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Acoustic turbidity as online monitoring tool for rivers and sewer networks

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ABSTRACT

This paper focuses on the use of the raw acoustical turbidity and velocity data as a flow online monitoring tool. Its aim is to demonstrate that, with adequate instrumental settings, interesting results can directly be seen on the raw data. As illustration, some experimental results on a combined acoustic turbidity and velocity analysis on a river are shown. It demonstrates the great potential of the acoustic measurements in sediment transport studies by the combined information on velocity and turbidity. Another application is the study of a wastewater collector inlet for which the comparison with standard measurement methods is possible. The acoustic turbidity raw data can easily be used for qualitative suspended solids concentration studies. It is also shown that more accurate results on the water height can be obtained through the acoustic turbidity.

1. Introduction

The demand for a better characterization of water quality in its natural environment or in sewer systems has increased with the evolution of the water policy laws. Erosion, transport, and deposition of sediments are primary and growing environmental, engineering, and agricultural issues around the world. Environmental impacts of sedimentation are various, going from mechanical obstruction to contamination by pollutants attached to and transported by sediments [1].

To monitor the pollutant load, an essential parameter is the Suspended Solids Concentration (SSC). Unfortunately only few monitoring techniques provide real time data. Currently, the suspended solids concentration in water is either measured through sampling and laboratory measurement, or by optical methods (nephelometric and optical backscatter sensors) [2,3]. The major drawback of the first method is the time delay between the sampling and the measurement which forbids any real time retroaction on the water regulation. On the other side, the optical measurements might provide values of the total suspended solids concentration after adequate calibration.

Due to the importance of flow velocities in the pollutant load behaviour, monitored water ways are often equipped with Acoustic Doppler Velocimeters (ADV), Acoustic Doppler Current Profilers (ADCP) [4–7] or Acoustic Doppler Velocity Profilers (ADVP) [8]. In addition to velocities, these devices also monitor the acoustic backscattered signal amplitude, or directly the acoustic turbidity, which is proportional to the SSC. In this work, we focused on the analysis of the raw acoustical turbidity and velocity data at high spatial and temporal resolution for the flow description in a river and a wastewater plant inlet.

2. Acoustic measurement

2.1. Pulsed measurement principle

All ADVs, ADCPs and ADVPs work on the Doppler principle. In the beginning of a measurement cycle, an ultrasonic burst of a given frequency and of fixed duration is emitted into the medium. At the end of the emission, the instrument switches into reception mode. The emitted signal travels along the beam axis and each

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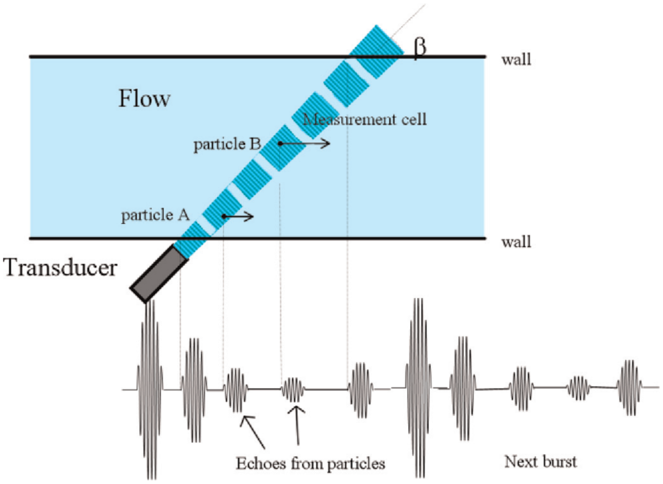

Fig. 1. Pulsed Doppler principle.

encountered particle partly backscatters the acoustic wave. If the particle is moving in the medium, a frequency shift is observed in the backscattered wave (the so-called Doppler shift). If a measurement of the fluid velocity is intended, this assumes that the velocity of the suspended particles, tracers in this case, is equal to the flow velocity.

Fig. 1 shows the schematic pulse emission and its encounter with particles in the flow. One can also see the shape of the backscattered signal on the bottom of the figure.

During its propagation in the medium, due to thermal conduction and viscosity effects, the intensity of the ultrasonic wave decreases. In particle laden flows, an additional attenuation due to the scattering and the absorption by the particles themselves contribute to the intensity decay.

Anyhow, the investigated water depth has two limitations. On one end, in the transducer near-field zone, it is difficult to extract accurate data. Thus, pulsed systems suffer from a blind zone that avoids the detection in the front of the transducer. The upper detection limit will depend on the beam attenuation in the medium.

The interesting fact with pulsed Doppler instruments is that the flow velocity and the backscattered signal amplitude profiles can be simultaneously recorded on the insonified water column.

2.2. Acoustic turbidity

On the theoretical point of view [9–11], for an acoustic flowmeter, the recorded root-mean-square of the backscattered voltage can be written at range r, distance from the transducer, as follows:

$$V_{rms} = \frac{k_s k_t}{r\psi} M^{1/2} e^{-2\alpha r} \tag{1}$$

where the medium depending variables are

$$\alpha = \alpha_w + \alpha_s = \alpha_w + \frac{3}{4\rho_s\, r} \int_0^r \frac{\chi m}{\langle a_s \rangle} M(r')dr'$$

$$k_s = \frac{\langle f \rangle}{(\rho_s \langle a_s \rangle)^{1/2}}$$

V_{rms} is an average value over a large number of backscattered receptions. k_t is an acquisition system parameter which is constant for a given instrument working at a given frequency. ψ stands for the near field correction: it takes account for the departure of spherical spreading. The transducer near-field, $r_n = \pi\, a_t^2/\lambda$, where λ is the wavelength of the emitted pulse and a_t the transducer radius, is avoided in our measurements thus ψ=1. M is the particle concentration. α_w is the attenuation due to the water absorption and can be calculated using the semi-empirical formula in [12]. α_s is the particle attenuation mainly due to scattering for non-cohesive particles insonified at megahertz frequencies ultrasound [13]. As shown, α_s is related to the normalized total scattering cross-section χ_m of the particle. k_s represents the particle backscattering properties, with $<f>$ the averaged form function which describes the backscattering characteristics of the particles, ρ_s the particle density, $<a_s>$ the mean particle radius.

Given Eq. (1), the exact expression of the acoustic turbidity would be

$$T = \frac{V_{rms}\ r}{k_t} e^{2\alpha_w r} = k_s M^{1/2} e^{-2\alpha_s r} \tag{2}$$

In Eq. (2), the right part only depends on the particle characteristics. Thus, the acoustic turbidity directly includes information about the particles encountered in the explored medium. With adequate analysis, different elements concerning the nature and the concentration of the particles can be extrapolated. If the particles in the medium are well known, in terms of shape, size and density, their acoustic characteristics can be determined. If the content of the flow is unknown, only a qualitative interpretation can be made as the relative behaviour of the SSC for example.

When using multi-frequency backscattering measurements, it should be noted that when $\lambda > 2\pi\ a_s$ mostly backscattering is observed and scattering losses rise rapidly with increasing sediment size [14,15]. Therefore, if the smallest particle to be detected has a radius a_{min}, with c the speed of sound, the optimal choice of the observation frequency F would be:

$$F = \frac{c}{2\pi a_{min}} \tag{3}$$

Anyhow, if comparison data are available, the acoustic turbidity can be linked to the SSC after adequate calibration or give more precise concentration values by using the data inversions techniques mentioned in [11,14,16,17]. In this paper, our aim is to avoid the data inversion and to rely only on the raw acoustic turbidity and velocity data to describe the flow behaviour.

2.3. Instrumentation

All the following measurements were done with UB-Flow ADVPs from Ubertone, France. They are the commercial devices with characteristics and performances similar to the fluxmeter presented during ISUD 2006 [18]. Both instruments allow multi-frequency measurements with two wideband transducers emitting with a given tilt regarding to the instrument's base (see Table 1). The river measurements were done with an UB-Flow 156 and the wastewater treatment plant ones with the more recent UB-Flow 315 flowmeter. The main benefit of this type of instruments is the simultaneous acquisition of different settings.

A measurement cycle with different configurations, frequencies and others parameters, can easily be constructed. For each configuration, the user has to set the emission frequency, the pulse repetition frequency, the number of recorded profiles, the position

Table 1
Technical details of Ubertone profilers.

Reference		Transducer 1	Transducer 2
UB-Flow 156	**Min frequency (MHz)**	0.80	3.75
	Max frequency (MHz)	1.94	7.54
	Tilt (deg)	75	55
UB-Flow 315	**Min frequency (MHz)**	0.80	2.08
	Max frequency (MHz)	2.08	4.25
	Tilt (deg)	65	97

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