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A MINIATURE UVP HARDWARE APPLIED TO ENVIRONMENTAL MONITORING

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ABSTRACT

A new hardware has been developed by Ubertone for low power and high resolution applications. This new development pushes further the technological limits of UVP (Ultrasonic Velocity Profiler) to reach a lighter and smaller board. The electronics consumes less than conventional profilers with similar performances and powers up very quickly. The device communicates through Modbus protocol over RS485. The comparison with a reference UVP proved that the velocity measurement have the 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 with a 2 cm resolution and the bottom tracking showed good results. Easy data visualisation and post-processing is provided by the online Web Assistant from Ubertone.

Keywords: Instrumentation, Environmental flows, high resolution velocity mapping, Flow field monitoring.

1. INTRODUCTION

The UVP (Ultrasonic Velocity Profiler) technique has been introduced to Fluid Mechanics by Takeda (1986). This technique based on coherent Doppler allows to measure velocity profiles with a high spatial and temporal resolution. Since then, many researchers have shown promising applications, especially in flow metering, rheometry, flow mapping and environmental flow studies, as shown in Hurther et al. (2002). Kojima (2006) have shown the possibility to measure a velocity field with a UVP unit, but the device weights 10 kg and needs to be attached to a computer and to the power grid. Indeed, robustness and power consumption are two major obstacles for environmental application of UVP. On the other side, the ADCP technique is dedicated to long range measurement using long coded pulses inducing a low spatial resolution as shown in Brumley (1991). But ADCP devices are designed to fit for outdoor applications.

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 (Fischer 2010; Fischer 2012). This device can be considered as a high resolution ADCP that fits particularly for shallow flows. The new device presented in this paper is based on the same UVP 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 in two flumes and an urban river are presented.

2. MATERIALS, EXPERIMENTS AND METHODS

2.1 Measurement method

An ultrasonic pulse is emitted in a narrow beam and the particles, suspended in the flow, scatter the pulse. The echoes of the particles are received by the same transducer which allows to observe a profile composed of many measurement cells distributed along the beam axis (see Fig. 1). The signal is processed providing information of velocity (Takeda 1986).

Our devices use the coherent pulse Doppler method to estimate the velocity from the phase shift of the acoustic signal in a same volume during consecutive emission-reception cycles. The set of data samples coming from the same volume is called "Doppler signal" and has a frequency f_D which is related to the flow velocity v in the corresponding volume according to:

$$V = c.f_D/(2.f_0.\cos(\beta)) \quad [1]$$

where c is the sound speed in the water, f0 the emitting frequency and β the Doppler angle between flow and beam.

A common limitation of the pulsed technique is the blind zone that occurs in front of the transducer. The same transducer being used to emit and receive, the processing unit is first blinded by the high energy being emitted.

One more limitation of the UVP technology is the bias induced by "ghost echoes", i.e. echoes from a previous pulse. This is filtered thanks to the phase coding method which is part of a unique technological system devised by Ubertone.

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, ie. the maximal range of velocities the device can measure. Indeed, the velocity range along the flow direction, R_v, is given by the pulse repetition frequency PRF and the emission frequency f_0:

$$2.f_0.R_v.\cos(\beta) = c.PRF \quad [2]$$

If the velocity of the scatterer exceeds R_v, a Nyquist jump occurs.

The fact is that the velocity range is a limiting factor of the exploration depth H_v, ie. the maximal depth where the device can measure:

$$H_v.R_v = c^2.\tan(\beta)/(4.f_0) \quad [3]$$

For example the velocity in river Aar reaches 50 to 100cm/s where the measurements were done. Thus, the exploration depth for the velocity profile is limited in comparison to the river depth (~2m).

It is possible to set a parameter, the minimal measurable velocity, to shift the velocity range. Indeed, by default, the measurable velocities are between $-R_v/2$ and $+R_v/2$: the minimal measurable velocity is in fact equal to $-R_v/2$. But measuring in the direction of the main flow in a flume for example allows to assume there are almost no negative velocities to measure. So putting the minimal measurable velocity to nearly zero and thus measure velocities up to $+R_v$.

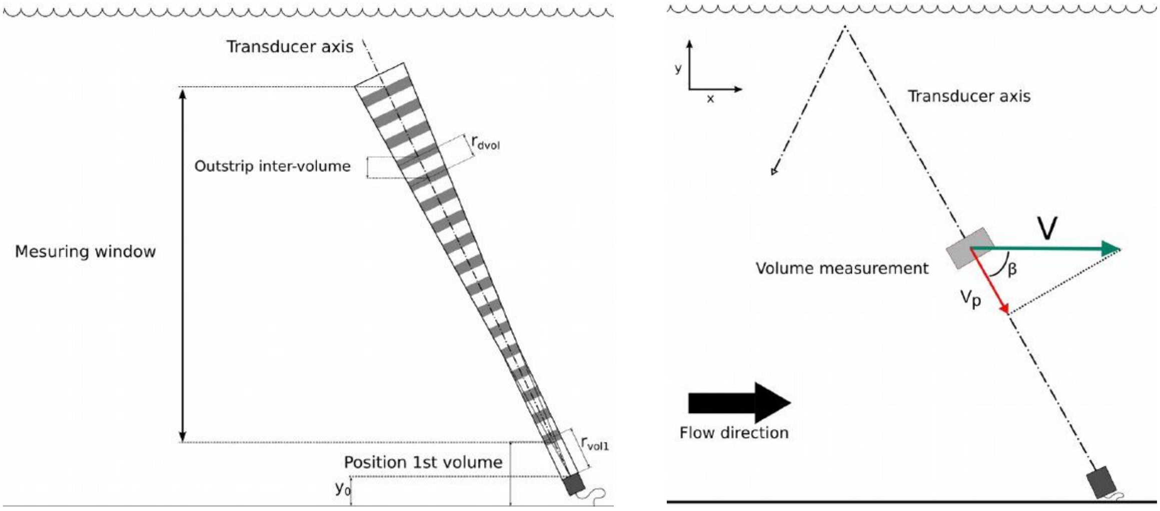


Figure 1. Spatial distribution of the cells and velocity measurement principle

2.2 Mini UVP Hardware

The Mini UVP Hardware (see Fig. 2) 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 2. 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 have access to much information as the velocity profile, SNR (signal-to-noise ratio) profile, echo profile, temperature and pitch and roll angles.
The main technical 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

ACOUSTIC	
Number of transducers	2
Emitting frequency	400kHz to 3,6MHz
PROFILING PERFORMANCES	
Spatial resolution	down to 1-2mm (frequency dependent)
Number of cells	100
EMBEDDED SENSORS	
Temperature	± 0.5°C
Pitch + Roll	± 0.5°

2.3 Experiments

Several experiments have shown the capabilities of this new hardware.
Measurements have been done in the small flume at Ubertone's office, in the taller flume of ICube (Strasbourg, France) and in the Aar, a branch of the river Ill (Alsace, France).

In this article, we present some experiments conducted in three different environments:

- In Ubertone's flume:

The purpose of those measurements was to compare the new hardware with an UVP device dedicated to laboratory measurements (UB-Lab).
The same transducer of 3MHz was used for both devices. It was placed horizontally outside the small flume (8 x 30 x 200cm), on the wall, with a Doppler angle β of 70° between the transducer axis and the main flow direction (see Fig. 3 – a). Ultrasonic transmission gel was put between the transducer and the wall.

- In ICube's flume:

The purposes here were to compare velocity profiles for two flow rates and to evaluate the ability of the new hardware to measure moving over a transect.
Two 1MHz transducers were fixed on a floating board: one with a Doppler angle β of 97° for the bottom tracking, the other with a Doppler angle β of 65° for the velocity measurement. They were connected to the Mini UVP Hardware, which was plugged on a Raspberry Pi board. A computer could communicate with it through Wi-Fi.
This flume is 15 m long and 60 cm large and on the left bottom corner of the flume there is a step of 20 x 20 cm all along the flume. Two types of measurements have been conducted on this flume:

  - The board was floating in the flume and maintained at a given position with a rope (see Fig 3 – b). Measurements have been done for two flow rates: about 266m^3/h and about 436m3/h, with water levels of respectively 43 and 50cm.
  - The board was pulled cm per cm perpendicularly to the stream, from one side to the other and staying 20s immobile each time. The flow rate was set to 436m^3/h, leading to a water level of 50cm.

- In the Aar:

To test the new hardware in natural environments, bathymetry and velocity profiles measurements over a transect of a river have been conducted.
The same board as in ICube's flume was used here. The board was floating on the Aar, a branch of the river Ill (Alsace, France). It was moved on the water surface along the transect with a rope (see Fig. 3 – c). As a consequence, the board was never completely immobile, the trajectory was not exactly straight-lined and the translation speed was approximated.

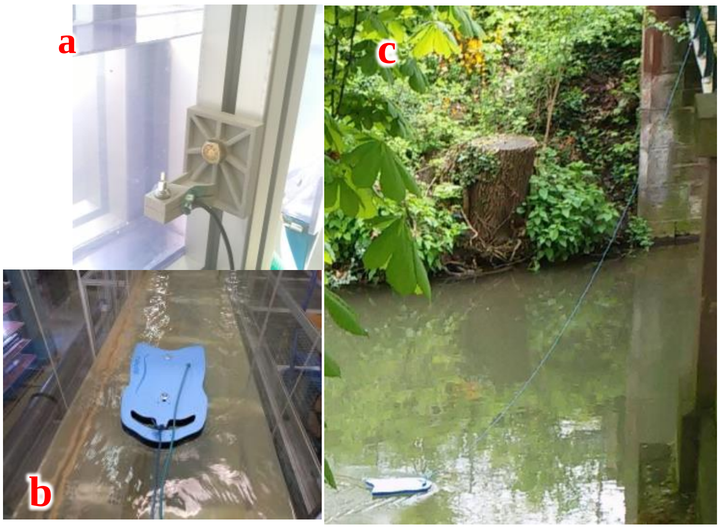


Figure 3. Measurement in Ubertone's flume (a), in ICube's flume (b) and in river Aar (c).

2.4 Data analysis tool

Ubertone has developed a set of online tools allowing to visualize and post-process the raw data recorded from the device. The measurement data are stored in the cloud and can be immediately viewed and evaluated in ready to use and comprehensive plots. It is possible to display simple plots, like averages and time series, but also to make advanced processing, like interface detection. The post-processing of the data can be adapted to the site and to the conditions.

For all the following analysis, this web server has been used.

3. NEW UVP HARDWARE VS. EXISTING VELOCITY PROFILER

When comparing the new UVP Hardware with the UB-Lab, the results show that both devices have almost the same noise level, i.e. 2.5 µV.

Moreover, the velocity profiles measured perpendicularly to the flow direction in Ubertone's flume, for both devices, are almost perfectly superimposed (see Fig. 4) and give similar values of SNR. The velocity profile is typical of a turbulent flow between smooth walls. Details on the devices configuration are given in Table 2.

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

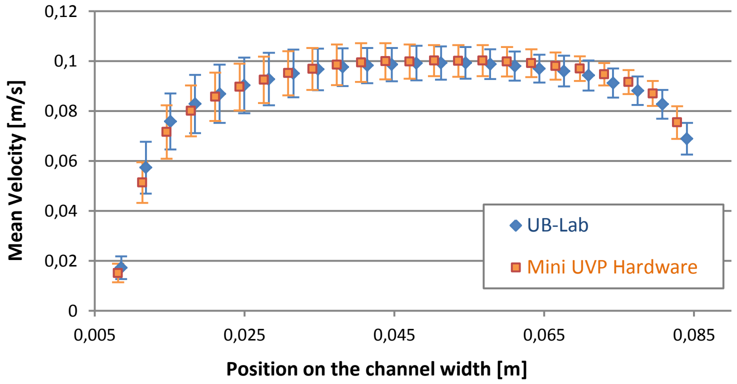


Figure 4. Horizontal velocity profiles in a rectangular flume. Velocity average and standard deviation over 40 seconds

4. MINI UVP HARDWARE IN A FLUME

For the measurements in the ICube Laboratory flume presented here, the configurations given in Table 3 were used. The one in the first column was for the bottom tracking and the second one for velocity measurement.

Table 3. ICube flume velocity measurement configuration

	Bottom tracking	Velocity
f_0 [MHz]	1	1
Doppler angle [°]	97	65
PRF [Hz]	300	600
Min measurable velocity [m/s]		-0.03
Nyquist Range [m/s]		1.05
Number of cells	100	100
Position of 1st cell [mm]	9.27	9.64
Cell thickness [mm]	5.19	5.93
Inter-cell distance [mm]	5.93	5.93
Number of samples	50	128
Number of profiles	10	10
Gain	19.98dB	auto

4.1 Velocity profiles for two different flow rates

The next two measurements have been done in the flume of the ICube Laboratory. Measuring the velocity profile with the 1MHz transducer floating on the water with a Doppler angle of 65°, we obtained regular good quality profiles for both flow rates.
The velocity values are higher and the water level is greater for the highest flow rate (see Fig. 5).

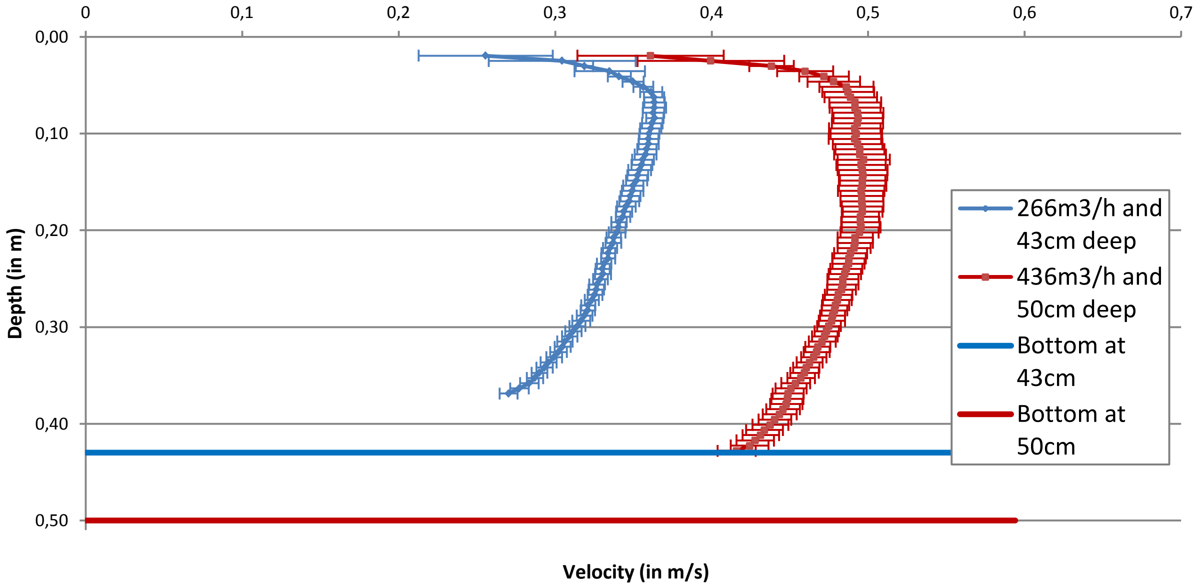


Figure 5. Average velocity profiles and standard deviation for two flow rates in the flume of ICube Laboratory

In Fig 5, we can notice, that when the flow rate was higher, the velocity profile was still of good quality deeper than for the lower flow rate. This is due to the fact that the water level was also higher, making the bottom blind zone due to the side lobes of the acoustic beam deeper. In both cases, this blind zone is why the bottom of the flume could not be reached with the velocity profile.
The fact that the transducer has to be in contact with the water is also to be considered because it influences the velocity profile in front of it: this is why the velocity seems also to tend towards 0m/s near the water surface.
As a validation of the measured velocity values, we also saw that those values, combined with the size of the flume section, give flow rates matching to those given by the flume command tool.

4.2 Data acquisition moving along a transect of the flume

By pulling the board over the flume, the evolution of the echo profiles (with the 97° transducer), and of the SNR and velocity profiles (with the 65° transducer) could be observed (see Fig. 6, resp. a, b and c).

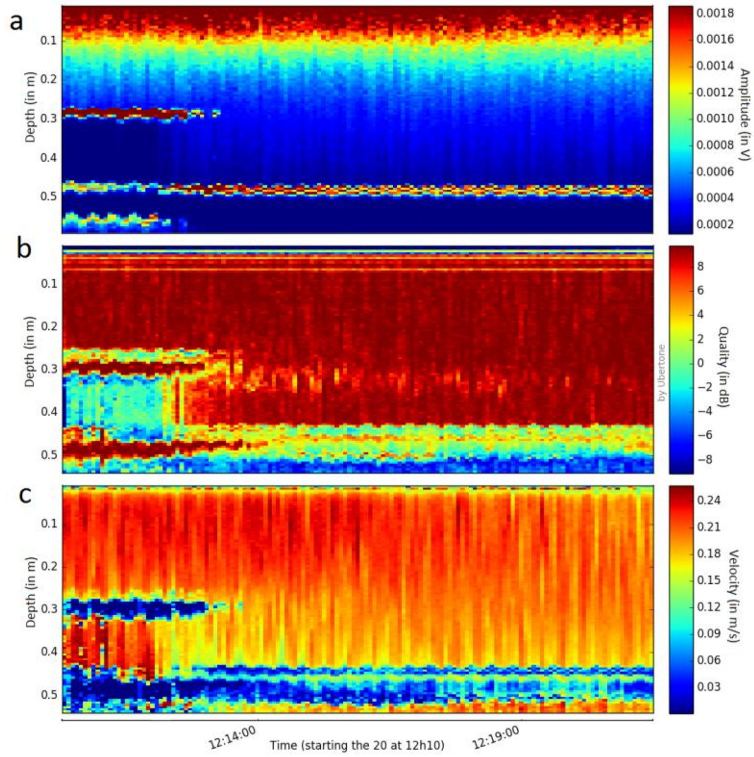


Figure 6. Evolution over time of the profiles of the echoes amplitude (a), of the SNR (b) and of the velocity (c) in the ICube Lab flume

In Fig. 6 – a, we can clearly identify the echoes amplitude peak of bottom of the flume. At the left side three peaks appear. The first is due to the surface of the 20 x 20cm step. The second is due to the main bottom wall. It can be seen because the step is filled with water. And the third is a second echo of the first peak. This kind of situation puts in difficulties the algorithm of bottom tracking. In the deeper water part, we can recognize that the bottom position relative to the device varies in a sine wave pattern, which is probably induced by the waves.
Fig. 6 – b indicates a very good quality of the signal over almost the entire water depth, the SNR being higher than 6-8dB.
Fig. 6 – c, shows the capability of the high time and spatial resolution. 141 mean profiles based on 10 instantaneous profiles each, and each instantaneous profile calculated with 128 profile samples, have been measured in 11 minutes. Spatially, each profile was made up of 100 cells with a resolution of about 6mm here.

5. MEASUREMENTS ON RIVER WITH THE MINI UVP HARDWARE

For the river measurements, three sets of configuration (see Table 4) have been used: one for the bottom tracking along the transect, another for the velocity profile on a fixed position and a last one for the velocity profiles through the transect. The bottom tracking and the velocity measurement over the transect were made simultaneously, moving on the 10m transect for 4 minutes. The position on the transect is here given by considering the manually crossing speed to be constant.

5.1 Bottom tracking

The data analysis tool processed the amplitude data given by the first transducer to a color plot (see Fig. 7 – a). Each vertical is an echo amplitude profile. The bottom is characterised by a peak in the amplitude profile. An algorithm of level detection in the data analysis tool is able to give automatically the position of the river bottom giving an estimation of the river bed (see Fig 7 – b).

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

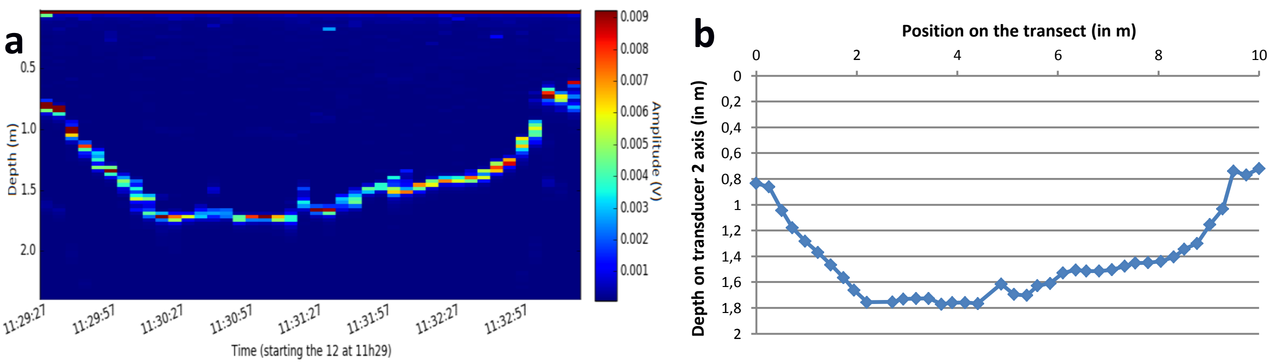


Figure 7. Amplitude profiles over the river in Volts with the Mini UVP Hardware (a) and corresponding bottom tracking (b).

On Fig. 7 – b, when the algorithm does not find the bottom peak, the point is missing on the curve. Irregularities are due to the manually transect crossing. Moreover, the position on the transect is given approximately by considering the crossing velocity to be constant. 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).

5.2 Velocity profile in the river

The following measurement (Fig. 8) was done at a fixed position in the middle of the river, where the water level is 1.80m high. The velocity profile is obtained almost until the river bottom. The velocity decreases starting at a velocity of about 31cm/s in the main flow axis direction. We can also see that the standard deviation is quite constant along the whole profile with a value of about 5cm/s, which is 16% of the maximal measured velocity. This is mainly due to the turbulences and also to the uncertainty of the estimation.

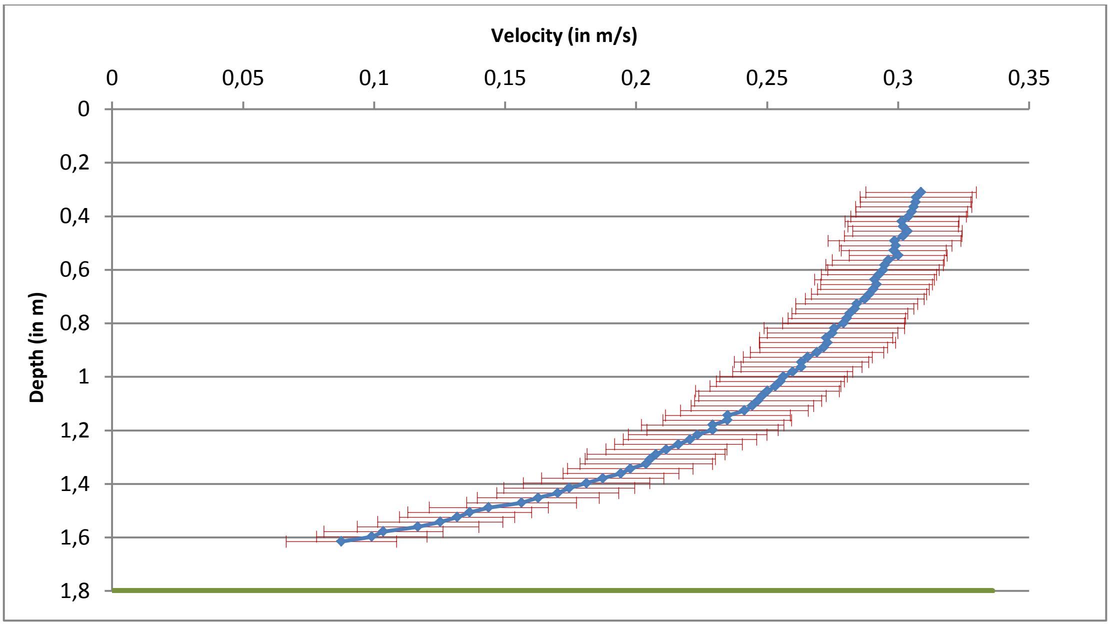


Figure 8. Average river velocity profile with corresponding standard deviation, measured at one given and fix position (approximatively the middle of the river) with the Mini UVP Hardware. The river bottom position is in green.

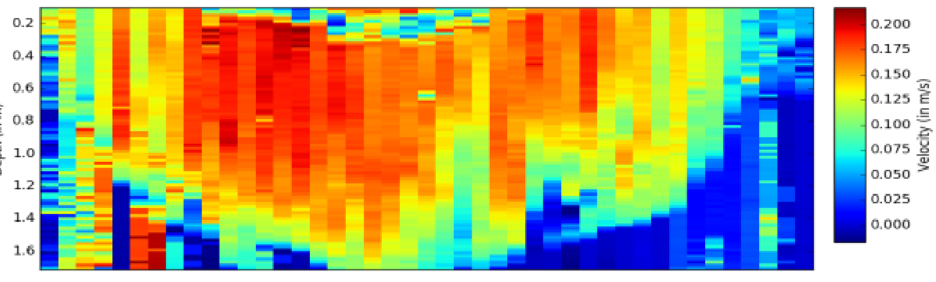
Fig. 8 shows a velocity profile for which the standard deviation is quite constant along the whole good quality profile depth. The velocity was not obtained in the first 30cm. The first cell of the profile is set 10cm away from the transducer because as the transducer touches the water, it modifies the stream in the first centimetres. And then the first 20cm of the velocity profile are rejected because of ghost echoes. As shown in Tezuka et al. (2006), the velocity could be obtained in the first 20cm by changing the PRF, which shifts the ghost echoes.
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. Settings the minimal velocity to -10cm/s in case of turbulences leads to a maximal measurable 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 over 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. 9 – a and b) and we obtained the evolution of the mean velocity when moving from one shore to the other (see Fig 9. c). Moreover, the values beneath the bottom given by the water level algorithm were suppressed. And as in paragraph 4.1, there may be a blind zone at the bottom, so values in this area have also been removed.

a



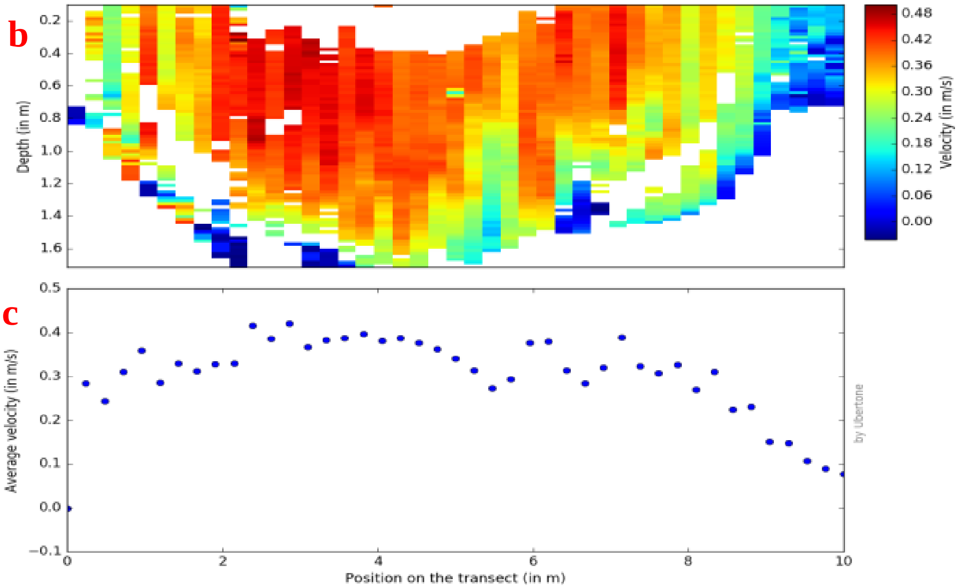


Figure 9. River raw velocity profiles (a), filtered velocity profiles (b) and mean filtered velocity (c) on flow axis, along the transect

The results presented in Fig. 9 – c could be improved. 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. 9. 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.

6. CONCLUSIONS

With this new hardware development, we pushed further the technological limits of UVP to reach a lighter and smaller board. The electronics consume less and power 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. The first measurements are promising for applications in shallow waters, 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 have to be explored, as those presented by Franca et al. (2006). The missing values due to ghost echoes can 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 Environnement and Alerion and is co-funded by the European Union as part of the operational program “Feder-FSE Lorraine et massif des Vosges 2014-2020”.
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REFERENCES

Brumley B. H., Cabrera R. G., Deines K. L., Terray E. A. : Performance of a Broad-Band Acoustic Doppler Current Profiler, IEEE J. Oceanic Eng. OE-16, pp 402-407, 1991.
Fischer S: A new high resolution velocity and acoustic turbidity profiler for open-channels, ISUD, 2010.
Fischer S: Evaluation of a High Resolution Acoustic Profiler for Hydraulic Erosion Studies, ICSE, 2012.
Franca M.J. and Lemmin U.: Eliminating velocity aliasing in acoustic Doppler velocity profiler data, Measurement Science and Technology, Vol. 17, pp. 313-322, 2006.
Hurther D. and Lemmin U.: A high-resolution 3-D acoustic Doppler profiling current Meter/Sediment Flux Profiler and its use in Laboratory and environmental studies, 2002.
Kojima S., Tasaka Y., Murai Y., Takeda Y. : UVP Measurement for Flows Accompanying Free Surface, ISUD 5, 2006.
Tezuka K., Mori M., Suzuki T., Kanamine T.: Application of Ultrasonic Pulse-Doppler Flow meter for Hydraulic Power Plant, 5th ISUD Proceedings, 2006.
Takeda Y: Velocity profile measurement by ultrasound Doppler shift method, International Journal of Heat and Fluid Flow, Vol. 7, pp 313-318, 1986.