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A new ultrasonic water meter with window time adjustment algorithm

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Abstract. The ultrasonic water meter with small pipeline is easily affected by the installation environment and noise signal. The short sound path, weak echo signal and different temperature gradient result in the decline of accuracy and stability. The traditional thresholding detection is easily flooded by noise signal, leading to the measurement of transit-time inaccurately, too. Aiming at these phenomenons, an algorithm is proposed utilizing a window time to slide through the received signal automatically with the U pipeline, which can effectively reduce the impact of noise signals on transit-time measurement, and improve the quality of signal obviously.

1. Introduction

As an intelligent instrument, the ultrasonic flow meter has been gradually used to measure the water flow in large and medium-sized pipes because of a lot of advantages such as low-pressure loss, high accuracy, wide range ratio and good repeatability [1-3].

However, the transit-time ultrasonic water meter with small pipeline has a lot of disadvantages such as high power consumption, instability of measurement and complex installation environment, which limits its wide application. In the traditional crossing-zero detection method, the useful signal is mixed with the noise signal, which may cause the zero shift of the sensor. It is difficult to extract useful signal from the original signal [4-6]. The traditional threshold method can not eliminate the noise interference if the amplitude exceeds the threshold point. Secondly, the amplitude of the ultrasonic signal has a high correlation with temperature. If the amplitude of the echo signal decays in the fluid field, the value of the threshold will change, which can result in the inaccurate measurement. In view of the shortcomings of the traditional echo signal processing methods, this paper proposes a new signal processing method, which can diminish the influence of the echo signal and improve accuracy as well as repeatability. The experimental results demonstrate the effectiveness of the proposed method.

2. Measurement principle

In this paper, an ultrasonic water meter with transit-time difference measurement has been designed, which uses U-shaped channel and pipeline model with embedded reflector [7-8]. Pipeline model and the installation diagram of transducer and temperature sensor is shown in Figure 1.

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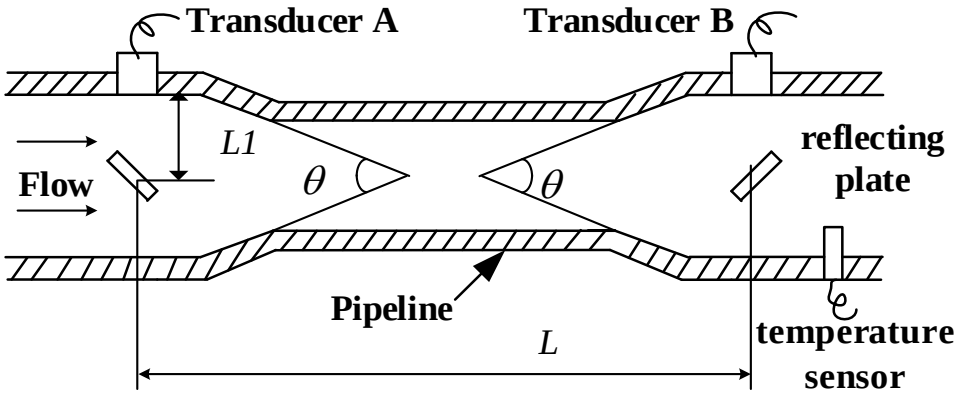


Figure 1. Installation diagram of transducer and temperature sensor

The diameter of the pipeline(D) is 20 mm. The two reflectors have the same central height as is the pipeline. The horizontal distance between the two reflectors(L) is 50 mm, and the angle is 20^o. The distance between the two transducer and the reflector(L_1) is 10 mm. Thus, the distance of the acoustic path is 70mm. And the angle between the extension line of the retracted pipeline and horizontal pipeline is θ. The temperature sensor is installed behind the reflector of downstream. The downstream time T_{AB} and upstream time T_{BA} can be obtained formula (1) and (2).

$$T_{AB} = \frac{2L_1}{C} + \frac{L}{C+V} \tag{1}$$

$$T_{BA} = \frac{2L_1}{C} + \frac{L}{C-V} \tag{2}$$

In the formula, C is the velocity of ultrasonic wave in the water, and the velocity of flowing water is V. The transit-time can be calculated by formula (3).

$$\Delta t = \frac{2VL}{C^2 - V^2} \tag{3}$$

Actually, the velocity of ultrasonic wave in the water is much larger than the water flow. Thus, it can be neglected in the formula (3), and calculation of the V can be simplified as the formula (4):

$$V = \frac{C^2 \cdot \Delta t}{2L} \tag{4}$$

According to the formula (5), the instantaneous flow q_v can be obtained.

$$q_V = V \times \pi \times (\frac{D}{2})^2 = \frac{C^2 \times \pi \times D^2}{8L} \times \Delta t \tag{5}$$

3. System design

A new ultrasonic water meter is designed in this paper, which consists of hardware and software.

3.1. Hardware design

The hardware design of the ultrasonic water meter mainly includes the minimum system of MSP430F4371, time measurement system, echo signal processing circuit, temperature sensor circuit, power module, low voltage detection circuit, data storage circuit, LCD display module and communication module of M-BUS, etc. The hardware diagram of the ultrasonic water meter system is shown in Figure 2.

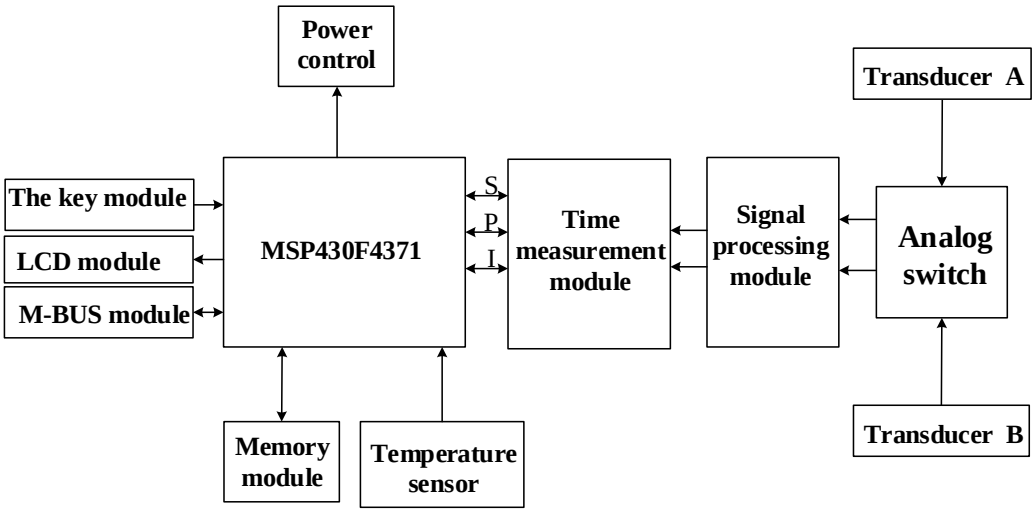


Figure 2. Circuit Frame of system

MSP430F4371 is used as the micro-controller, and TDC-GP22 high-speed clock processing chip is used as time measurement system. The module is powered by 3.6 V. RH5RL30AA chip is used as the voltage regulator in order to convert 3.6V to 3.0V. The temperature sensor adopts PT1000 platinum resistance.

3.2. Software design

The thresholding detection by traditional hardware method is widely used. But in practice, the minimum peak value of echo signal is easily flooded by the noise signal, which leads to measure the transit-time inaccurately [9]. If the voltage of the excitation signal increases, the power dissipation of the ultrasonic water meter increases too. The schematic diagram of threshold value detection for echo signal and noise are shown in Figure 3.

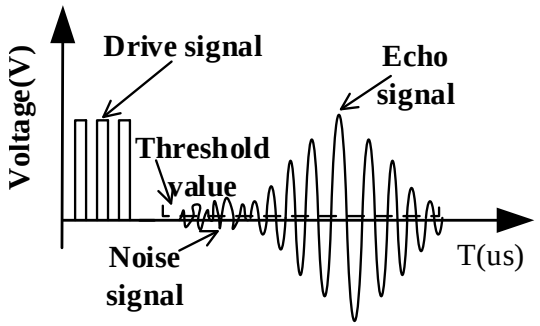


Figure 3. Echo signal is flooded by the noise signal

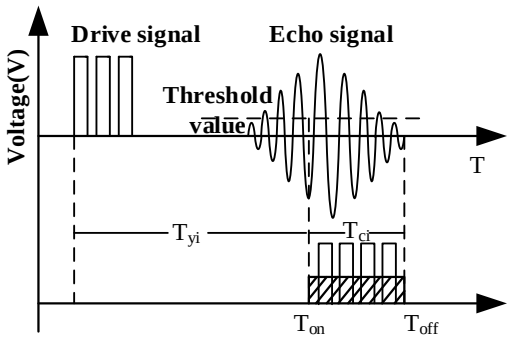


Figure 4. Measurement by the window time

In order to prevent the above phenomenons, this paper designs the method of window time of echo signal. In order to improve the signal-to-noise ratio (SNR), T_{yi} starts timing from the excitation signal to the trough position of the previous peak wave near the maximum peak wave of the echo signal, and the high-speed time measuring chip starts receiving and processing the echo signal when the window time is equal to T_{yi}. When the high-speed time measurement chip collects a certain number of pulse signals, the signal processing window of the echo is closed, and the measurement schematic diagram of the window time is shown in Figure 4.

The T_{yi} value of the window time is between the time of the peak wave detected by the oscilloscope and the arrival time of the echo signal when the temperature remains unchanged and no flow occurs.

T_{ci} is the time during the processing of echo signal. Assuming that the acquisition time of high-speed time measurement chip is T, the T is the downstream or upstream time value of the output of high-speed time measurement chip, and the value of T is

$$T = T_{yi} + T_{ci} \tag{6}$$

When the water temperature is T_0 degrees, the oscilloscope can detect the window time of echo signal T_{y0}, and calculate the velocity of ultrasound in water is T_0 degrees. Then, marks the velocity as C_0. When the water temperature is T_i, the window time T_{yi} which at any temperature can be set to

$$T_{yi} = \frac{T_{y0} \times C_0}{C_i} \tag{7}$$

The C_i is the velocity of ultrasonic wave in water at T_i temperature. The C_i can be calculated from formula (8) by measuring the downstream time T_{AB} and upstream time T_{BA} of the chip at T_i temperature.

$$C_i = \frac{2 \times (2L_1 + L)}{T_{AB} + T_{BA}} \tag{8}$$

By controlling the window time T_{yi} of the echo signal, the disturbance of the noise signal in the echo signal to the ultrasonic water meter can be effectively eliminated. But it will leads to uncertainty in the measurement if the echo signal exceeds or lags behind the expected signal.

Although the above method of controlling the window time of the echo signal T_{yi} can calculate the flying time of the echo signal, but it will lead to large errors in the measured.

In this paper, in order to prevent the above phenomenon, the temperature sensor is installed in the pipeline, measuring the water temperature *temi* in the current pipeline. Thus, the window time of the echo signal at the current temperature can be estimated by querying and calculating the sound velocity C_{temi} in the water at the same temperature. The specific calculation formula is shown in formula (9).

$$T_{temi} = \frac{T_{y0} \times C_0}{C_{temi}} \tag{9}$$

The window time of echo signal is adjusted automatically by software algorithm. According to formula (7), the deduced window time T_{yi} and the estimated window time T_{temi} obtained by formula (9) and temperature sensor. Comparing the two methods, the deduced echo window time T_{yi} is taken as the new echo window time if their substation is within one echo signal cycle. Otherwise, the T_{y0} measured by the oscilloscope is adjusted by the value of T_t. Then the new T_t is substituted into the formulas (7) and (9) to obtain the new window time T_{yi1} and T_{temi1}. Compared the T_{yi1} with T_{temi1}, if the substation is within one echo cycle T_t, the new T_{yi1} will be used as the new window time of the echo. On the contrary, T_{y0} will continue to be adjusted. The flow chart of the automatic adjustment algorithm of the echo signal is shown in Figure 5.

Automatic temperature measurement by TDC-GP22 chip ensures the accuracy and temperature measurement in a real time.

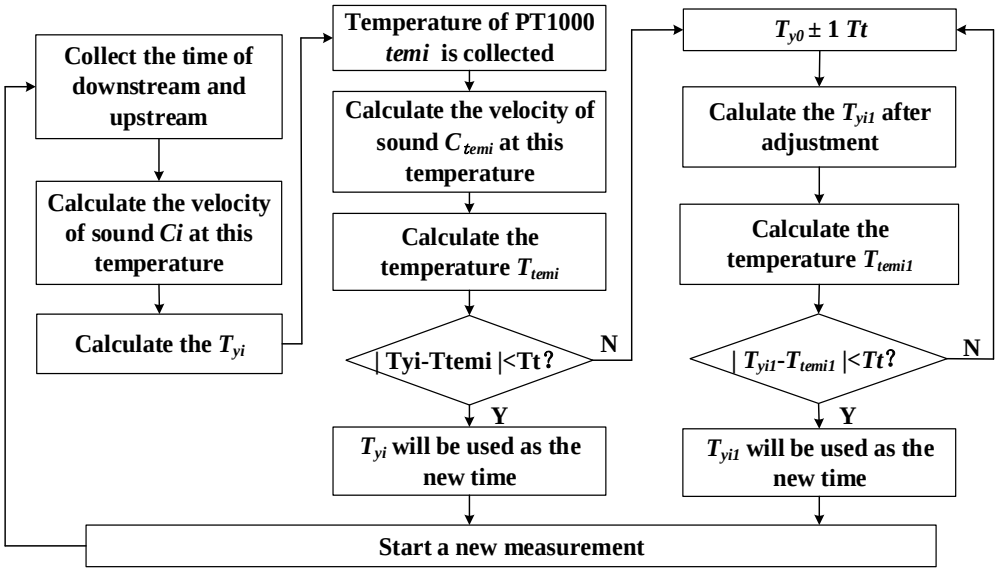


Figure 5. Main Software Block of system

4. Experimental tests

In this paper, according to the verification requirements of the type evaluation of measuring instruments in the verification regulation, the experiments of the ultrasonic water meter are carried out.

The experimental platform is mainly calibrated by weight method. The whole device consists of three standard electromagnetic water meters of different diameter, two standard weighing platforms of different sizes, a water tank, a pump, a pressure regulator, a pressure sensor, two temperature sensors and a set of heating and cooling system devices. The electromagnetic water meters adopt yokogawa AXF. The three different pipelines are DN2.5, DN10 and DN25. The maximum flow rate of three different pipelines are 0.1767 m3/h, 2.8274 m3/h and 17.671 m3/h, respectively. The accuracy is 0.2%. The distinguishability of small standard container weighing table is 0.001 kg, and that of large standard container weighing table is 0.025 kg. And it has a heating and cooling system, which can work at 0 ~90℃.

The prototype of the ultrasonic water meter is shown in the Figure 6. The photo of ultrasonic flow meter is shown in Figure 7.



Figure 6. Prototype of the ultrasonic water meter

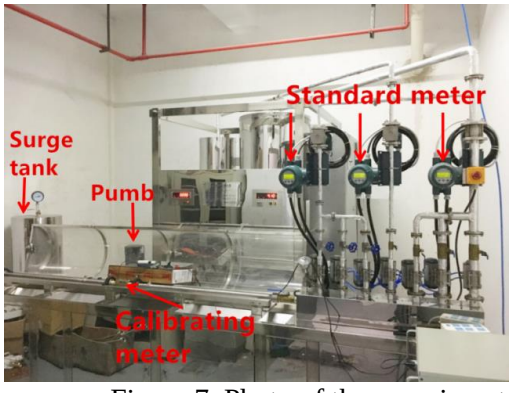


Figure 7. Photo of the experiment

This section is mainly about the experimental study of the window time adjustment algorithm proposed in this paper. The experimental data are shown in Table 1 and Table 2 under 20℃ water.

Table 1. Results with the window time algorithm.

Flow (L/h)	1(%)	2(%)	3(%)	Repeatability
5000	0.75	0.6	0.64	0.08
4000	0.97	0.99	0.98	0.01
2697	1.14	1.25	1.23	0.06
1328	1.66	1.33	1.39	0.18
26	0.14	-0.14	0	0.14
16	0.55	0.77	0.6	0.12

Table 2. Results without the window time algorithm.

Flow (L/h)	1(%)	2(%)	3(%)	Repeata -bility
5000	0.44	0.47	0.5	0.03
4000	0.26	0.1	0.18	0.08
2697	-0.17	-0.22	0.13	0.19
1328	-0.24	0.04	0.24	0.24
26	0.24	0.48	1.47	0.65
16	1.4	3.29	1.9	0.98

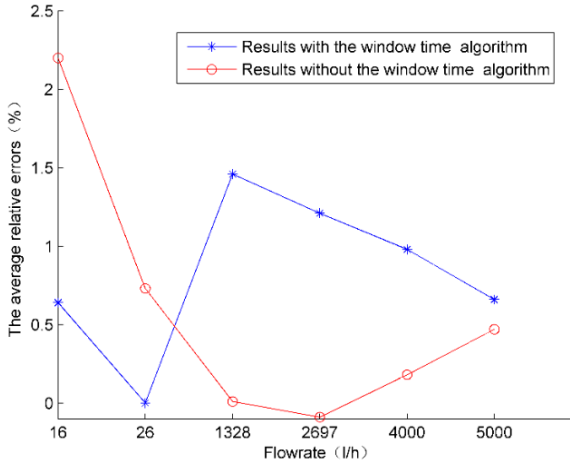


Figure 8. The average relative errors with two different methods

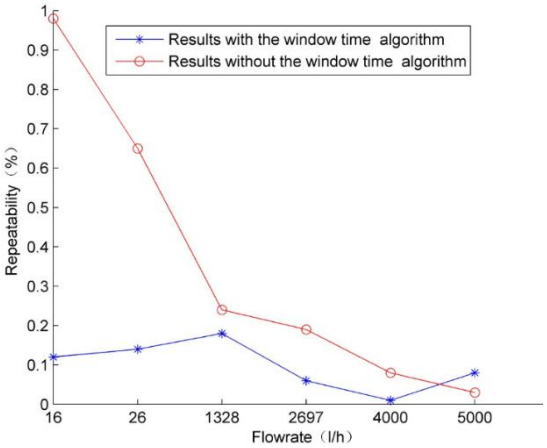


Figure 9. Repeatability with two different methods

It can be seen from the experimental data of 16/h~26L/h in the above table that the stability is weak without the window time adjustment algorithm proposed in this paper. The accuracy and stability of the measurement are enhanced.

5. Conclusions

The ultrasonic water meter with small pipeline is easily affected by the installation environment and noise signal. The short sound path, weak echo signal and different temperature gradient result in the decline of accuracy and stability. Compared with the traditional thresholding detection, a new method of the window time which can be automatically adjusted according to the ultrasonic echo signal is proposed. Through comparison of the average relative errors and repeatability, the accuracy and

stability of the measurement are enhanced with the window time algorithm. Not only it prevents the signal attenuation, but also diminishes the influence caused by the change of threshold value through experiment data. Thus, this algorithm reduce the effect of the echo signal decay on the measurement effectively. Finally, the accuracy and stability of the measurement improved, and the construction of smart water utilities enhanced, too.

Acknowledgment
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