OpenUVP in Comparison with Commercially Available Devices

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The OpenUVP system was proposed in the ISUD9 and started to prepare a standard configuration of the system, which could be a model for the general users. The simplest hardware configuration is composed of pulsar/receiver and fast ADC unit plus PC. Software was developed on LabVIEW platform. The system was designed as a general measurement instrumentation rather than machines targeting any specific application field such as pipe flow or field flow. It was aimed to maintain the highest flexibility in measurement range as well as velocity range. The software is open for each researcher to modify for implementing or incorporating his own idea of signal processing or on-line data analysis algorithm. Specifications of the developed system are compared with commercially available four machines; UVP Duo of Met-Flow, UB-lab and Peacock UVP of UBERTONE and a unit of Incipientus, assuming for the system to be a standard machine, so as to find the most adequate fields for those instruments to be used.

Keywords: Minimum hardware components, Flexible signal processing methods, Comparison with commercial machines

1. Introduction

UVP has been established and accepted and now used widely worldwide after its first appearance in 1980s [1]. At present, many commercial UVP machines areavailable on the market. As the user community expands along with ISUD conference [2], many advanced users crave highly flexible UVP machines since commercial devices are often designed under restrictions from certain limited application targets. We have proposed the OpenUVP system in ISUD9 as such an option. The OpenUVP is intended to be simple and flexible in its philosophy to expand the applicability of UVP as well as modifiability of the system. This paper explains the standard configuration and software of the OpenUVP system and discusses its feature in comparison with commercially available devices.

2. OpenUVP

2.1 Standard configuration

A standard configuration of the OpenUVP system is illustrated in Fig. 1. The hardware is composed of (1) a pulser/receiver (P/R), (2) a fast ADC (Analog to Digital Converter) unit, (3) a PC and (4) a transducer. The system is intended to be as simple as possible to pursue the highest flexibility, which will be the ideal machine for a general measurement instrumentation. This high flexibility is achieved by open-source OpenUVP software running on the PC which absorbs different hardware configuration and performs Doppler signal processing from echo sequence. In addition, the PC controls both the P/R and the ADC. Those general-purpose components can be selected from the market with few points to be considered.

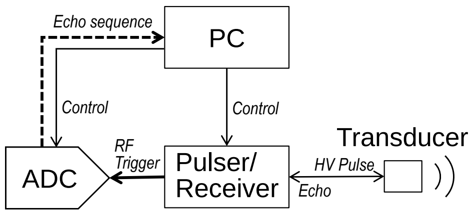


Figure 1: Configuration of the OpenUVP system.

(1) P/R is readily available on NDE (Non-Destructive Evaluation) market. Many devices, however, cannot transmit ultrasound pulse at a certain pulse repetition frequency (PRF). A device as such is able to transmit pulses at the rate of 100 to 10,000 Hz since UVP detects Doppler shift frequency among pulse repetitions. Ideal pulse shape is ideally tone burst to achieve higher quality measurement while it is reported that spike pulse can be utilized with some optimization [3]. Amplifier gain of the receiver circuitry is at least 0 to 40 dB in order to observe echoes from small tracer particles. Many P/Rs have integrated ADCs. Nevertheless, those ADC cannot be used for UVP measurement since they are not designed to capture echo RF signals as pulse to pulse sequence. Therefore, external RF out is required for the P/R.

RF signal is sampled with (2) ADC. Sampling speed shall be decided considering the Nyquist criteria, but usually it should be faster than 5 times of the basic frequency of ultrasound. (Namely, 20 MS/s for 4 MHz) Ideally, pulse to pulse sequence is sampled upon trigger signal. Even though such a sampling mode is not available, many ADCs have longer sample memory length. Then, pulse repetition sequence can be recorded as one long continuous waveform and latter divided into the sequence. This post-triggering technique enables for user to select a cheap oscilloscope as an ADC. Note that that post-triggering cause jittering noise due to different clock domain between the P/R and the ADC.

(3) PC can be any device even a microcomputer as long as it can handle relatively broadband ultrasound RF signal. In our experience, a standard PC (<1,000 USD) can well handle UVP signal processing in real-time. Many commercial UVP devices have a certain overhead time gap between profiles due to signal processing, data transfer, etc. This time gap was troublesome when it comes to the data synchronization with other measurements. On the other hand, zero-gap can be realized if an ADC is installed in a PC through a broadband data bus. Since the entire pulse-echo sequence is stored, UVP output from the sequence can be stored without any time gap between profiles as well.

(4) transducer selection requires a certain consideration. NDE transducers can be utilized in general. However, narrow band transducer designed for UVP gives higher quality measurement.

Considering above mentioned criteria, one of the standard configurations are as follows: (1) Pulser/receiver: JPR-10CN, Japan Probe Co, Ltd. (2) ADC: APX-5040, Aval Data Corp. (3) Standard PC with PCI Express bus

2.2 Software

The UVP software is written on LabVIEW platform in order to achieve higher flexibility. Fig. 2 shows the snapshot of the main screen. The software has sub-routines: ADC control, signal processing core, post-processing and display control. The key of the OpenUVP software is the signal processing core. Current version integrates several signal processing methods such as autocorrelation [4], FFT [5, 6], phase difference [7], UTDC[8]. The basic signal processing method is autocorrelation technique.

Autocorrelation technique is also termed as pulse-pair technique. Digital echo sequence acquired with the hardware is Doppler frequency modulated echo signal. Thus, demodulation is required to obtain in-phase and quadrature phase as complex sequence $z(t)$.

$$z(t) = \mathrm{LPF}\left[E(t)\{\cos(2\pi f_0 t) + j\sin(2\pi f_0 t)\}\right] = \frac{A}{2} e^{j2\pi f_D t} \qquad (1)$$

As Doppler frequency f_D is sampled at the pulse repetition frequency f_{PRF}., cut-off frequency will be $f_{PRF}/2$. Due to a static wall echo, amplifier distortion, ADC bias, etc., DC component is often observed. UVP usually applies high gain setup and saturation of an amplifier causes strong DC component noise. These noises can be minimized by subtracting average amplitude from the sequence. These procedures are illustrated in Fig. 3 (a). Parallel signal processing is performed to increase the performance in the implementation. After the demodulation, Doppler shift frequency is estimated.

$$f_D = \frac{f_{PRF}}{2\pi} \arg \sum z^*(t) \cdot z(t + 1/f_{PRF}) \qquad (2)$$

Some measurement configuration has slowly moving wall. HPF or BEF can be useful in such case.

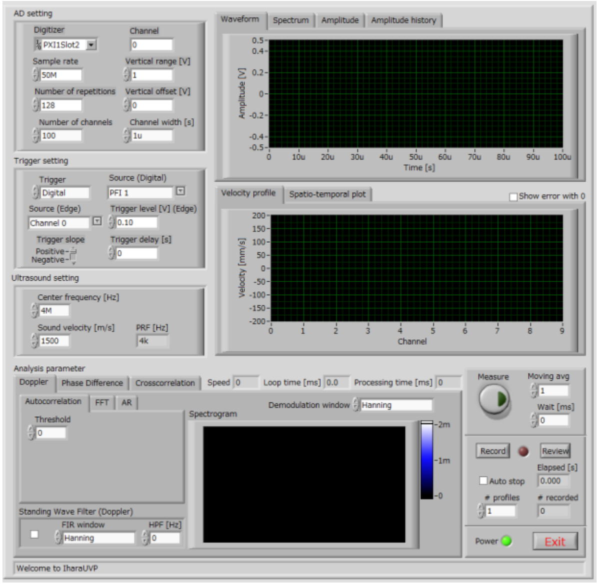
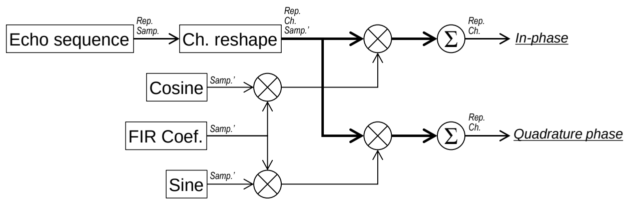
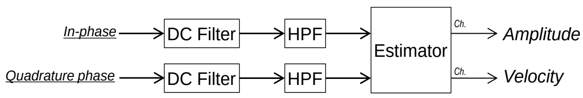


Figure 2: Main screen of the OpenUVP software.



(a) Quadrature demodulation.



(b) Doppler signal processing.

Figure 3: Implementation of the autocorrelation technique.

3. Comparison with other devices

3.1 List

Table 1 shows comparison with commercially available devices. Four devices are listed from the market: UVP Duo of Met-Flow (Switzerland), UB-lab and Peacock UVP of Ubertone (France) and ILV In-Line Flow Visuzlizer of Incipientus (Sweden). Note that Peacock UVP is a multi-purpose module, and not a device for velocity profile measurement by itself. Important parameters are tabulated. Listed values and parameter ranges are typical obtained from their open data, and do not show their maximum capability.

Table 1: Comparison with commercially available devices

Model	UVP Duo (Met-Flow)	UB-lab (Ubertone)	Peacock UVP (Ubertone)	IFV Incipientus Flow Visualizer (Incipientus)	Open UVP (tentative)
Number of transducers	1 (5/20 MUX available)	2 (TRX) 2 (RX)	2 (TRX)	2 (TRX), 2 (RX) (Independent Tx/Rx stages)	1
Frequency range	0.5, 1, 2, 4, 8 MHz	0.5–7.5 MHz	0.4–3.6 MHz	0.2–3 MHz, 1–7 MHz, 5–7 MHz (module depends)	0.03–10 MHz
Ultrasound pulse	Tone burst	Tone burst, Coded	Tone burst, Coded	Arbitral wave, DDS (14 bit / 4096 word)	Tone burst, Coded (3 level)
Voltage ($V_{p\text{-}p}$)	30, 60, 90, 150	30, 60	-	1–80 by step of 1	10–300 by step of 10
Wave cycle	2–32 by step of 1	2–128	2–128	1–40 (DDS/AWG) Pulse windowing available	0.5–32 by step of 0.5
PRF (f_{PRF})	244 to 443,114 Hz	9 to 10,000 Hz	-	Any value practical, Staggered/Dual PRF	100, 500, 1k, 2k, 4k, 8k or Ext. Trig.
Repetitions per profile (N_{rep})	8 to 2048 by step of 1	2–128	2–128	2–16384 by step of 1	min. 2 by step of 1
Amplifier gain	6–54 dB (TGC available)	20–68 dB (TGC, AGC available)	13.7–61.7 dB (TGC, AGC available)	7–55 dB (TGC, AGC available)	0–80 dB (Flat gain)
Sampling range (water)	min. 0.37 mm	5–4,000 mm	0.5–10,000 mm	min. 15 µm	min. 0.37 mm
Number of cells	2–2,048	2–200	1–200	min. 1	min. 1
Cell distance	min. 0.19 mm	3.5–100 mm (0.3 mm optional)	0.2–30 mm	min. 0.21 mm	min. 0.19 µm
Profiles per display update	1 (Moving average available)	>1	>1	>1 (Moving average available)	1 (Moving average available)
Update rate	up to 1 kHz	up to 1 Hz (100 Hz optional)	up to 5 Hz	up to 5 Hz (via ethernet) up to 25 Hz (FPGA onboard)	up to 5 kHz ($f_{\mathrm{PRF}}/N_{\mathrm{rep}}$)
Velocity resolution	256	0.25 ppm (4,000,000)	65,536	65,536 (16 bit ADC)	-
Analog output	RF, TRIG Out, SYNC In	n.a.	n.a.	RF, TRIG Out, SYNC In	RF, TRIG Out, SYNC In
Digital output	Velocity, Amplitude, IQ	Velocity, Amplitude, IQ, Turbidity, Mean RF, Quality	Velocity, Amplitude, Quality	Velocity, Amplitude, RF, IQ, FFT	Velocity, Amplitude, RF, etc.
Communication	Ethernet	Ethernet	Modbus, USB	Ethernet	USB, PCI-Exp.
Power	-	<12 W	0.5–1 W	<7.5 W	-
Size Weight	340×130×400 mm 9.3 kg	55×113×385 mm 1.45 kg	21×85 mm 14 g	90×295×285 mm 3.82 kg	-
Other features	ActiveX API available	Sensor: Temperature Internal data logger eq.	Sensors: Temperature, Rotation angles (pitch, roll)	Decimation 4–128 (RF), Aluminum box with superior EMC characteristics	Zero-gap measurement

3.2 Features

Each device has its own history for development and marketing, and therefore machines are specialized for their marketing fields and areas. UVP-Duo (Met-Flow S.A.) has a long history of development as a starter and its specification has been prepared for an engineering lab use. They have rich experience and expertise in applications of UVP for fluid mechanical and engineering problems. UB-Lab (Ubertone.) is a model converted from their original machine for their civil engineering applications (UB flow), and it has wider flexibility for parameter setting than original machine. It is ideal to be worked in good net-work situation for remote application and data processing. Peacock UVP module of Ubertone is an excellent extension of their device for integrating this unit in sensor system for flow monitoring. From its physical size and low power consumption, it is easy to install this unit in harsh environment such as deep sea or far offshore. It is expected to be a module for engineering and industrial sensory system. ILV of Incipientus has been prepared for rheological application and specialized for civil engineering or construction engineering. They have experience in field installations and for solid-liquid two phase flow.

All those devices are prepared for practical application of UVP, so-called ready-to-go unit. OpenUVP was intended to develop for those researching the UVP method itself. University researchers wish to try their own idea of signal processing, flow analysis from the measured profiles, and extension of UVP application itself. Therefore it is OPEN and free to test their own ideas.

4. Summary

A development of OpenUVP has reached to its first stage for general audience to participate. System construction has been finalized and the first machine is available to be used. A comparison with commercial machine indicates that the OpenUVP might be a basic tool for further improvement and/or new application of the UVP method. Information regarding this unit and others would be accumulated in its own website as http://openuvp.org/.

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