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Shallow water benthic imaging and substrate characterization using recreational-grade sidescan-sonar

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ABSTRACT

In recent years, lightweight, inexpensive, vessel-mounted 'recreational grade' sonar systems have rapidly grown in popularity among aquatic scientists, for swath imaging of benthic substrates. To promote an ongoing 'democratization' of acoustical imaging of shallow water environments, methods to carry out geometric and radiometric correction and georectification of sonar echograms are presented, based on simplified models for sonar-target geometry and acoustic backscattering and attenuation in shallow water. Procedures are described for automated removal of the acoustic shadows, identification of bed-water interface for situations when the water is too turbid or turbulent for reliable depth echosounding, and for automated bed substrate classification based on singlebeam full-waveform analysis. These methods are encoded in an open-source and freely-available software package, which should further facilitate use of recreational-grade sidescan sonar, in a fully automated and objective manner. The sequential correction, mapping, and analysis steps are demonstrated using a data set from a shallow freshwater environment.

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Software availability

Name of software: PyHum
Version: 1.3
Developer: D. Buscombe
Contact email: daniel.buscombe@nau.edu
Year first available: 2015
Available from: Python package index: (https://pypi.python.org/pypi/PyHum);
development versions available on GitHub: (https://github.com/dbuscombe-usgs/PyHum).

1. Introduction

1.1. Acoustic imaging of benthic abiota (bottom substrates and morphologies)

Sidescan sonar systems have been widely used to map and image benthic environments for over 60 years (e.g. Chesterman et al., 1958; Klein and Edgerton, 1968; Singh et al., 2000; Brown et al., 2011), including the water column and bed, harnessing the radiative properties of sound waves in water (Blondel, 2009). Recent decades have seen increasing use of swath sonar in shallow water, down to less than a meter depth, in fluvial (e.g. Anima et al., 2007; Amiri-Simkooei et al., 2009; Buscombe et al., 2014a,b), lacustrine, and estuarine (e.g. Hobbs, 1985; Kennish et al., 2004) environments, providing high (up to centimetric) resolution acoustic imagery of an area up to thousands of square kilometers per day, principally for the purposes of characterizing bottom structure and morphologies; physical and biological substrates; identification of geological facies; for imaging physical structures such as cables, pipelines, and sunken vessels; and detection and characterization of substrates in habitat suitability studies (e.g. Allen et al., 2005; Ehrhold et al., 2006; Yeung and McConnaughey, 2008; Todd and Kostylev, 2011).

Typically, a sidescan sonar system consists of: (1) a topside unit for sonar display and recording; (2) a data transmission cable; and (3) a subsurface streamlined transducer containing a linear array of interconnected transceivers to transmit and receive the acoustic energy. The transducer emits a sound pulse ('beam') in two downward directions (i.e. port and starboard) which is symmetric about, and having broad width in, the vertical plane. The beam is perpendicular to the transducer's direction of forward motion and ensonifies a fan-shaped volume of water. The directionality and

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intensity of the beam (the directivity pattern) is a function of the operating frequency (in shallow water, typically hundreds of kHz) as well as the shape and dimension of the transceiver arrays. The beams are designed to be narrow along-track (parallel to the transducer, or in the direction of the boat) for high-resolution imaging, and fairly wide in the across-track direction (perpendicular to the transducer) in order to maximize bed areal coverage. The swath is the thin strip (footprint) ensonified instantaneously by the sonar (both transducers collectively). A ‘ping’ consists of the emission of a sound pulse in the water and the simultaneous reception of energy scattered back from the water, then the bed, at increasing range. A short (in time) pulse of emitted sound produces a short (in space) length of sound wave train, resulting in high resolution, but relatively noisy, backscatter data. A longer pulse is typically less sensitive to the background noise, at the expense of spatial resolution.

1.2. The democratization of sidescan sonar technology

In the past few years, low-cost, consumer-grade (hereafter, ‘recreational-grade’, to distinguish from ‘survey’ or ‘scientific’ grade) sidescan sonar platforms, have been developed for leisure activities such as fishing and hobbyist archeology. Recreational-grade sonar lack standardization in (and description of) the acoustic signal processing used, often without high-quality (‘survey grade’) positioning and measured boat attitude (heave, pitch, yaw, etc), and reporting of those quantities. It is not usually possible to process data from such sonars using conventional commercial hydrographic surveying software, to post-process the positioning of the scans or carry out a calibration that corrects for radiative properties of individual transducers. However, these inexpensive, lightweight (portable) sidescan sonar units can be deployed on almost any waterborne craft without the requirement of specialist knowledge of sonar and geodetics, and with little to no experience with acoustic remote sensing. This accessibility is behind the rapid increase in popularity of these sonar systems, among the scientific research community for benthic imaging in a range of aquatic environments, both marine and freshwater, lotic and lentic (Kaeser and Litts, 2008, 2010; Gonzalez-Socoloske et al., 2009; Collins et al., 2010; Havens et al., 2011; Goclowski et al., 2013; Kitchingman et al., 2013; Kaeser et al., 2013; Flowers and Hightower, 2013; Powers et al., 2014; Bilkovic et al., 2014; La Croix and Dashtgard, 2015; Sterrett et al., 2015; Froehlich and Kline, 2015; Buscombe et al., 2015; Cheek et al., 2016; Dunlop et al., 2016; Smit and Kaeser, 2016). Such spatially distributed benthic data are especially important in the development and evaluation of models for habitat suitability and vulnerability (e.g. Roberts et al., 2010; Marsili-Libelli et al., 2013; Surridge et al., 2014) since they provide a means to produce georeferenced maps of substrates and bottom morphologies.

This rapid and ongoing ‘democratization’ of inexpensive sidescan sonar technology will be further facilitated by a technical description of the underlying scope and principles-of-operation behind these sonar systems and, with their limitations in positioning, attitude, and acoustic standardization in mind, through the development of processing routines, encoded in open-source software, to support a burgeoning interdisciplinary community of users in fields such as hydrology; aquatic ecology; fluvial and coastal geomorphology; and environmental sciences. The present contribution is motivated by this urgent need. Some novel approaches to the processing and georectification of sidescan sonar data are described, implemented in an open-source and freely available software tool, called PyHum, for extracting and working with data from the sidescan sonar in the Humminbird® series (made by Johnson Outdoors Marine Electronics, Inc., Alabama, USA) of pole-mounted fishfinder sonar systems, which to date have emerged as the most popular recreational grade sidescan among scientists. These processing procedures could easily be adapted to work with data recorded by similar recreational sidescan sonar systems, such as those (at the time of writing) made by Lowrance Electronics (Tulsa, Oklahoma, USA) and Garmin Ltd (Schaffhausen, Switzerland), or indeed for any continuous-wave, single-frequency, non-bathymetric, non-interferometric, imaging sonar. Drawing upon the technical literature on sidescan image processing (e.g. Reed and Hussong, 1989; Cervenka and De Moustier, 1993; Collier and Brown, 2005; Burguera and Oliver, 2016) the present contribution details the algorithms, assumptions, and structure of a freely available, open-source software designed for ease of use by the non-acoustician.

At the time of writing, at least two proprietary (low-cost yet closed-source) software programs are available for automating rudimentary analyses and for projecting low-cost sidescan data on the bed, namely SonarTRX (http://www.sonartrx.com/web) and Reefmaster (http://reefmaster.com.au). Another semi-automated program, described by Kaeser and Litts (2010), has been developed for use within a Geographic Information System platform to make georectified montages of screenshots from the sonar topside unit, without geometric or radiometric correction. The program `PyHum` has been produced as an open-source alternative for the use of sidescan sonar data specifically in scientific research, which demands transparency in documentation of the algorithms used, the ability of an individual researcher to adapt the freely available code to her/his specific needs, fostering community development of the software. A physics-based model for the ensonification of the sonar, which is detailed in Section 5, is used to correct the sonar data for uneven ensonification, as well as attenuation and other transmission losses caused by the water column. In doing this, `PyHum` has a potentially much greater scope than existing software for defensible scientific research. Unlike existing software, `PyHum` accounts for the effect of system gains on depth and slant-range estimates, and provides modules for the removal of echogram shadows, for carrying out spatially distributed textural analyses for substrate classification, and full-waveform echosounder analysis for substrate characterization (which are detailed in the present contribution). In addition, `PyHum` provides the user with the ability to correct for radiative losses due to water (given user-defined water temperature, salinity and pH) and suspended sediment (given user-defined sediment concentration and grain size), as well as manually pick the bed and edit noisy scans. `PyHum` users can modify existing code and add additional modules, as their needs dictate.

2. Data structure, definitions, and data processing assumptions

2.1. Data structure

The Humminbird® series of ‘high definition’ sidescan sonars, which use narrowband bursts of continuous sound wave pulses at a single frequency, do not record backscatter phase, so no bathymetric information (from phase) is available. Units record receive-levels in unsigned eight-bit digital integers rather than units of relative acoustic power (such as decibels or decibel-Watts). The units simultaneously record up to four echograms: separate channels for port and starboard sidescan intensity; and up to two channels for singlebeam (downward-looking) echosounder intensity. Positions are reported by the instrument as coordinates in a World Mercator Meters coordinate system (EPSG code 3395, with no UTM zone) but the user of the PyHum toolbox can work with the data in any geographic or projected coordinate system described by

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