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A Miniature UVP Hardware Dedicated to Process and Environmental Monitoring

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Ubertone has developed a new hardware for industrial and low power applications. This new development pushes further the technological limits of UVP to reach a lighter and smaller board. The electronics consumes less and powers up very quickly. The device communicates through the Modbus protocol over RS485. The comparison with a reference UVP proved that the velocity measurement reached same accuracy and comparable noise level. The first measurements on river are promising for environmental applications. The device provided a velocity profile over 1,50m deep section and the bottom tracking showed good results. The range-velocity ambiguity was optimized by shifting the minimum velocity. The ghost echoes could be filtered thanks to the phase coding method.

Keywords: Hardware, Environmental flows, Flow metering and flow mapping, Flow field monitoring.

1. Introduction

The UVP technology has been introduced to Fluid Mechanics in 1985 by Prof. Takeda [1]. Since then, many researchers have shown promising applications, especially in flow metering, rheometry and flow mapping. Nevertheless, robustness and power consumption are two major obstacles for environmental and industrial application of UVP (or UDV).

Ubertone has shown the possibility to embed a complete UVP in a single probe, the UB-Flow, allowing the measurements of high resolution velocity profiles in open channels and harsh environments. This hardware was presented six years ago at the 8th ISUD [2] and the 6th ISCE [3]. In these papers, the characteristics of the UB-Flow device, the measurement principle and first results were described. The new device presented in this paper is based on the same measurement principle. However, the size, the weight and the power consumption were reduced. In this paper, the characteristics of the new device, as well as the first results on two flumes and an urban river are presented.

2. Materials, experiments and methods

2.1 Mini UVP Hardware

The Mini UVP Hardware (see Fig. 1) is based on a completely new design, including innovation in the emitting circuit and the demodulation process. The signal processing was optimized for this new architecture and includes coherent Doppler estimation, automatic gain control, static echo filter, phase coding and blind zone compensation.

Figure 1: The new Mini UVP Hardware

This results in a much lighter, smaller and low power circuit that can drive two transducers, opening several application perspectives. Communication goes through Modbus protocol via RS485, which can be wired through USB directly on the computer. The user can access to many information as the velocity profile, SNR (signal-to-noise ratio) profile, echo profile, temperature, pitch and roll. Its main characteristics are given in Table 1.

Table 1: Main characteristics of the Mini UVP Hardware

POWER	
Input	5V DC
Consumption	0,5 to 1W
Power up	0.6s
PHYSICAL	
Size	21 x 85mm
Weight	14g
ACOUSTICS	
Number of transducers	2
Emitting frequency	400kHz to 3,6MHz
PROFILING PERFORMANCES	
Spatial resolution	1 to 2mm (frequency dependent)
Number of cells	100
EMBEDDED SENSORS	
Temperature	± 0.5°C
Pitch + Roll	± 0.5°

2.2 Experiments

This article presents three sets of experiments. The first one was done at Ubertone's office. The performances of the new device were compared to a reference UVP: the UB-Lab profiler [4]. The measurements were made in a small flume (8 x 30 x 200cm) and the same transducer of 3MHz was used for both devices. It was placed horizontally outside the flume, on the wall, with a Doppler angle β of 70° between the transducer axis and the flow axis (see Fig. 2 - a). Ultrasonic transmission gel was put between the transducer and the wall.

For the second and the third experiment, two 1 MHz transducers were fixed on a floating board with a Doppler angle β of respectively 65° and 97°. The transducers were connected to the Mini UVP Hardware, which was plugged on a Raspberry Pi board. A computer could communicate with it through Wi-Fi.

The second experiment was done on the flume (0.6 x 15m) of ICube (Strasbourg, France). The floating board was maintained at a position with a rope (see Fig. 2 - b). Measurements have been done for two flow rates: about 266m^3/h and about 436m^3/h, with water levels of resp. 43 and 50cm.

The third experiment was done on the Aar, a branch of the river Ill (Alsace, France). The board was moved on the water surface along the transect with a rope (see Fig. 2 – c). As a consequence, the board was never completely immobile, the trajectory was not exactly straight-lined and the translation speed was approximated.

Figure 2: Measurement on Ubertone's flume (a), on ICube's flume (b) and on river Aar (c)

2.3 Method

As it is not common to use the UVP technology in rivers, the setup of the device is a critical point in this environment. The configuration is mainly constrained by the velocity range. Indeed, the velocity range along the flow direction R_v is given by the pulse repetition frequency *PRF* and the emitting frequency f_0:

$$2.f_0.R_v.\cos(\beta) = c.PRF \qquad (1)$$

c is the sound speed in the water. If the scatterer velocity exceeds R_v, a Nyquist jump occurs.

The fact is that the velocity range is a limiting factor of the exploration depth H_v [5]:

$$H_v.R_v = c^2.\tan(\beta)/(4.f_0) \qquad (2)$$

In the small flume used for the comparison between Mini UVP Hardware and UB-Lab, the speed is quite slow, 10 to 20cm/s. In this case, it is easy to measure through the full flume width (8cm) or the water depth (<30cm). However, the velocities in rivers can be much faster. For example the Aar reaches 50 to 100cm/s where the measurements were done. Thus, the explorable depth for the velocity profile is limited in comparison to the river depth (~2m).

One more limitation of the UVP technology is the bias induced by "ghost echoes", i.e. echoes from a previous pulse. For all the results presented in this study, the phase coding method was used to differentiate echoes from the current pulse and echoes from previous ones. The ghost echoes are turned into white noise and can thus easily be identified in the SNR. This filtering method is part of a unique technological system devised by Ubertone.

3. New UVP Hardware vs. UB-Lab

3.1 Noise

The measurement of the RMS value of the noise is done by setting the cell thickness to 0 (no emission pulse) and the gain to the maximum. The results show that both devices have almost the same noise level, i.e. 2,5 µV.

3.2 The velocity

Table 2: setup used for velocity measurement in the flume

	UB-Lab	Mini UVP HW
f_0 [MHz]	2,88	3,0
PRF [Hz]	799	800
Number of cells	30	30
Position of 1st cell [mm]	9,08	8,76
Cell thickness [mm]	3,30	3,21
Inter-cell distance [mm]	3,49	3,45
Number of samples	128	128
Gain	Auto	Auto

Fig. 3 shows the velocity profile in the flume for both hardwares. The depth is given along the horizontal axis, perpendicular to the flow direction. These measurements have been made with the setup given in Table 2.

Discussion: The profiles of both devices are almost perfectly superimposed and give similar values of SNR. The profile is typical of a turbulent flow between smooth walls.

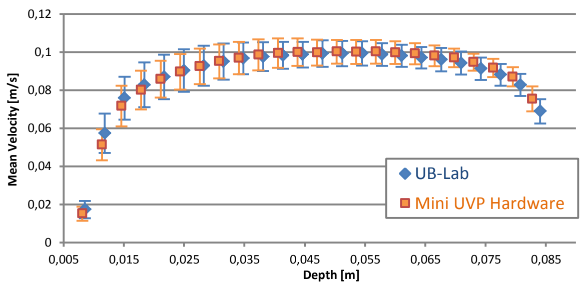

Figure 3: Horizontal velocity profiles in a rectangular flume. Average and standard deviation over 240 instantaneous profiles.

4. Measures on flume with Mini UVP HW

In Fig. 4, the average of 50 velocity profiles for two flow rates: about 266m3/h and about 436m3/h, are given. The measures have been done with the same configuration in both cases (see Table 3).

Discussion: On Fig. 4, the bottom of the flume could not be reached with the velocity profile because of the bottom blind zone due to the side lobes of the acoustic beam.

Table 3: ICube flume velocity measurement configuration

f_0 [MHz]	1
PRF [Hz]	600
Min measurable velocity [m/s]	-0.03
Nyquist Range [m/s]	1.05
Number of cells	100
Position of 1st cell [mm]	9.64
Cell thickness [mm]	5.93
Inter-cell distance [mm]	5.93
Number of samples	128
Number of profiles	10
Gain	auto

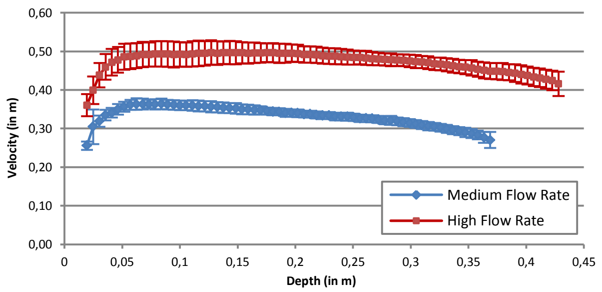

Figure 4: Average velocity profiles and standard deviation for two flow rates in the flume of the ICube Laboratory

5. Measurements on river with Mini UVP HW

For the river measurements, three sets of configuration (see Table 4) have been used: one for the bottom tracking through the transect, another for the velocity profile on a fixed position and a last one for the velocity profile through the transect.

Table 4: Measurement settings for river measurements

	Bottom Tracking	Velocity Profile	Transect Velocity
Doppler angle [°]	97	65	65
f_0 [MHz]	1	1	1
PRF [Hz]	300	420	420
Min velocity [m/s]		-0.10	-0.03
Nyquist Range [m/s]		0.74	0.74
Number of cells	82	85	85
Position of 1st cell [mm]	19,6	96.74	96.74
Cell thickness [mm]	20,0	20.02	20.02
Inter-cell distance [mm]	29,7	18.53	18.53
Nb of samples	50	128	128
Nb of profiles	10	10	10
Gain	20 dB	auto	auto

5.1 Bottom tracking

An estimation of the river bed (see Fig. 6) was obtained pulling the board manually across the river and using the settings given in Table 4. The bottom of the river is located by a peak in the backscattered echo profile.

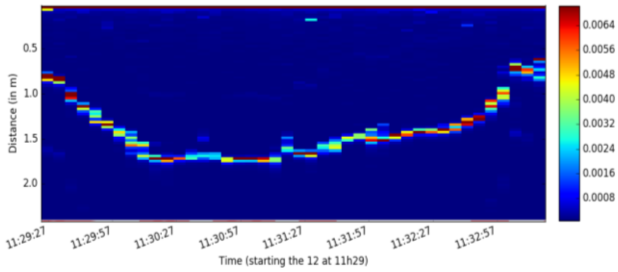

Figure 5: Amplitude profiles over the river (V)

The Fig. 5 represents the echo amplitude of the transducer (β=97°) and shows the evolution of the depth. Each vertical is an amplitude profile. An algorithm of level detection is able to give automatically the position of the river bottom, as shown on Fig. 6.

The bottom tracking (Fig. 5 and 6) and the velocity measurement (Fig 8) were made simultaneously: the board was moved along the transect in 4 minutes. In Fig. 6 and 8, the position on the transect is given as abscissa. The 0 and 10m positions are related to the first and last measurements that were made. Both are located at about 1.5m from the shore.

Discussion: On Fig. 6, when the algorithm does not find the bottom peak, the point is missing on the curve. Irregularities are due to the manually transect crossing. The position on the transect is given approximatively. A precise bathymetry could be obtained by recording precisely the position of the board (with an external positioning system) and by taking into account the pitch and roll angles (given by the Mini UVP Hardware).

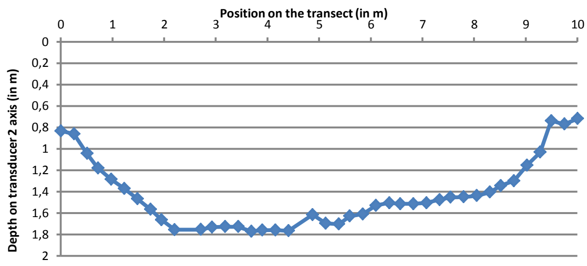

Figure 6: Bottom tracking with the Mini UVP Hardware

5.2 Velocity profile in the river

The following measurement (Fig. 7) was done at a fixed position using the settings given in Table 4, in the middle of the river, with a depth of 1.80m.

The first 20cm of the measured profile have been rejected because of ghost echoes. From there, the velocity decreases starting at a velocity of about 31cm/s in flow axis.

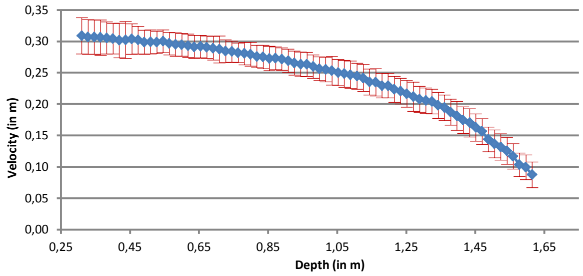

Figure 7: River velocity profile with the Mini UVP Hardware

Discussion: Fig. 7 shows a velocity profile for which the standard deviation is quite constant along the whole measured depth. The velocity profile is obtained almost until the river bottom, but not in the first 30cm. In the rejected 20cm, the velocity could be obtained by changing the PRF, which shifts the ghost echoes [5].

As for the configuration, it is important to pay attention to the Nyquist range, which is given by the PRF, and to the minimal measurable velocity to set. Here, the PRF of 420Hz gives a range of 74cm/s. Setting the minimal velocity to -10cm/s in case of turbulences leads to a maximal measurable average velocity of 64cm/s. Knowing that the maximal velocity is around 31cm/s we can say that this configuration leaves margin for turbulences and is therefore well suited.

5.3 Mean velocity through the transect

When measuring the velocity by coherent Doppler method, the visibility may be limited by the presence of ghost echoes. In this case, it is possible to use phase coding and to apply a SNR filter to improve the velocity profile.

This filter was applied on the velocity data of the first transducer (β=65°) during the crossing of the transect (see Fig. 8 – a) and we obtained the evolution of the mean velocity when moving away from the shore (see Fig. 8 - c). Moreover, the values beneath the bottom given by the water lever algorithm where suppressed. And as in paragraph 4, there may be a blind zone at the bottom, so the values in this area have also been removed.

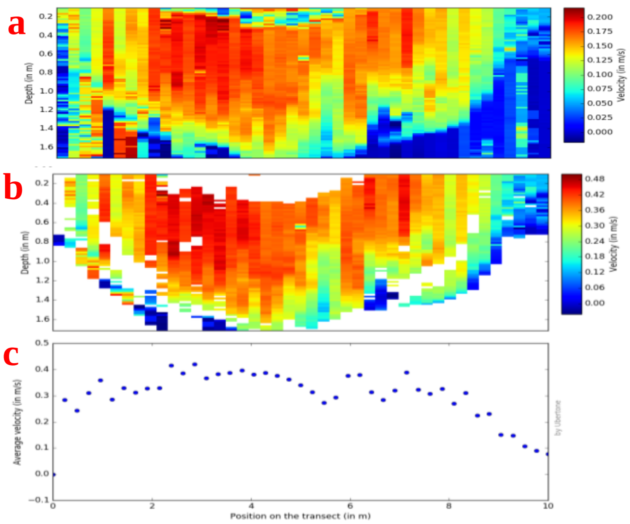

Figure 8: River raw (a), filtered (b) and mean filtered (c) velocity on flow axis, along the transect

Discussion: The filter is determined on the mean SNR profile of each mean velocity profile (one column on the color plots). Each profile is actually an average of 10 profiles. Thus, there are still some values that are not properly filtered as shown on the color plot in Fig. 8. Filtering individually each of the 10 profiles with its corresponding SNR profile before averaging would enhance the result.

Moreover, the board was moving with the waves and the pitch and roll angles have not been taken into account, nor for the bottom tracking in part 5.1, neither for the velocity profiles here.

6. Summary and outlooks

With this new hardware development, we pushed further the technological limits of UVP to reach a lighter and smaller board. The electronics consumes less and powers up very quickly. It is equipped with two transmit/receive channels allowing to measure up to 100 cells in a profile. The communication protocol allows easy usage of the device. The main features remain: automatic gain control, static echo filter, phase coding, blind zone compensation, signal-to-noise ratio estimation.

The Miniature UVP Hardware shows results close to the devices already commercialized by Ubertone. These first measurements are promising for application in small rivers and open channels. The main limitation for this application is the range-velocity ambiguity which is inherent to the coherent Doppler method. To be able to see deeper in the river even with high velocities, other methods [6] have to be explored.

The missing values due to ghost echoes could be measured by changing the PRF, which shifts the ghost echoes.

The specifications of this new UVP Hardware devised by Ubertone break new ground for a wide range of applications. Indeed, this 14g board will be embedded on a flying drone for flow measurement on rivers. This project is in partnership with LORIA, Pedon Environement and Alerion and is co-funded by the EU.

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