TELKOMNIKA, Vol. 11, No. 9, September 2013, pp. 5293~5298
ISSN: 2302-4046

A Signal Pre-processing Algorithm Applied for Ultrasonic Flow-meter

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Abstract

In order to solve the problem of time difference ultrasonic flow meter's low accuracy, against the basic characteristics of the sample data, a data-processing algorithm is proposed. First, we use shell sort do a data pre-processing to the samples, then remove the error of the sample space by complex digital filter, and use the error compensation algorithm to get the final sample results. Among them, the complex digital filter is mainly composed by median filtering algorithm, sliding window, Peters algorithm and the weighted average algorithm. This kind of data processing algorithm can effectively filter out the error of the sample space. It can also make a large improvement to the accuracy of ultrasonic flow meter while ensure the stability and real-time.

Keywords: *ultrasonic flow meter, sort method, digital filter, error compensation*

1. Introduction

In the industrial and agricultural applications, flow meter is generally used for real-time measurement of fluid, so in the course of their work it was usually affected by random factors, such as environmental factors and human factors. The data signal which was measured from flow meter contains a large part of noise. When those noises mix with measured signal, accuracy will be seriously affected, even cannot work by the strong interference of noises [1]. For the above reasons, data processing to the signal measured by flow meter is becoming the essential part in the design process.

This article analyzed about the features of digital signal of the time difference ultrasonic flow meter which is based on MSP430F449 chip, and proposed data sorting method and filtering method [2] commonly used which are corresponded to it, summarized and integrated the various types of optimal algorithms, and implemented in software, finally got the digital processing algorithms to meet the requirements of measurement system accuracy.

2. Data Features of the Time Difference Ultrasonic Flow Meter

The time difference ultrasonic flow meter uses the time difference between ultrasonic waves in the fluid downstream and upstream in the same distance, while this time difference has a relationship with the rate of fluid flow, so flow rate can be drawn if the time difference has been measured, we can also calculate the fluid flow, the basic principle is shown in Figure 1. H1, H2 is a pair of rotation transmitting and receiving ultrasonic transducers, D is the pipe diameter, V is the fluid flow rate, and θ is the angle between channel and the axis of the pipeline.

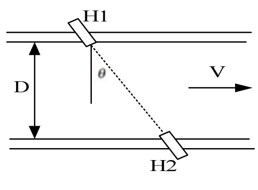

Figure 1. The Basic Principle of Ultrasonic Flow Meter

Received April 5, 2013; Revised June 10, 2013; Accepted June 21, 2013

Assuming the speed of ultrasonic in the measured fluid is C, time from H1 to H2 is t_1, from H2 to H1 is t_2. τ_0 is the circuit delay time, which is far less than propagation time, then:

$$t_1 = \frac{D / \cos\theta}{C + V\sin\theta} + \tau_0 \tag{1}$$

$$t_2 = \frac{D / \cos\theta}{C - V\sin\theta} + \tau_0 \tag{2}$$

$$\Delta t = t_2 - t_1 = \frac{2DVtg\theta}{C^2 - V^2\sin^2\theta} \tag{3}$$

In general industrial measurement, propagation velocity of ultrasonic in the liquid (about 1450m / s in the water) is larger than the liquid's, which is $C^2 >> V^2\sin^2\theta$, so the time difference can be simplified as:

$$\Delta t = t_2 - t_1 = \frac{2DV}{C^2} tg\theta \tag{4}$$

Therefore, the basic equation of the instantaneous flow rate can be written as:

$$V = \frac{C^2}{2Dtg\theta}\Delta t \tag{5}$$

Then, the instantaneous flow rate is:

$$Q = K_1 \times S \times V = K_1 \frac{\pi D^2}{4} V = K_1 \frac{\pi DC^2}{8tg\theta}\Delta t \tag{6}$$

And $K_1 = \frac{2n}{2n+1}$, n has a relationship with the Reynolds number, S is the Pipe cross-sectional area.

It can be seen from (6), as long as we get the measured time Δt, the instantaneous flow can be calculate [3].

As can be seen from Figure 2, the actual sampling time difference has four very distinct characteristics; these are dispersion, disorder, randomness and the limited. If use the directly measured time difference data to calculation the corresponding velocity and flow, the result is bound to make a great error.

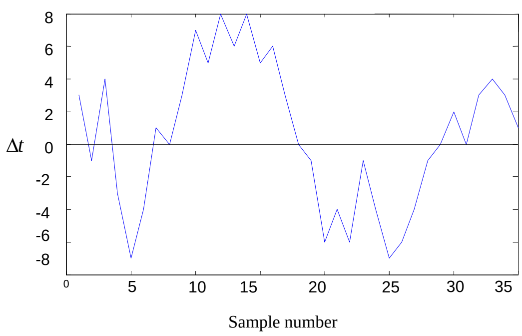

Figure 2. The Actual Time Difference under Static

Time difference measured is not a constant value, namely, there are many reasons, mainly from the following aspects. 1) Ultrasonic transducers. 2) The working conditions. 3) Secondary instrument and so on. Except the hardware processing, we should use reasonable software algorithm to improve the accuracy of flowmeter.

3. The Design of Digital Processing Algorithm

There are many processing methods for measurement data, based on the signal characteristics of the time difference ultrasonic flowmeter, designed a more practical digital signal pre-processing algorithms. That the test data can be sorted, filtered, error compensated. Through these three processing stages, we can get an ideal measurement data for flow measurement.

3.1. Sorting Algorithm

There is a lot of sorting algorithms with the time efficiency is very different. More common sorting algorithms are bubble sort, insertion sort, shell sort, heap sort, quick sort, selection sort, merge sort, and so on. Assuming n is the number of data should be sorted, then:

$$f(n) = O(g(n)) \tag{7}$$

$f(n)$ is the times of exchange, $O(g(n))$ is the complexity, while $g(n)$ is a function of n.

In the research process of time difference ultrasonic flowmeter, considering the system's power and measurement accuracy, the number of samples is set to 10, namely $n = 10$, during calculating the complexity of the sorting algorithm, also took into account the sample space. Can be obtained by calculating the complexity of the algorithm, Hill sort is the lowest average complexity, that is $O(n^{1.25})$. This sorting method is particularly suitable for small and medium amounts of data, and very easy to implement.

3.2. Digital Filtering Algorithm

For the characteristics of single-chip system, here main research several digital filtering methods are as follows. 1) Median filtering. 2) Weighted average filtering method. 3) Moving average filtering method. 4) Peters filtering method [4-6]. Here we use the Peters formula

$$s = \sqrt{\frac{\pi}{2}} \sum_{i=1}^{n} \left| x_i - \bar{x} \right| / \sqrt{n(n-1)} \tag{8}$$

In this formula, s is the sample standard deviation, x_i is the NO.i sampled data, $\bar{x}$ is the average of measurements n times, the last measurement, and n is the number of measurements, if there is:

$$\left| x_{new} - \bar{x} \right| \le 3s \tag{9}$$

The results of this measurement is effective, otherwise, measurement results is the random error, should be removed. In this formula, x_{new} the last measurement, if the number of measurements $n \le 10$, then (9) should be rewritten as:

$$\left| x_{new} - \bar{x} \right| \le 2s \tag{10}$$

If we only use one of these filtering methods to deal with the actual measurement data, it is difficult to meet the system requirements. Therefore, in this research, we have used median filtering method, the weighted average filter, moving average filtering method and Peters filtering to form a composite filter, it can ensure the stability and accuracy while increasing the real-time data processing, thus increasing the usefulness of the test system [7-10].

3.3. Error Compensation Method

Error compensation can be achieved through a variety of ways, depending on the principle can be divided into arithmetic average method, weighted average method, interpolation method and so on [10].

This article took care of the stability and real-time requirements of measurement results which the system required into consideration, used the weighted average method for error compensation, at the same time, each sample value of weight coefficient can be adjusted according to conditions to get a different error compensation value, improved the flexibility of the system. After the error compensation the measured data has been fully able to meet the measurement requirements of flow meter, and then obtained final fluid flow through the measurement formula.

4. Data Processing Algorithms

In this paper, microcontroller MSP430F449 is the core of the transit-time ultrasonic flowmeter system in the hardware, under IAR Embedded Workbench environment, using C430 in the software to achieve the data sorting, filtering, and error compensation algorithm. The reference codes are as follows.

4.1. Hill Sort Algorithm

```
void shellsort( signed long *shellData[10], int CONT )
{   int k=CONT/2;
   //CONT is sample space, and CONT=10;
while(k>0)
{  for(int i=k;i<CONT;i++)
{   signed long  t=shellData[i];
int  j=i-k;
while( j>=0  &&  t<shellData[j] )
{   shellData[j+k] = shellData[j];
j=j-k;
}
shellData[j+k] = t;
}
k=k/2;
}
}
```

4.2. Peters Filtering

```
char Peters(signed long *peter[9])
{  signed long sum=0;
for(int i=1;i<9;i++)
sum+=absFuction(peter [i]-peter[0]);
sum = sum>>1;
if(sum>absFuction(peter[8]-peter[0]))
return 1;
else
return 0;
}
```

4.3. The Error Correction Algorithm

```
signed long JQYes(signed long *Yes[9])
{  signed long JQY;
Yes[J][8] = Yes[8]<<2;
```

```
JQY=(Yes[4]+Yes[J][5]+Yes[6]+Yes[7]+Yes[8])>>3;
Yes[8] = Yes[8]>>2;
return JQY;
}
signed long JQOk(signed long *Ok[9])
{   signed long JQO;
      JQO=(Ok[5]+Ok[6]+Ok[7]+Ok[8])>>2;
   return JQO;
}
signed long JQNo(signed long *No[9])
{   signed long JQN;
      JQN=(No[5]+No[6]+No[6]+No[7])>>2;
return JQN;
}
```

5. Analysis of Experimental Results

The test platform is 150mm diameter time difference ultrasonic flowmeter while microcontroller MSP430F449 is as the MCU. In accordance with national metrological verification, we have got seven flow points' actual calibration results, $1m^3/h$, $1.3m^3/$ h, $1.6m^3/h$, $75.48m^3/h$, $176.12m^3/h$, $250m^3/h$, $265m^3/h$, and show the analysis diagram of $1.3m^3/h$, $75.48m^3/h$, $176.12m^3/h$ flow points.

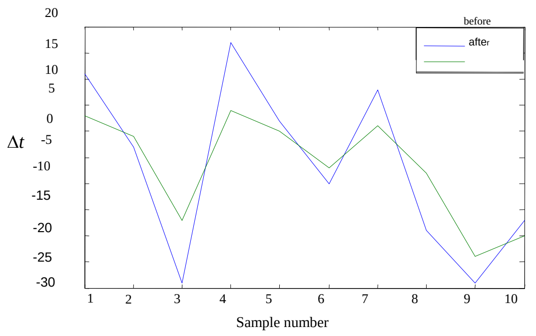

Figure 3. Under Static

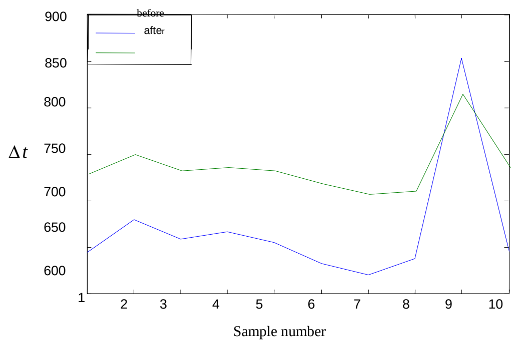

Figure 4. Under 1.3m³/h

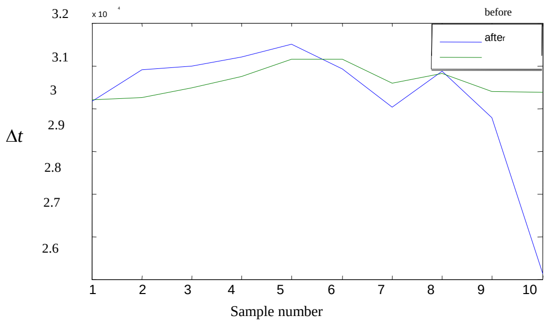

Figure 5. Under 75.48m³/h

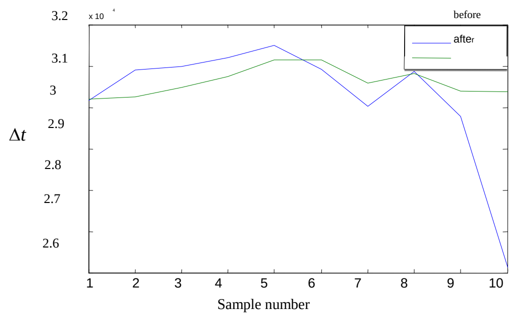

Figure 6. Under 176.12m³/h

The standard deviation of the time difference for each flow point is in Table 1, including both before and after the digital processing.

Table 1. Analysis of the Standard Deviation to the Time Difference

Flow point	Original Standard deviation	New Standard deviation
static	15.63	9.64
1.3m³/h	63.46	28.72
75m³/h	1466.18	323.09
175m³/h	899.34	381.00

6. Conclusion

This article mainly analyzed about the features of time difference data of the time difference ultrasonic flow meter which is based on MSP430F449 chip, and various types of classical data processing algorithms corresponding with it, designed and implemented practical digital signal pre-processing algorithm, proved by actual test results, using this method can be very effective in removing error of the sampled data, improving the measurement accuracy of flow meter, enhancing the stability and real-time of the test system.

Acknowledgement

This work is supported by Zhejiang science & technology preferred projects of China (2010C11025), Zhejiang province education department key project of China (ZD2009012).

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