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A PYTHON TOOL FOR AUV-BORNE ADCP CURRENTS DATA PROCESSING

S. Cusí, P. Rodríguez and N. Pujol

UTM-CSIC, Marine Technology Unit (CSIC), Barcelona, Spain

Abstract *– Most Autonomous Underwater Vehicles (AUVs) mount Doppler sensors to navigate precisely underwater, where the Global Positioning System (GPS) is unavailable. These sensors, aside of providing accurate AUV velocity with respect to the ground, can perform currents profiling, measuring currents along the water column. It has been shown that currents measurements taken by AUVs are very close to those taken by bottom-mounted ADCPs and that a 3D data processing approach can yield differences between both instruments of about 0.07* ms^{-1}*, averaging AUV data in 90 second time windows. In this paper we present an OceanServer Iver2 AUV 3D water currents processing tool, developed in Python 2.7. The tool outputs .csv files for further data processing/representation as well as plots of the main variables, along with water currents plots.*

Keywords *– Autonomous Underwater Vehicle, Acoustic Doppler Current Profiler, OceanServer Iver2, SonTek ADCP, Python 2.7*

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) can run for several hours (~10 h) and kilometers (~50 km) collecting biogeochemical/physical data of water masses, exploring the seafloor with acoustic or optical technologies, or executing specific tasks with other commercial or custom sensors. One sensor most AUVs mount is the Doppler Velocity Log (DVL), which provides valuable data on platform velocity with respect to the bottom (bottom-tracking); used to accurately navigate underwater, where the Global Positioning System (GPS) becomes useless. In many occasions, the DVL can perform as an Acoustic Doppler Current Profiler (ADCP), turning the AUV into a potential currents measurement tool. This capability, however, has seldom been exploited, judging by the amount of studies one can find in which oceanographers use AUV currents data to characterize water circulation. Some studies have compared currents data measured by AUVs to those measured by moored ADCPs [1]-[3], in order to explore the AUVs' capabilities as reliable current meters. Results show promising differences of about 0.1 ms^{-1} in horizontal velocity values. A comparison study evaluating the OceanServer Iver2 AUV versus a bottom-mounted Nortek AWAC, Acoustic Wave and Current Meter, [4], shows that 3D AUV-borne ADCP data processing yields differences of about 0.07 ms^{-1} with respect to the AWAC, using data averaging time windows of 90 seconds.

OceanServer Iver2 AUVs are one of the most commercialized AUV models due to their relatively low cost and ease of operation. However, no data processing software is provided by the manufacturer. ADCP currents data present higher processing complexity than other data as the measurement points or cells are away from the vehicle and, the measurements being vectors, require coordinate transformation to match the North-East-Down directions. Also, Doppler technology measurements contain Gaussian noise that needs to be removed by averaging data during a certain period of time.

In this text we present a first version of Python 2.7 scripts aimed at processing Iver2 ADCP water currents. It explains how data are processed as well as filtered and averaged. It also explains what are the graphical outputs and generated files. These scripts are to be freely distributed and modified.

II. INSTRUMENTS

A. Iver2 AUV

Iver2 is one of the lightest man-portable commercial AUVs (Fig. 1). In spite of its low weight (~20 kg) and size (~15 cm diameter and ~1.5 m long), it can carry a DVL/ADCP, a side scan sonar, optical cameras and a CTD. The Ecomapper version mounts an YSI multi-parametric sensor capable of measuring different biogeochemical parameters such as PH and Chlorophyll. These AUVs can perform continuous surveys down to 100 m depth for about 10 h at speeds ranging from 1 to 4 knots.

Fig. 1. The two OceanServer AUVs owned and operated by CSIC's Marine Technology Unit. One is equipped for seafloor imaging (front) and the other for water quality monitoring (rear). Both are provided with a SonTek DVL/ADCP sensor.

B. SonTek ADCP

ADCPs installed on Iver2 AUVs can have two different configurations: 6 and 10 beams [5]. The former setup, with 4 down-looking transducers working at 1 MHz, allows for downward water profiling up to 40 meters and bottom-tracking for navigation; while the latter, with 4 down-looking and 4 up-looking transducers working at 1 MHz, provides water currents measures below and above the vehicle covering up to 80 meters, as well as bottom and surface-tracking velocities. Both setups are provided with one up and one down-looking 500 KHz vertical transducer used to range the bottom and the surface at distances up to 80 meters. The beams devoted to water profiling are oriented with a 25º slant angle and have a width of 3.5º. Even though the ADCP delivers averaged data to the AUVs PC for navigation and currents logging at 1Hz, the ADCP's internal sampling rate is higher: the 10 beam ADCP internally samples at 2.3 Hz while the 6 beam one does it at 3.1 Hz –more if ranging less distance and/or disabling some functionalities-. The manufacturer [5] defines the Doppler noise according to the following formula:

$$\sigma = \frac{235}{F \Delta z \sqrt{N}} \qquad (1)$$

where σ is the Doppler noise of horizontal velocity in ms^{-1}, F is the acoustic frequency in kHz, Δz is the cell size in meters, and N is the number of pings in the average. The last 2 variables can be modified when setting up the ADCP in order to reduce the noise. The 4 beam configuration allows for redundant calculation of vertical water velocity, which is used to evaluate the quality of the measurement. The AUVs PC logs the standard error velocity (SEV) for every measured cell, representing the sum of the difference between the calculated vertical velocities. The manufacturer recommends discarding the cells in which the SEV value is higher than 0.5 ms^{-1}.

C. Python 2.7

The ADCP currents processing tool presented here is coded in Python 2.7, a common programming language among scientists and engineers. It is an interpreted high-level programming language intended for general programming purposes. Python counts with a large community of users worldwide who develop and maintain a wide range of libraries. It is free and can run on a variety of platforms, including Linux, Windows and Mac, among others.

III. DATA PROCESSING

Currents measures are provided at 1 Hz and can be represented by 3D vectors in an AUV-based coordinate system (Fig. 2). Each of these vectors represents the currents' value at one cell (cells are placed along the vertical axis of the sensor), the number and size of which can be set before the mission starts. Removing AUV's velocity from the measured values is needed to obtain absolute AUV-referenced water currents, which then need to be rotated, by using AUV's attitude (pitch θ, roll ϕ and heading ψ), to match the Earth's reference system (i.e. North-East-Down):

$$\vec{v}_{Earth} = J \cdot \vec{v}_{AUV} \qquad (2)$$

where J is the rotation matrix (*c* represents the cosine function and *s* the sine function):

$$J = \begin{bmatrix} c\psi \cdot c\theta & -s\psi \cdot c\phi + c\psi \cdot s\theta \cdot s\phi & s\psi \cdot s\phi + c\psi \cdot c\phi \cdot s\theta \\ s\psi \cdot c\theta & c\psi \cdot c\phi + s\phi \cdot s\theta \cdot s\psi & -c\psi \cdot s\phi + s\theta \cdot s\psi \cdot c\phi \\ -s\theta & c\theta \cdot s\phi & c\theta \cdot c\phi \end{bmatrix} \qquad (3)$$

This process is done every second as currents measures, bottom-tracking velocities and attitude values are updated at this rate. The 3D approach could be simplified to a 2D one (correcting only for AUV heading), considering navigation underwater is steady, with pitch and roll values close to zero, but would make surface (unsteady pitch and roll) and yoyo (~ ±15º pitch) navigation measures useless. In addition, the 3D approach places the Earth-referenced currents vectors according to AUV's attitude; which means, for example, that the most distant cells of a 10-beam ADCP (one 40 m below and one 40 m above) mounted on an AUV navigating at 15º pitch and neutral roll, are separated 21.4 m (instead of coincident) in the horizontal plane and 77.3 m (instead of 80 m) in depth.

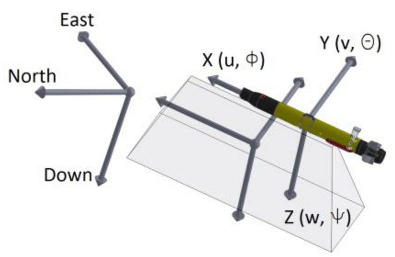

Fig. 2. Earth-referenced coordinate system (left) and AUV-referenced coordinate system, which is coincident to the cells' coordinate system. The first cell is represented underneath the AUV in real proportions.

The tool presented here processes AUV-Borne ADCP data applying a full 3D approach, described above, allowing for multi-purpose sampling and, therefore, avoiding the need of currents mapping devoted missions. This way, currents data can be a by-product of a mission where yoyo and/or surface navigation play an important role.

IV. RESULTING SCRIPTS

The script takes Iver2 AUV output files (.dvl, .pfd and .pfu) and outputs one file containing raw data at 1 Hz. From this file, it generates another file with filtered (min/max), depth binned, time averaged (moving average) currents (Fig. 3). Both files adopt CSV format in order to be compatible with widespread tools such as Ocean Data View or Microsoft Excel. The raw data file, aside of currents data, includes data describing AUV navigation (attitude, velocity, position) as well as data on ADCP configuration and performance (cell size, number of cells, bottom-tracking quality, noise). It also stores other calculated parameters such as cell volume. Data can be discarded by filtering (min/max values) by any of the mentioned parameters when generating the second, conditioned currents data file.

The tool, aside of being distributed as open source code, is packaged into a stand-alone Windows executable file in order to be easily run on any Windows machine, without the need of installing the Python interpreter.

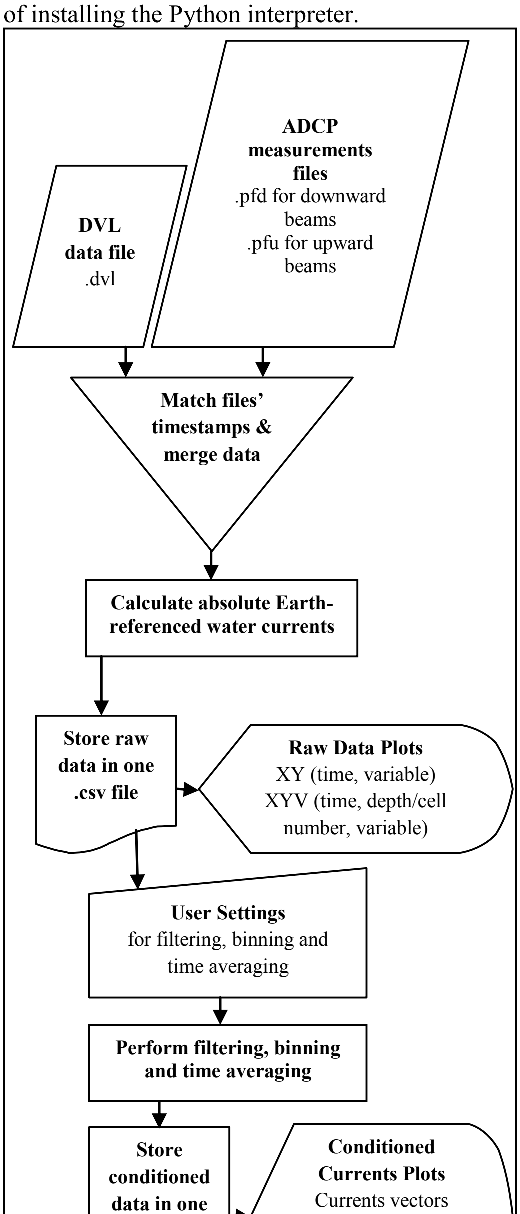

Fig. 3. Data processing flow chart.

V. CONCLUSIONS AND NEXT STEPS

The use of AUVs to map currents is not yet widespread; in spite of most AUVs carry ADCP sensors. Currents measured by AUV-borne ADCPs show good agreement with those measured by more established techniques, such as moored ADCPs. In this paper we introduce a first version of a tool developed in Python 2.7, aimed at processing Iver2 AUV currents data using a 3D approach. The tool outputs processed data files as well as a variety of plots.

Once released, the tool will need to go through a validation process where user feedback will be key to adjust usability, functionality and other aspects. Parallelly, in order to settle AUVs as valid current meters, more experimental work comparing AUV currents measures to those of other instruments will need to be done.

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