

Novel software developments for the automated post-processing of high volumes of velocity time-series



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ABSTRACT

This paper describes novel software developments designed to automate the parsing, filtering (despiking) and calculation of mean flow and turbulence parameters of velocity time-series. The software was written to facilitate the processing of the large number of time-series (approximately 4000) generated by the authors' experimental work, mapping velocity and turbulence fields in a laboratory flume using an acoustic Doppler velocimeter. The software will import all, or selected, data files from a specified directory, desprike them using one of a number of filters (Phase-Space Thresholding, for example) and graphically present the parameter distribution over the cross-section under investigation. Many different data file formats are supported, including Nortek binary formats, Turbulent Flow Instrumentation "Cobra" probe format and delimited plain-text files, meaning that the software has applications in a significant number of different environmental engineering applications where large data sets are routinely collected and analysed.

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1. Introduction

The purpose of this paper is to describe software, the velocity signal analyser, ("VSA") developed to automate the parsing of data files of velocity time-series, and the post-processing of the data. It is anticipated that the VSA software will prove to be of great value to other researchers investigating velocity and turbulence fields. Before describing the software fully, a brief overview of the work which served as the motivation behind the development of the software is given as this will serve to clarify some of the functionality it provides. This paper is based on Jesson et al. [1], but the current paper includes additional description of time series analysis and, in particular, the quadrant-hole analysis functionality for identification of turbulence propagating events.

The modelling of river flow is important for a number of reasons, from predicting flood events to evaluating the effects of proposed river engineering works to understanding scouring processes. In order to investigate open-channel flow over heterogeneously rough beds the authors undertook a series of experiments using a rectangular flume in the University of Birmingham Civil Engineering Laboratories. The aim of this work (which is described fully in [2–4]) was to identify distributions of the 3-D velocity components, Reynolds stresses and other turbulence parameters, and also to identify coherent structures with the flow. The data was used to calculate the

parameters of the Shiono–Knight method (SKM; see [5,6] for details), a recognised open–open channel flow model, allowing recommendations to be made regarding its application in rivers with heterogeneous bed roughness.

This experimental work involved creating a high resolution map of the velocity and turbulence distributions over cross-sections of the flume. Two bed configurations were used, one with full-length, longitudinal strip roughness (smooth PVC on one side of the channel and rough gravel on the other) and the other with a "checkerboard" of rough and smooth sections (illustrated in Fig. 1). Each permutation of bed configuration, discharge and longitudinal position of the measured cross-section resulted in a new data-set consisting of over 500 individual data-points, each situated at the node of a 10 mm spaced grid spanning the cross-section. Here, data-point refers to one location at which a velocity time-series has been recorded; a data-set consists of a number of data-points. Six full data-sets were gathered, along with six partial data-sets, making a total of approximately 4000 data-points. A 60 s long, 200 Hz, 3-D velocity measurement was made at each data-point, resulting in 12,000 instantaneous measurements in each dimension per data-point.

The measurements were made using Nortek acoustic Doppler velocimeters (ADV). ADVs transmit pulses of high-frequency sound waves which are reflected back to the ADV by impurities in the water. The frequency of the reflected waves is Doppler shifted due to the velocity of the impurities, allowing calculation of the 3-D velocity. ADV data are subject to invalid measurements (caused by aliasing when the magnitude of the phase shift is greater than 180° and also

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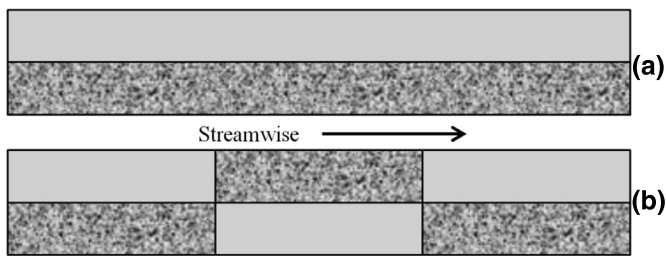


Fig. 1. Schematic of the heterogeneous channel bed configurations: (a) full-length, longitudinal strip roughness; (b) checkerboard roughness.

insufficient impurities to reflect the sound waves – see [2,7,8] which appear in the form of “spikes” in the time-series. These spikes may significantly affect turbulence parameters calculated from the time-series and thus should be removed from the time-series in a process termed “despiking” (see [8] for an overview of the causes of these spikes and the despiking process).

In common with many instruments, the raw data from the ADV is recorded in a proprietary, binary format. While this has the advantage of reducing file size, it necessitates a somewhat convoluted process to extract this data before any post-processing or analysis can be performed. Streamlining this process was important in order to reduce data analysis times to reasonable levels – as an example, it takes approximately 10 min to import and despik one of the authors’ datasets (530 Nortek Polysync files, making 412 MB of raw data) on a laptop with a 2 GHz Intel i7 processor; with the process being fully automated once the files have been selected, this can be performed in the background while continuing other work. The VSA software was initially intended simply to parse all data files from a specified directory, outputting the raw velocity data in a format suitable for import into a spreadsheet. However, it soon became clear that a filtering algorithm was required to remove “spikes” of invalid data and that a simple graphical display of mean value data would be beneficial to allow quasi-real-time inspection of the data during the experiments. In its current form, the VSA software offers major advantages to the user via automating the parsing of the raw data files, filtering of invalid values, calculation of 3-D mean velocity distributions, calculation of turbulence characteristics such as turbulence intensity and Reynolds stresses, and determination of data-point and data-set mean values. The software also provides graphical display of the results, with parameter values automatically plotted at the appropriate position of the cross-section. To facilitate additional processing using software such as Matlab and spreadsheets the filtered time-series may be exported to either Matlab (.mat) or plain text (.dat) files.

Although the software was originally written to parse data files produced by the Nortek PolySync software, it is easily extendible to other formats and can also import data from other Nortek probes (such as Vector, Vectrino and Vectrino II), Turbulent Flow Instrumentation “Cobra” probes and data held in delimiter-separated (e.g. comma- or tab-separated) plain text files. Similarly, it now supports a wide range of filtering algorithms, from simple limiting values based on the time-series standard deviation through to Phase-Space Thresholding and Velocity Correlation methods (these are described briefly later), and includes additional display functionality and more advanced processing such as quadrant-hole analysis and power spectra calculation. Recent modifications include allowing the definition of custom, non-rectangular cross-sections, the addition of trim functionality for the data-point time-series, and the automated splitting of large data files into a number of shorter time-series. The VSA is downloadable as free software from www.mikejesson.com.

Following this introduction are two sections which describe the VSA. The first introduces the functionality which it provides, whilst the second discusses the implementation of this functionality. This latter section will be of interest to users as it describes how the raw data files are handled and the files created by the VSA.

2. The user perspective

In order to give an overview of the functionality of the VSA, this section describes the steps involved in creating a data-set, importing data from the raw data files, and examining the calculated parameters. It is necessarily brief and does not cover all functionality – for more details the reader is referred to the user guide [9]. Hereon, “probe” signifies a part of an instrument which is measuring velocities at a single point.

2.1. Configuration

Before importing data a number of data-set parameters must be set. These include characteristics of the cross-section (e.g. left- and right-bank position for rectangular channels, or the specification of a boundary definition file for more complex cross-sectional shapes) and filtering options. If multiple probes are being used then the relationship between the probe positions should be specified. In multi-probe scenarios, the “main” probe traverses the data-point positions, while the second probe may be either “fixed” (i.e. held at a constant absolute position) or offset (i.e. maintains a constant position relative to the main probe). The former case may be used if, for example, a single position is used as a baseline to verify that the flow does not change during the course of the experiment, while the latter allows faster traversing of a measured section by measuring multiple data-points simultaneously. More than two probes may be used, allowing for multiple offset probes, though only one probe can be marked as fixed. Default values for these parameters are set via the configuration dialog (Fig. 2); any data-set created will take those values, although the settings for individual data-sets are customisable through their own configuration screen.

2.2. Data-set creation

Four types of data-set may be created. The simplest is a single-probe data-set, in which each raw data file contains data from one probe only. In the case of the PolySync software, for example, data from multiple probes is recorded to a single file. For such systems, a multi-probe data-set should be created. When importing multi-probe data, the position of each probe within the cross-section is determined from the relationship specified in the configuration dialog.

In the authors’ current work, simulating thunderstorm downbursts, a multi-run approach is required. The velocity time-series associated with a downburst is highly unsteady and both full-scale and laboratory data show significant variation between downburst events or experimental runs, although the large-scale features are consistent (see [10–12]). It is therefore appropriate to represent a “typical” time-series by the ensemble-mean of time-series gathered over a number of experimental runs, here termed the “run-mean”. The VSA incorporates multi-run functionality, producing a time-series which is the run-mean of a number of synchronised time-series. The individual run time-series are synchronised by offsetting each run such that the measurement which is the first exceedence of a limiting value (or the time of the maximum value if preferred) occurs at the same time for each run. To use this functionality, a multi-run data-set should be created; as for single-run data-sets, multi-run data-sets may be single or multiple probe.

2.3. Importing from raw data files

There are three overarching file types which may be imported:

1. Delimiter-separated files of u , v and w measurements (these being the streamwise, lateral and bed-normal velocity components respectively).

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