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Research on Water Velocity Measurement of Reservoir Based on Pressure Sensor

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Abstract: To address the problem that pressure sensor can only measure the liquid level in reservoir, we designed a current velocity measurement system of reservoir based on pressure sensor, analyzed the error of current velocity measurement system, and proposed the error processing method and corresponding program. Several tests and experimental results show that in this measurement system, the liquid level measurement standard deviation is no more than 0.01 cm, and the current velocity measurement standard deviation is no more than 0.35 mL/s, which proves that the pressure sensor can measure both liquid level and current velocity synchronously. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Pressure sensor, Current velocity measurement, Liquid level measurement, Error processing.

1. Introduction

Almost all the current velocity measurement devices on the market are designed based on the principle of ultrasound or hydrodynamic [1], and it's too expensive for the medium and small company to use it [2]. The liquid level pressure sensors are widely used in reservoir liquid level measurement [3], but it is rarely used in the current velocity measurement due to the serious drift phenomenon of liquid level pressure sensor [4]. This paper presents an error processing method to reduce the drift phenomenon of liquid level pressure sensor, which greatly reduces the drift problem, so that the liquid level pressure sensor can be used in current velocity measurement. This method does not only improve the measurement accuracy, but also lowers the costs for measurement.

2. The Overall Scheme

This system converts the height of liquid level into the voltage signal by liquid level pressure sensor. Using the low-power 16-bit micro-controller MSP430F149 manufactured by TI Company as the central processing unit [5], then we acquire, convert, store and calculate the analog signal. Accurately timed by the micro-controller's watchdog timer [6], and with the stored AD value combined, change of liquid level in a unit time is calculated, and then the current velocity [7-9] is acquired. This system uses Liquid Crystal Display with the size of 128 by 64 to display the measurement results for the users [10].

3. Connection of Pressure Sensor and Micro-controller Hardware

The sensor and system are connected as shown in Fig. 1. Resistance depends on the output of the voltage to ground. The reference voltage of AD is 3.3 V, so the resistor selects 2.7 K to ensure that the output voltage is between 0 ~ 3.3 V [11].

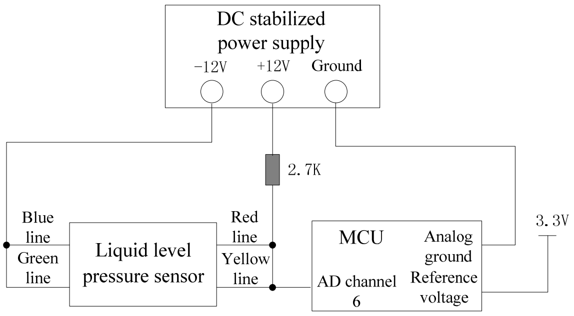

Fig. 1. Sensor and micro-controller hardware connection.

4. Error Analysis and Software Processing Method

As the liquid level and output are relatively small in water tank, slight vibration would lead to a greater liquid level change. It will be more obviously seen if this change is converted into digital value. Meanwhile, the liquid level pressure sensor also has drift, and the drift value almost equals to the liquid level changes when the output water is very small. What's more, the water of different densities also has a greater impact on the measurement in practical application [12].

In summary, the errors come from the following sources [13]:

1) Errors caused by the container vibrations. They are large errors;
2) Errors caused by the sensor drift. They are random errors;
3) Errors caused by the water of different densities. They are system errors.

For the above three points, we designed the following algorithm to deal with errors:

1) Using the AD value to calculate various indicators, minimizing the cross calculation among these indicators in order to avoid error accumulation;
2) Get the arithmetic average after many measurements $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ to reduce random error;
3) Get the residual of each AD value $v_i = x_i - \overline{x}$;
4) Using Bessel formula evaluates to get standard deviation of AD values $s(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} v_i^2} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (x_i - \overline{x})^2}$;
5) Using Wright test method to avoid the large errors of AD values: if the residuals $v_i > 3s(x)$, we eliminate the measured data corresponding to those residuals, then recalculate the average and standard deviation. Repeat the above rules until the residuals of each data satisfy the requirements;
6) As what this paper proposes is a current velocity measurement system, and as the liquid level is only a secondary quantity, we use an approximate method when converting AD value into liquid level: the table look-up scheme. Get the correspondence between AD value and liquid level, and make a look-up table. Sending commands through serial port to real-time rectified the look-up table when the system works;
7) The current velocity $= \frac{\mathrm{AD}\,(t_4) - \mathrm{AD}\,(t_0)}{4}$, and the AD sampling in t_4 and t_0 are independent-unrelated. Therefore, the independent-unrelated error synthesis method can be used to calculate the standard deviation of current velocity: $\sqrt{s^2(t_0) + s^2(t_4)}$
8) This experiment only considers the output from water tank, so the AD values should be always increased. Therefore, it can reduce the random errors caused by sensor direction drift.

The workflow of current velocity measurement system is shown in Fig. 2.

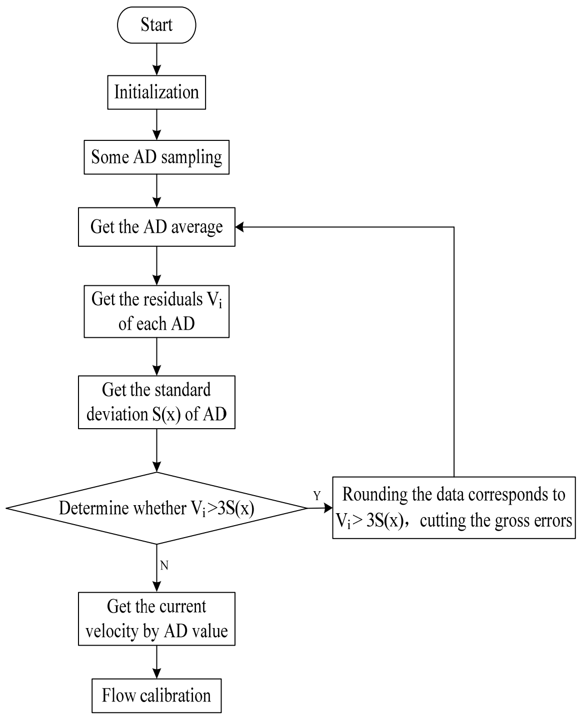

Fig. 2. Workflows.

5. Experimental Devices and Results Analysis

5.1. Experimental Devices

Experimental devices are shown in Fig. 3. The liquid level pressure sensor is put at the bottom of water tank to receive pressure changes.

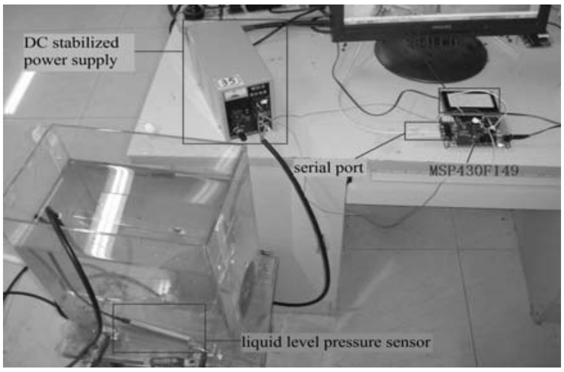

Fig. 3. Experimental devices.

The current signal would be converted into voltage signal by DC stabilized power supply and resistance, and then it will be got by the analog signal input of the micro-controller. By measuring the change of water pressure in a unit time, micro-controller can get the current velocity. 12864 LCD is used to display the current indexes; micro-controller send the data to manager PC by serial port, and manager PC is using the serial port to rectify the measurement system.

5.2. The Experimental Data Processing

The experiment result in the PC software has shown in Fig. 4.

The experiment data is shown in Table 1. S is the standard deviation before error processing, S' is the standard deviation after error processing, and AD value is the value that gets after error processing. In the experiment, multiple sampling resulted in a set of AD data; the large error of these AD data is removed. Then calculate the average and get the final AD value.

Analysis AD value from t_0 to t_4, as shown in Fig. 5. It can be seen that the standard deviation has changed significantly after error processing. The standard deviations are mainly between 4 and 15 before error processing. But after error processing, the standard deviations are between 0 and 2, and the average value is 1.

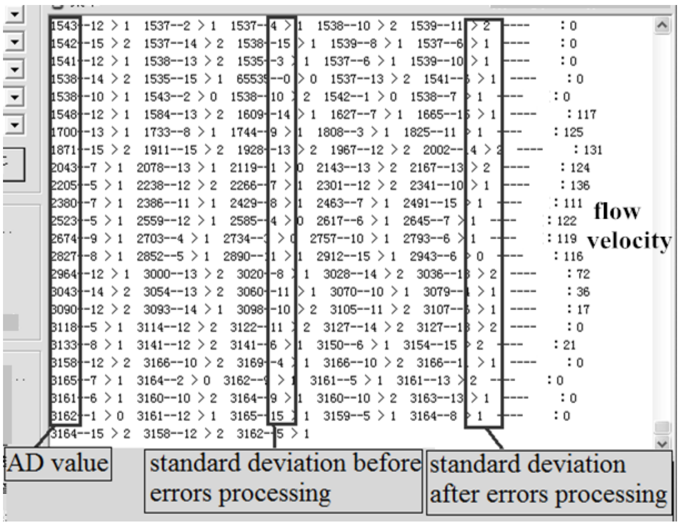

Fig. 4. The experiment result in the PC software.

$$\Delta h = \frac{h}{AD} \times \Delta AD, \tag{1}$$

where Δh is the changed liquid level, h is the range of liquid level, AD is the range of AD value, ΔAD is the changed AD value. According to Formula 1, the changed liquid level could be calculated by AD value.

$$V = \frac{\Delta h \times S}{t_4 - t_0}, \tag{2}$$

where V is the current velocity, S is the planar size of reservoir. According to Formula 2, we can use changed liquid level to calculate the current velocity.

5.3. Experimental Results

Liquid level measurement results are shown in Table 2.

Current velocity measurement results are shown in Table 3.

Table 1. Experimental data.

t_0			t_1			t_2			t_3			t_4		
AD value (mV)	**S**	**S'**	**AD value (mV)**	**S**	**S'**	**AD value (mV)**	**S**	**S'**	**AD value (mV)**	**S**	**S'**	**AD value (mV)**	**S**	**S'**
1543	12	1	1537	2	1	1537	4	1	1538	10	2	1539	11	2
1542	15	2	1537	14	2	1538	15	1	1539	8	1	1537	6	1
1541	12	1	1538	13	2	1535	3	1	1537	6	1	1539	10	1
1538	14	2	1535	15	1	65535	0	0	1537	13	2	1541	6	1
1538	10	1	1543	2	0	1538	10	2	1542	1	0	1538	7	1
1548	12	1	1584	13	2	1609	14	1	1627	7	1	1665	15	1
1700	13	1	1733	8	1	1744	9	1	1808	3	1	1825	11	1
1871	15	2	1911	15	2	1928	13	2	1967	12	2	2002	14	2
2043	7	1	2078	13	1	2119	1	0	2143	13	2	2167	13	2
2205	5	1	2238	12	2	2266	7	1	2301	12	2	2341	10	1
2380	7	1	2386	11	1	2429	8	1	2463	7	1	2491	15	1
2523	5	1	2559	12	1	2585	4	0	2617	6	1	2645	7	1
2674	9	1	2703	4	1	2734	0	0	2757	10	1	2793	6	1
2827	8	1	2852	5	1	2890	1	1	2912	15	1	2943	6	0
2964	12	1	3000	13	2	3020	8	1	3028	14	2	3036	13	2
3043	14	2	3054	13	2	3060	11	1	3070	10	1	3079	4	1
3090	12	2	3093	14	1	3098	10	2	3105	11	2	3107	6	1
3118	5	1	3114	12	2	3122	11	2	3127	14	2	3127	13	2
3133	8	1	3141	12	2	3141	6	1	3150	6	1	3154	15	2
3158	12	2	3166	10	2	3169	4	1	3166	10	2	3166	11	1
3165	7	1	3164	2	0	3162	9	1	3161	5	1	3161	13	2
3161	6	1	3160	10	2	3164	9	1	3160	10	2	3163	13	1
3162	1	0	3161	12	1	3165	15	1	3159	5	1	3164	8	1

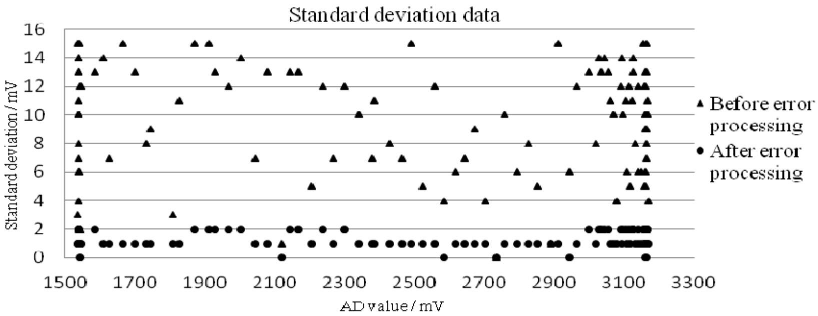

Fig. 5. Standard deviation data.

Table 2. Liquid level measurement results.

Actual liquid level (cm)	30.0	25.0	24.5	23.0	22.0	21.5	19.0	18.0	16.0
Measured liquid level (cm)	29.9	25.0	24.5	23.0	22.1	21.5	19.1	17.9	16.0
Standard deviation (cm)	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00

Table 3. Current velocity measurement results.

Actual current velocity (mL/s)	0	148.2	128.2	40.3	80.2
Measured current velocity (mL/s)	0	145.1	125.3	36.5	77.3
Standard deviation (mL/s)	0.12	0.35	0.35	0.35	0.35

It can be seen that we could use above method to get current velocity of reservoir. The measured liquid level standard deviation ≤0.01 cm, and the measured current velocity standard deviation ≤0.35 mL/s. The accuracy of liquid level pressure sensor has been significantly improved.

6. Conclusions

This paper presents a method to measure current velocity of reservoir based on pressure sensor. By eliminating the large error by error processing, the measurement accuracy of liquid level pressure sensor has been effectively improved. It can accurately measure the changes of liquid level and the current velocity. This current velocity measurement system is easy to use, and can be applied to current velocity measurement of reservoir.

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