Reliability study in Despiking of ADV Data to open channel flow

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ABSTRACT

The major problem in collection of data from ADV is generation of spikes due to misidentification of the frequency of Doppler signals, this occurs when the phase difference between outgoing and incoming pulse lies outside the range of -180° to 180°.This shift is caused when the velocity of flow exceeds the pre-set velocity range or when there is contamination from previous pulses reflected from the surface of complex geometrics. For despiking study, different methods are used such as phase space thresholding (PST) method, RC filter (RCF) method, Tukey 53H method (T53H), acceleration thresholding (AT) method, wavelet thresholding (WT) method. Phase space thresholding method uses the concept of three dimensional Poincare maps in which the variables and their derivatives are plotted against each other to determine the spikes. RC filter is a low pass filter used to detect the spikes. Tukey 53H method uses the principle that a median is robust estimator of the mean to generate a smooth time sequence that can be subtracted from original signal. The acceleration threshold method is detection and replacement with two phases one for negative acceleration and other for positive acceleration. WT Method is similar to the previous method except that all the calculations are done in wavelet phase. A review paper is made on the reliability of the most popular methods that are WT, PST and AT method and finally conclusion is prepared showing the most reliable method for ADV despiking

Keywords: ADV, Doppler signals, despiking, PST, RCF.

1. INTRODUCTION

The Acoustic Doppler Velocimeters (ADV) were introduced in 1993 and from then it has been widely used in measurements of 3D velocity in turbulent flow (Nikora and Goring 2002).The instruments are relatively rugged and easy to operate. The primary data stream provided by an ADV is a time series of velocity vector components. The complete working of the ADV is given by Kraus et al.(1994) . Unlike many other measuring methods that exploit the physical property of water to obtain the velocity measurement, ADV`s actually measures the velocity of the scattering particles in the flow. The major errors occurs during collecting the raw velocity data through the experiment is the Doppler noise and these problem is discussed by many ADV users (Goring and Nikora 2002 ; Lane et al. 1998). The methodology for despiking this noise is explained in recent years (Goring and Nikora 2002; Nikora and Goring 1998; Garcia et al. 2004a). After studying the noise developed during the measurement of velocity Goring and Nikora concluded that the noise will increase when the flow is turbulent and bubbly. Nobuhito Mori et al.(2007) studied the effects of bubbly flow on the velocity measurement and they found that the ADV performance reduces significantly in this type of flow.

However in past decades these errors has been analysed and the source of error is recognised. The major error occurred during the velocity measurement is due to the phase shift occurrence between the outgoing and incoming pulses. This shift should lie between -180° to

180°. If it lies outside this range the output of the ADV measurement shows errors in terms of spikes when plotted a graph between velocity and time. In this paper reliability of different methods of despiking the ADV data are studied by reviewing different author studies and the most reliable method is suggested.

2. METHODOLOGY

2.1 Acceleration threshold method:

The concept of this method depend on the idea that the maximum acceleration of the flow particles are directly proportional to the acceleration due to gravity g. This method is mainly depend on two methods, one is for negative acceleration and other is for positive acceleration. The algorithm computes the acceleration as

$$a_i=(u_i-u_{i-1})/\Delta t$$

Any data point is said to be a spike if following condition occurs.

$a_{x,i}>K_g g$ and $u_i>u^*+K_\sigma\sigma_u$
$a_{x,i}<-K_g g$ and $u_i<u^*-K_\sigma\sigma_u$

Where K_g and K_σ are constants, U* is the mean of the data and σ_u is the standard deviation

Goring and Nikora suggested the values of K_g =1-2 and K_σ =1.5. These values are based only on their experience. As the above constants are based only on experience, L. Cea et al. (2007) has used a constant λ in order to take different values of K_g,

$$k_{g,x}=\frac{\lambda\sigma_{a,x}}{g} \qquad k_{g,y}=\frac{\lambda\sigma_{a,y}}{g} \qquad k_{g,z}=\frac{\lambda\sigma_{a,z}}{g}$$

Due to this, it results into the values of K_g which might be greater or less than the values suggested by Goring and Nikora(2002). The authors observed that a minor change in K_σ value will either increase or decrease the proportion of the data that are filtered. It was introduced in the acceleration threshold method in order to prevent the valid data points to show as spikes when the value of K_g=1-2 is used. In their experiment it is observed that as K_σ value increases the number of filtered data reduces and thence it has been concluded that by adjusting the parameters K_g and K_σ the results obtained by this method can vary significantly. They analysed the dataset at three points In the turbulent flow number of spikes detected at the first point P1 is given below:

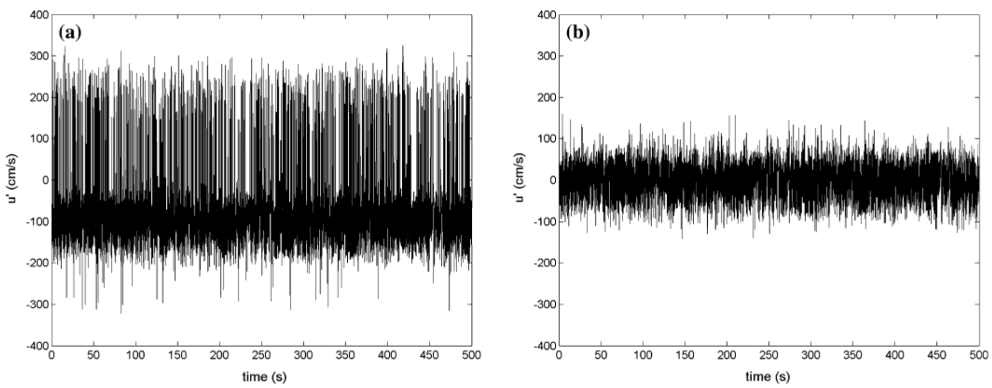
K_σ	N_f	$u`^2$	$v`^2$	$w`^2$	$\lvert\bar{U}\rvert$
0	233	297	97	237	37.4
1	204	297	97	236	37.4
2	167	295	97	235	37.3
5	87	295	98	232	37.3
10	71	302	98	238	37.3

Number of spikes (Nf), Normal Reynold stresses(cm^2/s^2) and mean velocity(cm/s) computed with the acceleration filter using several values of parameter K_σ

The flow around the third measurement point P3 being more complex, the large number of spikes are caused due to the high concentration of air bubbles. Results obtained by acceleration threshold method are:

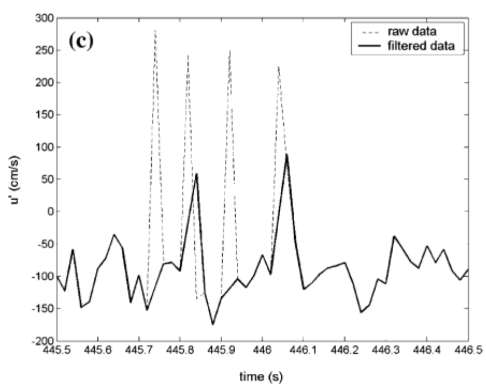
Method	**N_f**	$u`^2$	$v`^2$	$w`^2$	$\lvert\overline{U}\rvert$
Accel. K_σ =0	2091	2555	362	1067	96.3

Number of spikes(Nf), $u`^2$, $v`^2$, $w`^2$ are Normal Reynold stresses(cm^2/s^2) and $\overline{U}$ is the mean velocity(cm/s) computed with the acceleration filter using several values of parameter K_σ



Raw Data Filtered Data

Instantaneous velocity in x direction before and after filtering.



Acceleration Filter. 6 spikes

Details of raw and filtered dataset at third point , u`-velocity component

2.2 Wavelet threshold method:

This method has been widely used in signal denoising due to simple calculation and good denoising effect. The only parameter that is important in this method is the threshold that affects the denoising effect. The wavelet transform is analogous to the Fourier transform except instead of cosine function as the base function this method has a basis function (mother wavelet) that has compact support. Many mother wavelets can be used given by

Daubechies (1992). In Goring and Nikora (2002) paper they have suggested to use a mother wavelet HAAR as it gives similar results as of previous method. The wavelet thresholding method uses the lowest scale wavelet coefficients $d_{1,i}$.

The steps for each iteration given by Goring and Nikora (2002) are:

1. Calculate the wavelet coefficient, $d_{1,i}=\int_{-\infty}^{\infty} u(t)\psi_{1,i}(t)\,dt$, where $\psi_{1,i}(t)$ is the mother wavelet centered at i, with unit dilation.
2. Check the points where $|d_{1,i}| = \lambda_U\hat{\sigma}$ where λ is the universal threshold.
3. Generate a sequence $\hat{d}_{1,i}$ of zeroes except for the location of spikes where $\hat{d}_{1,i}$ =1.
4. Calculate the inverse wave transform of $\hat{d}_{1,i}$ to yield a time series of zeroes except for the points that are spikes.
5. Replace the spikes.

For the estimation of $\hat{\sigma}$ Katul and Vodakavic (1998) gives two possibilities of estimation of $\hat{\sigma}$

$$\hat{\sigma} = \sqrt{\frac{1}{\frac{n}{2}-1}\sum_{i=1}^{n/2}\left(d_{1,i}-\bar{d}\right)^2}$$

Where $\bar{d}$ is the mean of $\hat{d}_{1,i}$ and

$$\hat{\sigma} = \frac{1}{0.6745} < \left|d_{1,i}-\bar{d}\right| >_i$$

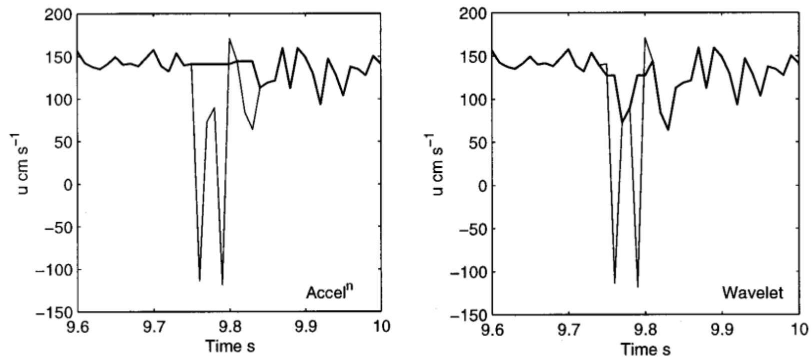
Where $<\ldots\ldots>_i$ denotes the mean over i.

Goring and Nikora (2002) conducted the experiments and collected the velocity data in the open channel flow and after plotting the velocity vs time they got spikes. They applied different methods for despike the data, the results obtained by applying acceleration threshold method and wavelet threshold method are:

Despiking Method	**Parameters**	**No. of spike events**	N_{it}	**Final standard deviation (cms^{-1})**	**Replacement strategy**
Acceleration	λ=1.5, K=1.5	834	10^b	13.17	1 preceding
Wavelet	Universal	213	2	14.33	Mean

b-five iteration for deceleration and five for acceleration

The results obtained by Goring and Nikora (2002) are:



Detection of typical multipoint spike event (light line) and its replacement (heavy line).

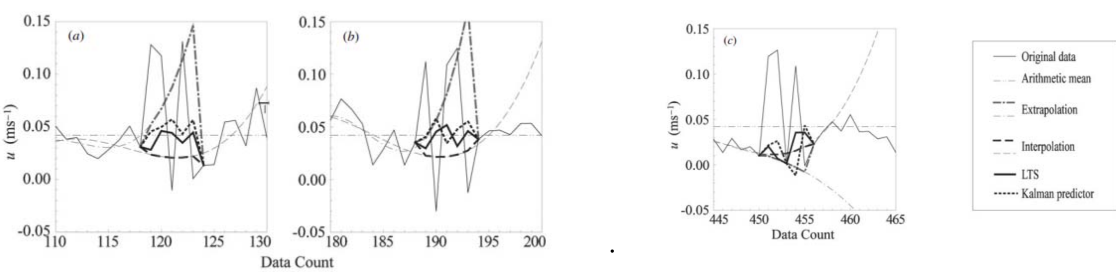
Despite the fact that it is not possible to find an extensive threshold for identifying the spurious data Mahdi Razaz and Kiyosi Kawanisi (2011) attempts to describe an effective technique for detecting spikes. They introduced a new parameter Q_n which is a robust scale estimator to modify the universal threshold. They assumed that the dataset is a stationary time series that means the mean and standard deviation of the dataset does not changes with time.They suggested the formula for Qn as

$$Qn=C_{Qn}\,2.2219\{|x_i - x_j|; i < j\}_k$$

Where C_{Qn} is a bias correction factor and its value suggested by authors is n/(n+1.4) when n is odd and n/(n+3.8) otherwise. The notation k stands for k^{th} statistical order. The steps that are followed in this method are:

1. The dataset is transferred to zero mean time series which is accomplished by high passing the series.
2. The wavelet packet basis is extracted using a spline filter. The data are represented in terms of wavelet basis d_i
3. Selecting the shrinkage criterion as Qn.
4. The components with non zero coefficients are considered to be the spikes.
5. These spikes are generally replaced by the methods like interpolation, extrapolation and arithmetic mean but Mahdi Razaz et al. (2011) used linear time series model and Kalman predictor.

The results obtained in this paper are



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2.3 Phase space threshold method:

PST method detects typical multipoint spike event and hrlp in their replacement .This method was first proposed by Goring and Nikora in 2002, it uses the concept of three dimensional poincare maps. The derivative of a signal enhances their high frequency component that is, it enhances the spikes. In the poincare map the variables and their derivative are plotted against each other thereby generating an ellipsoid. The points lying outside this ellipsoid are considered as spikes. After detecting the spikes the iteration process begins and it continues till all spikes detected falls to zero. The steps adopted by Goring and Nikora in their paper for this method are

a. Calculate the first and second derivative of the variables as

$$\Delta u_i=(u_{i+1}-u_{i-1})/2 \quad \text{and} \quad \Delta^2 u_i=(\Delta u_{i+1}-\Delta u_{i-1})/2$$

b. Then calculated the standard deviation of the three variables as σ_u , $\sigma_{\Delta u}$ and $\sigma_{\Delta^2 u}$ and from there calculating the expected maxima by the equation, $E=\lambda\sigma$. Where λ is a universal threshold and given by $\lambda=\sqrt{(2\ln n)}$ (Donoho and Johnstone 1994)

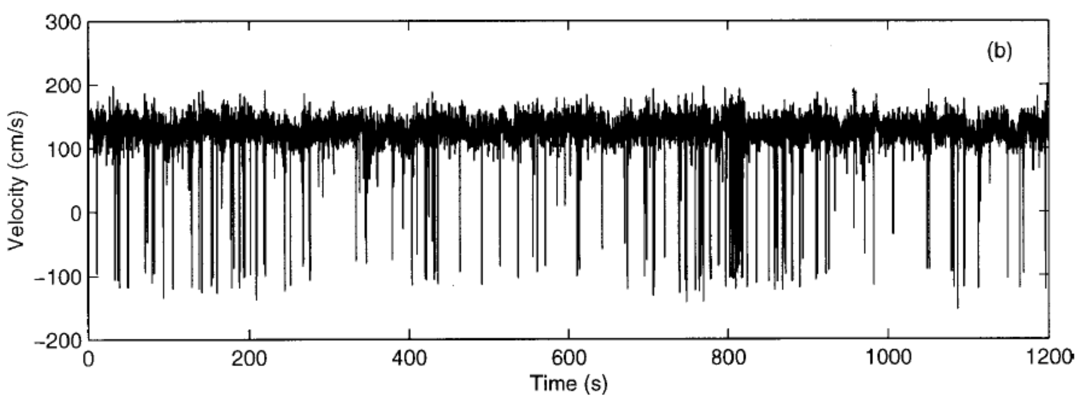
c. Calculate the rotating angle θ by the equation

$$\theta=\tan^{-1}(\Sigma u_i \Delta^2 u_i / \Sigma u_i^2)$$

d. Generate an ellipsoid of u, Δu and $\Delta^2 u$ with the angle calculated from the correlation between u and $\Delta^2 u$. For each pair of variables calculate maxima and minima. In the case of Δu vs u the major axis will be $\lambda\sigma_u$ and minor axis will be $\lambda\sigma_{\Delta u}$ while in the case of $\Delta^2 u_i$ vs Δu_i the major axis will be $\lambda\sigma_{\Delta u}$ and the minor axis will be $\lambda\sigma_{\Delta^2 u}$

e. The points that are lying outside then fitted to a third degree polynomial on either side of the removed spikes and this iteration continues until no spikes detected.

Goring and Nikora(2002) projected three different plots for the three variables in 2D and results obtained are:

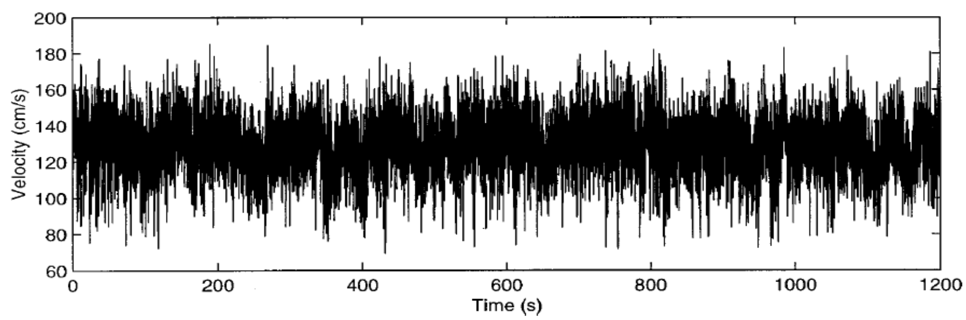


Sample dataset used for despiking method: Contaminated record

Results of applying different methods to contaminated data set for various parameters:

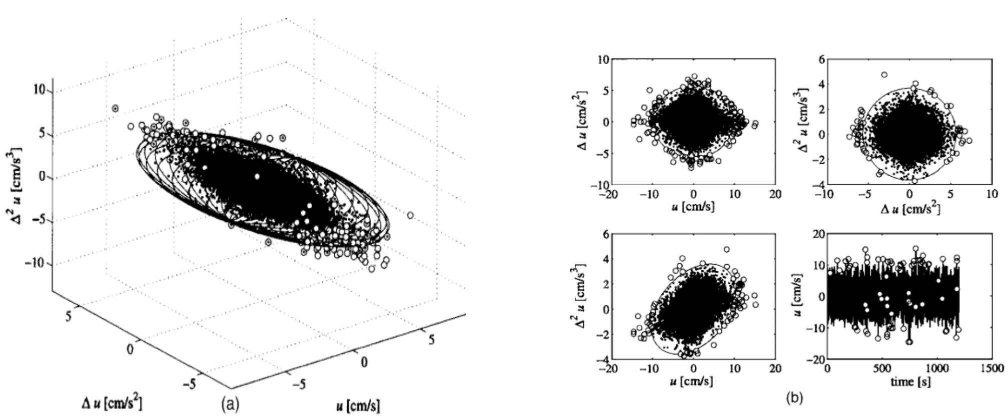
Despiking Method	**Parameters**	**No. of spike events**	**N_{it}**	**Final standard deviation (cms^{-1})**	**Replacement strategy**
Three-Dimensional phase space	Universal	194	4	13.78	Cubic fit

N_{it} is the number of iterations



Contaminated record of above figure after cleaning by phase space threshold method with cubic polynomial fitted to 12 points on either side of spikes

Nobuhito Mori et al. (2007) modified this method suggested by Goring and Nikora (2002). As the ellipse made in the paper of Goring and Nikora (2002) in 2D space for three different pairs. The authors Nobuhito Mori at al. (2007) drawn a true 3D ellipsoid and hence comparing with Goring and Nikora's (2002) result it gave more precise results. Comparison between a real 3D space ellipsoid and the 2D ellipse of three different pairs given by Nobuhito Mori et al.(2007) is given below:



Example of despiking by two phase space methods: (a) true three dimensional (3D) phase space method; (b) Pseudo-3D phase space method (top left) u-Δu, (top right) Δu-Δ^{2}u, (bottom left) u-Δ^{2}u, (bottom right) time history of u

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CONCLUSION:

In this paper, reliability of three important methods for despiking ADV data are studied and following conclusions are made:

1. Instead of using the conventional constant values of K_g and K_σ in acceleration threshold method, the results obtained from changing the parameter λ and thereafter the values of K_g and K_σ will show superior results.
2. The single point spikes produced on either side of the data are detected and replaced easily but the multiple spikes are much more difficult to detect.
3. The true 3D phase space method is more reliable than the original phase space method as this method removes spikes significantly.
4. The robust scale estimator Q_n found to be more satisfactory as it removes spikes compare with the phase space method significantly.
5. Therefore, modified wavelet threshold method is more reliable than the all methods mentioned above.

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