. The fourth channel is available for either water Raman or 1064-nm infrared backscatter depending on the application. All four channels are digitized synchronously with digitization beginning a few nanoseconds before the laser is triggered and ending as long as 16,000 ns later. A small portion of the outgoing laser pulse is sampled by fiber optic and injected in front of one of the photo-detectors to capture the actual shape, timing, and amplitude of the laser pulse shortly after it is generated. The backscattered laser energy for each laser pulse is digitized into 65,536 samples, resulting in more than 150 million digital measurements being taken every second. The resulting waveforms are partially analyzed in real time to locate the key features such as the digitized transmit pulse, the first return, and the last return. The real-time waveform processor automatically adapts to each laser return waveform and retains only the relevant portions of the waveform for recording. Thus, the storage space required for returns from tall trees or deep water is more than the

storage requirement for beach or shallow water backscatter. In addition to the LiDAR, the EAARL sensor suite includes a digital three-band color infrared camera, a red-green-blue (RGB) digital camera, a dynamically tuned Inertial Measurement Unit (IMU), and precision kinematic Global Positioning System (GPS) receivers that together provide for sub-meter geo-referencing of each laser and photographic pixel.

Post-processing of EAARL data is accomplished using a custom-built Airborne Lidar Processing System (ALPS) that combines laser return backscatter digitized at 1-ns intervals with aircraft positioning data derived from the IMU and GPS receivers. The ALPS software enables the exploration and processing of LiDAR waveforms and the creation of Digital Elevation Models (DEMs) for bare-Earth, canopy-top, submerged topography, and vegetation canopy structure. The EAARL system utilizes Earth-centered coordinate and reference systems, thereby eliminating the need for referencing submerged topography data to relative water level or tide gauges.

The EAARL has been operational since the summer of 2001, when it was used to survey the coral reef tract in the northern Florida Keys (Wright and Brock, 2002; Brock et al., 2004). Subsequent surveys in 2002, 2004, and 2006 along the Florida reef tract have enabled the creation of submerged topography products at Biscayne National Park (Brock et al., 2006a), Florida Keys National Marine Sanctuary (Brock et al., 2007), and Dry Tortugas National Park (Brock et al., 2006b). Several surveys have been conducted using the EAARL system in a variety of coastal communities, including barrier islands along the Atlantic coast (Nayegandhi et al., 2005) and around the margins of an urbanized Gulf of Mexico estuary (Brock et al., 2002; Nayegandhi et al., 2006). An EAARL survey also was conducted along the Platte River in central Nebraska in March 2002 (Kinzel and Wright, 2002). The Platte River is a braided sand-bedded river that presents technological and logistical challenges with regard to collecting topographic and bathymetric measurements. The vertical accuracy of the system when compared with Real-Time-Kinematic (RTK) GPS surveys was estimated to be 16–22 cm root mean square error (RMSE) in the Platte River (Kinzel and Wright, 2002). Subsequent shallow river surveys conducted in the Lower Boise River, Idaho, yielded vertical accuracies of 14–18 cm RMSE (unpublished data). Further studies have estimated the vertical accuracy of the EAARL system to range from 10 to 14 cm (RMSE) for submerged topography (0.1–2.5 m water depth) and 16–20 cm for sub-canopy topography under a variety of dense coastal vegetation communities along the margins of Tampa Bay, Florida (Nayegandhi et al., in press).

Specific design considerations for the EAARL system, which make it an ideal system for mapping the topography and morphologic habitat complexity of shallow reef substrates, include the high spatial (20-cm-surface footprint at nominal flying altitude of 300 m AGL) and sample (1-ns digitizing interval) resolution. The EAARL system also is designed to map substrates in shallow water (<5 m) where traditional hydroacoustic ship-borne instruments cannot operate efficiently, field surveys are time-consuming and cost-prohibitive, and traditional bathymetric LiDARs are not applicable. These design considerations also are uniquely well suited for the seamless and simultaneous mapping of shallow, clear channel-bed topography in rivers and streams, and for resolving the bare-Earth topography of the surrounding floodplain.

References

- Brock, J.C., Wright, C.W., Clayton, T.D., and Nayegandi, A., 2004, Optical rugosity of coral reefs in Biscayne National Park, Florida: Coral Reefs, v. 23, p. 48-59.
- Brock, J.C., Wright, C.W., Nayegandi, A., Clayton, T., Hansen, M., Longenecker, J., Gesch, D., and Crane, M., 2002, Initial results from a test of the NASA EAARL LiDAR in the Tampa Bay Region: Proceedings of the 2002 Gulf Coast Association of Geological Societies Conference (CD-ROM).
- Brock, J.C., Wright, C.W., Patterson, M., Nayegandi, A., Patterson, J., Harris, M.S., and Mosher, L., 2006a, USGS-NPS-NASA EAARL Submarine Topography – Biscayne National Park: U.S. Geological Survey Open-File Report 2006-1118 (DVD).
- Brock, J.C., Wright, C.W., Patterson, M., Nayegandi, A., and Patterson, J., 2006b, USGS-NPS-NASA EAARL Submarine Topography – Dry Tortugas National Park: U.S. Geological Survey Open-File Report 2006-1244 (DVD).
- Brock, J.C., Wright, C.W., Nayegandi, A., Woolard, J., Patterson, M., Wilson, I., and Travers, L., 2007, USGS-NPS-NASA EAARL Submarine Topography – Florida Keys National Marine Sanctuary: U.S. Geological Survey Open-File Report 2007-1395 (DVD).
- Feygels, V.I., Wright, C.W., and Kopilevich, Y.I., 2003, Narrow field-of-view bathymetric LiDAR: theory and field test, *in* Frouin, R.J., Gilbert, G.D., and Pan, D. (eds), Ocean Remote Sensing and Imaging II, Proceedings of the SPIE, v. 5155, p. 1-11.
- Kinzel, P.J., and Wright, C.W., 2002, Evaluation of EAARL, an experimental bathymetric and terrestrial LIDAR, for collecting river channel topography along the Platte River, Nebraska: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 232.
- Nayegandi, A., Brock, J.C., and Wright, C.W., in press, Small-footprint, waveform-resolving LiDAR estimation of submerged and sub-canopy topography in coastal environments: International Journal of Remote Sensing.
- Nayegandi, A., Brock, J.C., Wright, C.W., and O’Connell, M.O., 2006, Evaluating a small-footprint, waveform-resolving LiDAR over coastal vegetation communities: Photogrammetric Engineering and Remote Sensing, v. 12, p. 1408-1417.
- Nayegandi, A., Brock J.C., and Wright, C.W., 2005, Classifying vegetation using NASA’s Experimental Advanced Airborne Research LiDAR (EAARL) at Assateague Island National Seashore: Proceedings of the American Society of Photogrammetry and Remote Sensing Annual Conference, Baltimore, MD (CD-ROM).
- Wehr, A., and Lohr, U., 1999, Airborne laser scanning – an introduction and overview: Journal of Photogrammetry and Remote Sensing, v. 54, p. 68-82.
- Wright, C.W., and Brock, J.C., 2002, EAARL: A LiDAR for mapping shallow coral reefs and other coastal environments: Proceedings of the 7th International Conference on Remote Sensing for Marine and Coastal Environments, Miami, FL (CD-ROM).

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