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A GIS-based Computational Tool for Multidimensional Flow Velocity by Acoustic Doppler Current Profilers

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A GIS-based Computational Tool for Multidimensional Flow Velocity by Acoustic Doppler Current Profilers

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Abstract. Acoustic Doppler Current Profilers (ADCPs) provide efficient and reliable flow measurements compared to other tools for characteristics of the riverine environments. In addition to originally targeted discharge measurements, ADCPs are increasingly utilized to assess river flow characteristics. The newly developed VMS (Velocity Mapping Software) aims at providing an efficient process for quality assurance, mapping velocity vectors for visualization and facilitating comparison with physical and numerical model results. VMS was designed to provide efficient and smooth work flows for processing groups of transects. The software allows the user to select group of files and subsequently to conduct statistical and graphical quality assurance on the files as a group or individually as appropriate. VMS also enables spatial averaging in horizontal and vertical plane for ADCP data in a single or multiple transects over the same or consecutive cross sections. The analysis results are displayed in numerical and graphical formats.

1.Introduction

The Acoustic Doppler Current Profilers (ADCPs) has revolutionarily improved our ability to represent the hydrodynamics of riverine environments. ADCPs measure non-intrusively velocities along verticals and bathymetry with a great deal of spatial and temporal resolutions relatively enhanced with previous mechanical instrumentations. ADCPs provide three velocity components over flow depths and stream cross sections hence there is a considerable potential for supporting a wide range of scientific and practical analyses related to river investigations. Researchers in water communities have continuously attempted to utilize the detailed information provided by ADCPs based upon additional data processing software modules. Among the new innovative applications of ADCPs in support of riverine research are: (*i*) characterization of mean flow characteristics (e.g., Muste et al., 2004); (*ii*) estimation of turbulence quantities (e.g., Stacey et al., 1999, Lu and Lueck, 1999; Schemper and Admiraal, 2002; Nystrom et al., 2002; Howarth, 2002; and Kostaschuk et al., 2004); (*iii*) sediment transport (Rennie et al, 2002), (*iv*) characterization of the spatial distribution of velocities in riverine habitats and bed survey (Shields et al., 2003, Gaeuman and Jacobson, 2005), and (*v*) estimation of the longitudinal dispersion coefficient for river flow (Carr and Rehmann, 2007). However, the current ADCP companion software

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(WinRiver and RiverSurveyor for RD Instruments and SonTek, respectively) only focused on calculating streamflow discharge beyond these additional processing capabilities. Presented in this paper, therefore, is a standalone software that assembles in one package visualization and post-processing tools using an advanced computational environment for the benefit of the river monitoring and research communities. The software, labeled 'VMS' (ADCP Velocity Mapping Software), provide many additional processing capabilities driven by research needs and specific requests from the ADCP user community. The VMS brings stronger data filtering and quality control features as well as enhanced visualization capabilities. The VMS software tool is freely-downloadable online at: http://chl.erdc.usace.army.mil/vms. The paper describes the descriptions of main features along with the many other processing and/or visualization capabilities. The VMS mainly provides five categories: general features, quality assurance, spatial averaging, geo-referencing, detailed single transect view (see Table 1).

Table 1. Main features of VMS

Category	Features
General Features	• Read ASCII output format from WinRiver I and II (Teledyne RDI) and Matalab output format from RiverSurveyor (SonTek/YSI) • Processing multiple ADCP files • Incorporating ADCP data with GIS files (shapefile) • Exporting processed data into various formats (picture, csv, shapefile, kml) • Supporting 2D or 3D static or dynamic geographical display • Supporting both English/SI unit system • Supporting UTM coordinate (NAD 1983/1927) • Computing 3D geo-referenced positions of beam depth • Interpolating GPS locations using GGA and ADCP time • Layer extraction
Quality Assurance	• Error velocity filter • Beam depth filter • Boat speed filter • GPS location filter
Spatial Averaging	• Single group averaging along curvilinear path • Multiple group averaging along curvilinear path • Finding mean curvilinear path • 2D/3D averaged velocity data representation • 2D/3D averaging for user-supplied points (grids) • Supporting uncertainty (random error) of averaging
Geo-referencing	• Vertical referencing – water surface elevation • Horizontal referencing – no GPS data • BT / GPS tracking
Single Transect View	• ASCII viewer (1,2 and 3D info.) • Horizontal / Vertical viewer • Contour plot • BT/GPS track

2. GENERAL FEATURES

The VMS was designed to efficiently process multiple ADCP files for both SonTek and TRDI ADCP formats. When the loaded files are geo-taggged with GPS data, they can be mapped, and the users can easily identify where their measurements are located. Also, the ADCP measurements can be synchronized with GIS shape files, which enables ADCP measurements to be more geographically recognized (see Figure 1). The ADCP files can be exported into GIS format (e.g., shapefile or kml) for further processing.

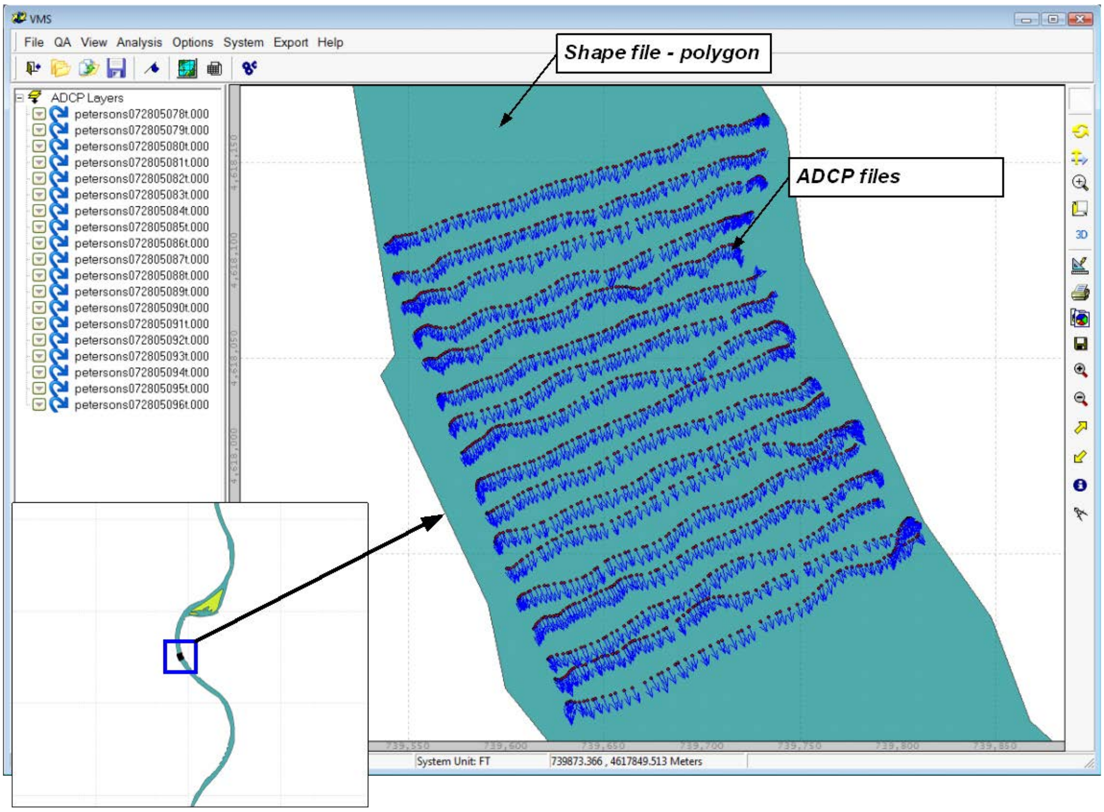

Figure 1. ADCP measurements back-grounded with a GIS shapefile of river boundary.

3. QUALITY ASSURANCE

The quality assurance in the VMS software is accomplished by applying various filters such as velocity filter, depth filter and boat speed filter. This quality assurance in VMS can be applied on a transect by transect. Moreover, the many of the data filters can be automated to provide a more efficient and consistent approach to quality assurance. The velocity filter uses the given error velocity, which represents error indicator of flow homogeneity checked by individual velocity measurement. When the error velocity is higher than the given criteria, the measured velocity is considered as an error, and filtered out of the dataset. The depth filter evaluates beam depth measurements which are usually averaged to generate mean depth. The spike or zero depth measurements are filtered out by applying Super Smoother (Friedman, 1984), where a smoothed line based on individual beam depths is generated and any spikes located above or below a given buffer of the smoothed line are filtered out and replaced. Figure 2 shows an application of the implemented filters (depth filter). Boat speed filter works similarly with the depth filter, where the abrupt speed change of the boat speed is filtered. After applying various filters, discharge is corrected.

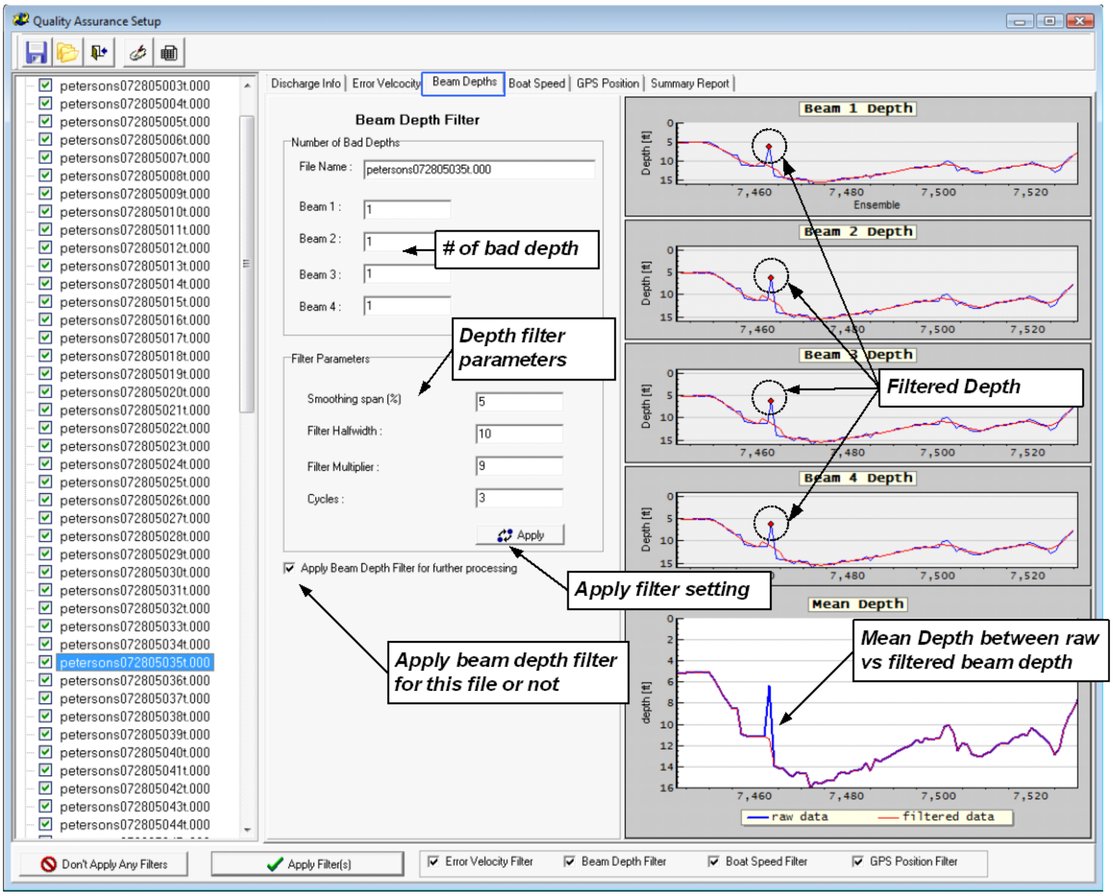

Figure 2. Beam depth filter.

4. SINGLE TRANSECT VIEW

VMS provides two different types of velocity profile: vertical and horizontal. First, the vertical profile at each ensemble can be examined in the Vertical tab (see Figure 3). Along the ship track, the user is able to move forward and backward to see velocity data in tabular and 3D graphical format. When the user starts the animation, dynamic variation of the 3D velocity in the transect can be visualized. Different from the conventional contour plot for the cross-section, dynamic three-dimensional plot of velocity vector with the two-dimensional location, the user is easily able to check out any erroneous velocity measurements or trend of the velocity direction. Second, the horizontal profile can be extracted for in the depth-averaged, nearest surface, nearest bottom, and user-defined layers.

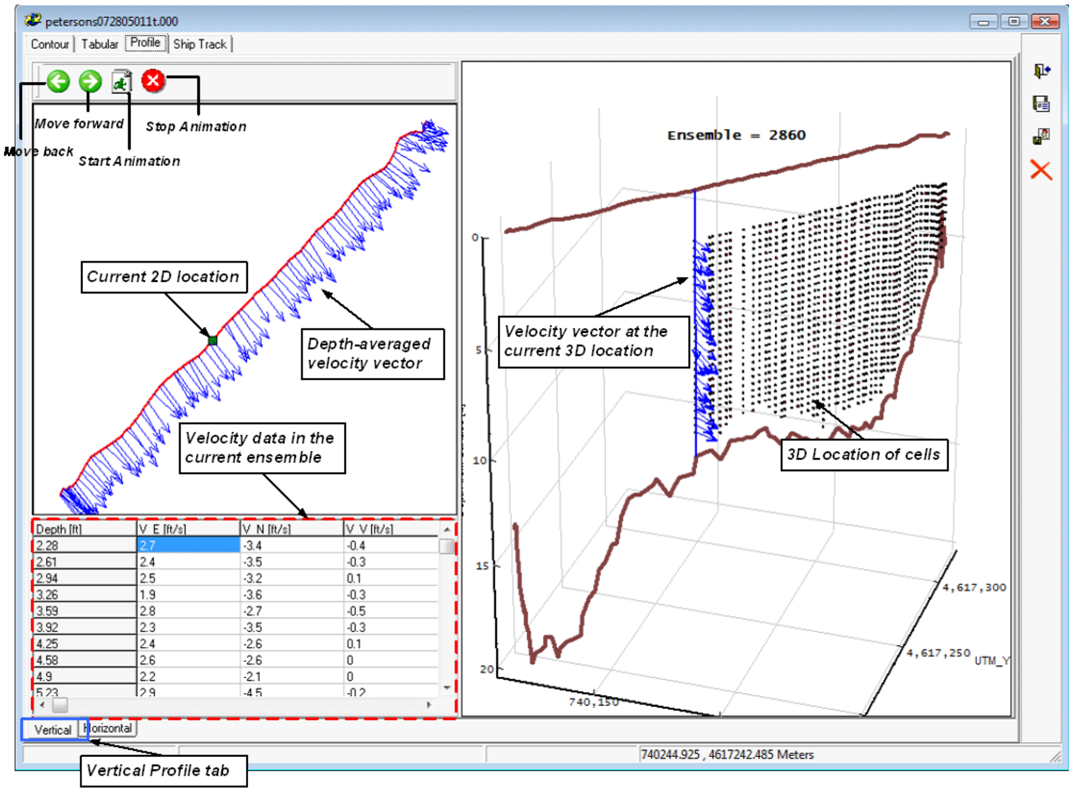

Figure 3. Three-dimensional dynamic view of velocity vector for the given cross-section.

5. SPATIAL AVERAGING

VMS supports horizontal averaging along the transect with specified averaging step (or spacing). The horizontal spacing of the averages is applied over the curvilinear path of the transect (see Figure 4). VMS provides averaging among multiple transects collected at the same cross section, which is expected to reduce the uncertainty associated with velocity averages. In general, the users collect multiple transects at the same cross section and look for horizontally and/or vertically averaged data using all of the transects in the group. The average path travelled for a group of transects is computed first to provide a method to compute a mean path. The spacing for horizontal averaging is then applied along that mean path and the points to be averaged will be those that fall within a user defined diameter. The depths along the mean path are averaged and smoothed, and depth at each spaced point will be taken from these depths. The user is able to process or reprocess the data for different purposes by changing options and averaging criteria without having to reselect the data files. VMS supports an automated approach to horizontal averaging that could avoid averaging across changes in flow distribution. This involves an algorithm to identify mean flow direction within the given search areas, where velocity vectors having less than a specified angle criteria are used in horizontal averaging. This approach only considers the flow distributions that are reasonably homogeneous and ensures data included in the average do not cross zones where flow directions change dramatically.

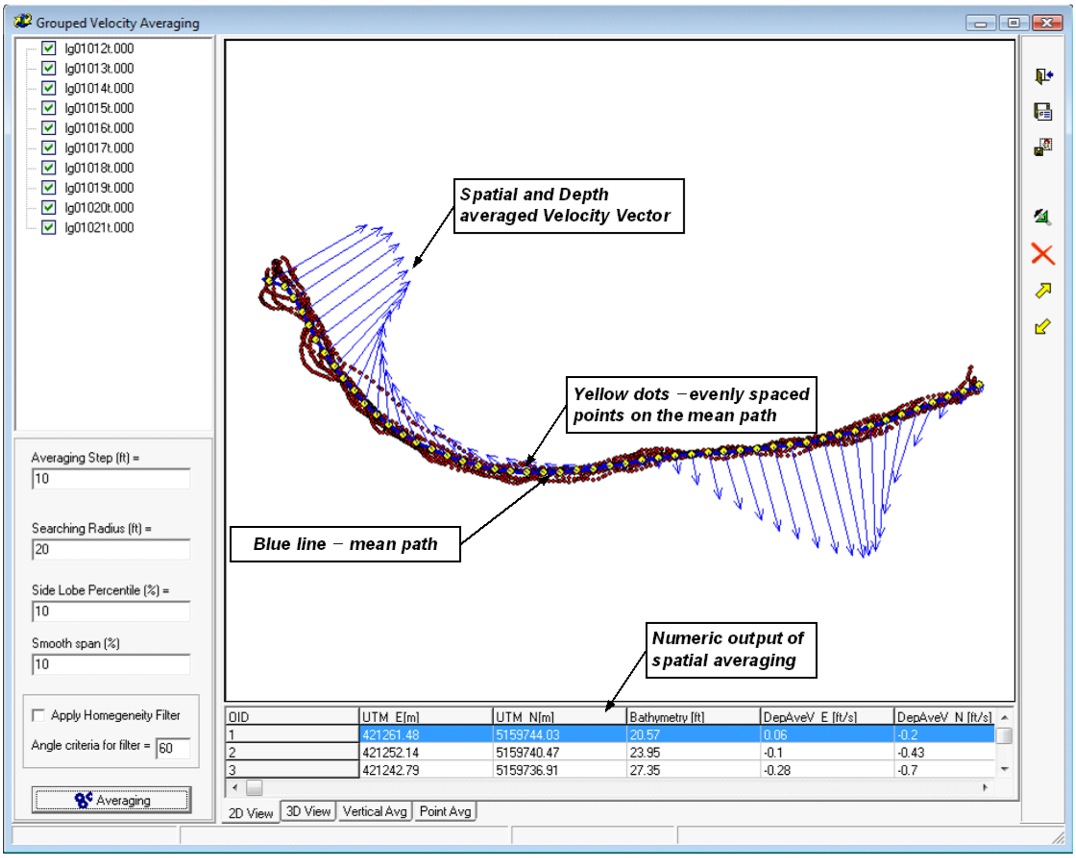

Figure 4. Spatial averaging of velocity vectors along the mean curvilinear path.

6. CONCLUSIONS AND FUTURE WORKS

The VMS currently contains several useful features that allow users to easily post-process multiple ADCP dataset to derive riverine information for further analysis. The key aspect of the VMS is to provide a community-based freely available ADCP post-processing tool, where the source algorithms and software are opened to the community and any contributors can update the code and interface of the VMS. The authors welcome any feedbacks from the community to eventually enhance the software.

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