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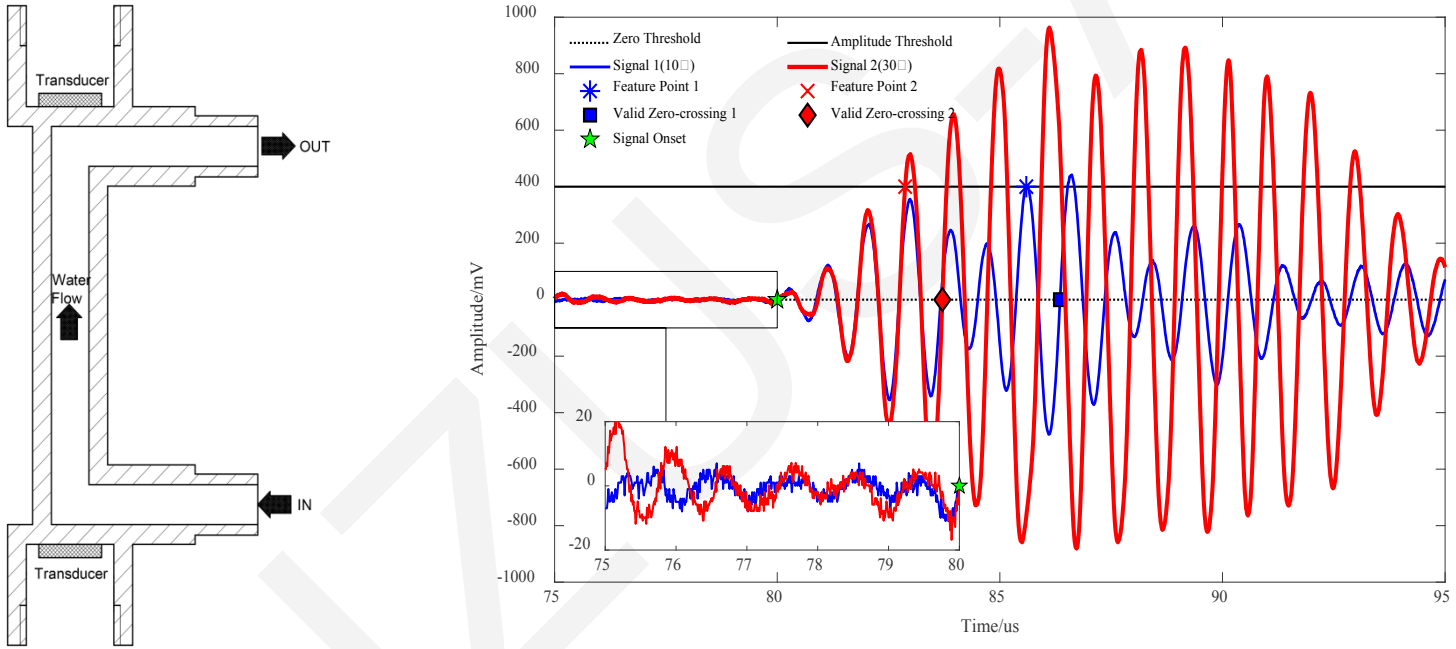
A method to avoid the cycle-skip phenomenon in time-of-flight determination for ultrasonic flow measurement

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Research Background

- The double-threshold method has been widely used in ultrasonic flow measurement to determine time of flight (TOF).
- Performance of this method is negatively affected by the cycle-skip phenomenon which is shown as Fig. 1.



(a)Sensor **(b) Signal sampled from the sensor**

Fig. 1. Illustration on Principle and Problems of Double-Threshold Method

- The paper proposes a method to estimate the onset of an ultrasonic signal based on correlation coefficient and power of the each period of the signal, thus the cycle-skip phenomenon is suppressed.

Principle of Method

Step1
- Signal de-noising
- Signal interpolation
- Signal segmentation

Step2
- Compute correlation coefficients
- Compute signal power
- Compute the judgement factors

Step3
- Determine the onset[1]
- Determine the TOF[2]

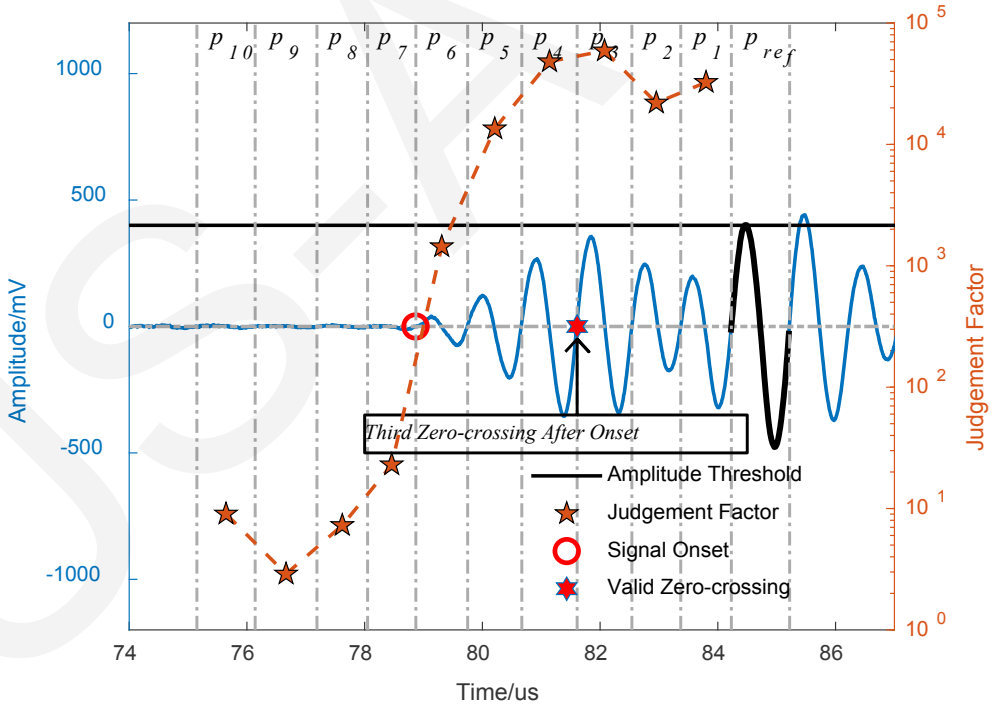


Fig. 2. Judgement factor of each period of Signal 1

1. Signal's onset is determined by detecting the decline in judgement factors.
2. In the paper, TOF is determined by the third positive zero-crossing for higher precision because of better SNR in latter periods of the signal.

Experimental Verification

- TOFs of ultrasonic signals sampled from 10°C to 70°C on a calibration system shown in Fig. 3 were calculated, and results indicated cycle-skip phenomenon was suppressed as shown in Fig. 4.

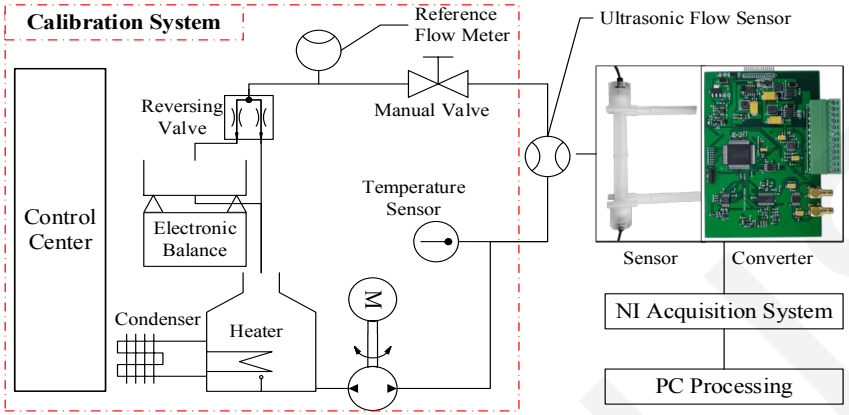


Fig. 3. Schematic of experimental setup

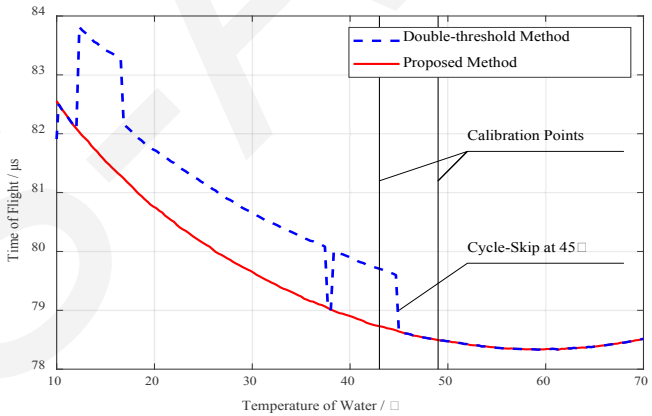


Fig. 4. TOF results

- The flow sensor was calibrated at 43°C and 45°C. Results presented the influence of cycle-skip on measurement precision and the importance to avoid it.

TOF Determination method	Temperature(° C)	43		49	
	Flow rate(L/min)	Average Error(%)	Repeatability(%)	Average Error(%)	Repeatability(%)
Double-threshold method	3	-0.090	0.036	1.850	0.072
	4	0.010	0.094	1.750	0.070
	5	-0.110	0.007	1.500	0.064
	6	-0.290	0.040	1.210	0.003
	7	-0.570	0.030	1.120	0.065
The proposed method	3	2.090	0.074	1.810	0.091
	4	2.010	0.096	1.690	0.125
	5	1.900	0.047	1.530	0.076
	6	1.640	0.015	1.200	0.032
	7	1.430	0.040	1.070	0.100

Conclusions

- This paper proposes a method to suppress the phenomenon for reliable determination of TOF in ultrasonic flow sensors based on the correlation coefficient and signal power.
- The proposed method has three main benefits: strong anti-noise capability due to the use of dual parameters, practicality due to the optimization skills, and robustness to signal waveform variation due to single-signal-based processing.
- We tested the method with an experiment based on an ultrasonic water flow sensor. Results prove that the proposed method is remarkably successful in suppressing the cycle-skip phenomenon.

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