Calibration system of underwater robot sensor based on CID algorithm

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Abstract. In the calibration of static characteristic of the sensor, the original measured data are usually a nonlinear distribution. Based on this situation, underwater robot sensor static calibration system is designed. The system consists of four parts: a sensor, I-V conversion with amplifying circuit, microcontroller STM32F107 and a PC. The lower computer and the upper computer communicate by USB. A kind of adaptive cyclic iterative denoising (CID) algorithm is presented for data processing. Finally the curve will be fitted with compensation processing.

1 Introduction
The ocean, which occupies 3/4 of the earth’s surface area and contains a large number of energy, mineral resources as well as biological resources, is considered to have the greatest potential for development. It is only inferior to the land to be the second largest area among four strategic areas including land, sea, sky and space. As the blue territory of the ocean has been closely related to the survival and development of mankind. Into the 21st century, increasing tension from limited land resources drives people to find a new way to compensate for the shortage. Ocean is our hope in the future for it has become another significant base for sustainable development.

Since 1970s, with the improvement of people’s understanding, developing and protecting the sea, underwater robots have become one of the most important means for people to explore the ocean and bring investigation towards ocean into a new stage [1].

Sensor technology is an important component of underwater robot. But by the measured data of sensor is usually a nonlinear distribution [2]. In the process of sensor calibration [3], the input and output of a linear relationship is the most ideal. Considering this situation, our team cooperates with China Academy of Sciences Hefei Institutes of physical science and the Technische Universitaet Muenchen in Germany to propose a static calibration system for sensors of underwater robots based on the CID algorithm.

2 Sensor Calibration
Calibration of sensor is a critical prerequisite for creating high-quality science data and, consequently, higher-level downstream products. Values obtained from standard equipment such as standard displacement, standard force act on the sensor to be calibrated to produce an input-output test data sheet. Sensor calibration can be divided into static calibration (determine the static characteristics of the sensor) and dynamic calibration (detecting the dynamic characteristics of the sensor) according to the contents of calibration. The purpose of this system is to obtain the measured results of the sensor’s static index [4-6].
3 Design of hardware
Besides easy installation, simple structure, economy and durability, Input Type Liquid Level Sensor has the function of power polarity reverse protection and overcurrent protection. Also, it can be directly into the measured medium. So our calibration system uses this kind of sensor as the front standard component.

3.1 Integrated Circuit
Operational principle diagram of Input Type Liquid Level Sensor’s static calibration:

Figure 1: The schematic diagram of the static calibration system of input liquid level sensor.

The functions of the calibration system contain the signal acquisition of the liquid level sensor, conversion and amplification of I-V signals, conversion of the analog and digital signals, communication with the upper computer as well as data analysis and processing.

3.2 I-V conversion and amplifier circuit
The current-output of Input Type Liquid Level Sensor is standard current signal ranging from 4 mA to 20 mA. According to practical requirements, we need to make it go through I-V conversion and amplifier circuit to convert it into voltage signals, then, amplify the signal appropriately and input it to the A/D conversion circuit, finally the original signals are converted into digital signals which will be sent to the computer later. After these procedures, it is easy for us to analyze and process the collected data. I-V conversion and amplifier circuit are shown in Figure 2.

Figure 2: I-V conversion amplifier circuit.

The amplifier used in this circuit is LM324 for it is a four op amp integrated circuit with a wide range of supply voltage, small static power consumption and low price. The magnification $A_1 = (R_3+R_4)/R_3$. In order to reduce deviation brought by the virtual short circuit, the resistance $R_2$ is taken as 4.7 MΩ.

3.3 Physical hardware circuit diagram
4 Analysis and handling of data

The data measured by sensor is nonlinear distribution, but a linear relation between the output and the input is the most ideal in sensor calibration. Therefore, the collected data need to be analyzed and handled by some theories and methods.

Based on the situation, a kind of self-adaptable CID algorithm is put forward in terms of data optimization, then curve-fitting. Finally, we are supposed to do compensation handling towards the fitting results.

4.1 Analysis of data statistics

Suppose the corresponding data of every sample site obey normal distribution, this could be verified by the normplot of Matlab software. Normplot could help people judge whether the date obey normal distribution in the visual sense, which uses the principle of normal probability paper [7]. The normal probability paper is a special kind of coordinate system, whose abscissa is equally spaced and the ordinate is given according to standard normal distribution function value. So, the definition of normal probability paper is to make the points of normal distribution fall over a straight line approximately. If all data fall on one straight line approximately, this group of data are considered as distributed normally. If not, the data are considered to be abnormal distribution. From the verification, the corresponding data of every sample site obey normal distribution. As is shown in Figure 4 and Figure 5.

Figure 3: Physical hardware circuit diagram.

Figure 4: Data distribution of liquid level 130cm.

Figure 5: Data distribution of liquid level 160cm.
4.2 CID algorithm
When handling the corresponding data of every sample site, a kind of self-adaptable CID algorithm is designed [8]. It is a process which continually use old value to launch new value so as to realize data optimization. The flow chart is as follows.

![Flow diagram of CID algorithm.](image)

At first, input the corresponding data of some sample site and calculate its average value $\bar{X}_i$; Delete the data of the largest difference after calculating the positive difference between every data and $\bar{X}_i$; Secondly, calculate its average value $\bar{X}_{i+1}$ and judge the positive difference of the two average value. If it is less than a definite value, $\bar{X}_{i+1}$ is output and the circulation is over, if not, continue the process. Because the infinite loop is impossible and the number of iterations required is not a fixed value, a control condition is added which restrains the CID algorithm, that is, when the number of output data is less than the number of initial data 1/10, the end of CID algorithm and output data.

The improvement of this CID algorithm lies in not using single algorithm stopping criterion. The number of stopping criteria of each sampling point corresponding to the data CID operation, according to their actual situation is different. According to this experiment, this algorithm improve the effectiveness and accuracy of data optimization.

4.3 Curve fitting
Curve fitting refers to a data processing method that seeks a certain smooth curve to represent or characterize a set of discrete points best. During the process of curve fitting, it is unnecessary to make the target line go through every discrete point but the local fluctuations must be avoided.

We obtained a group of new data after using CID algorithm to optimize the data corresponding to each sampling point. It is easy to conclude that the relation between input (liquid level) and output (value of AD) is nonlinear. So we fit the curve of the characteristic relation [9-10]. Nowadays, there are quantities of theoretical research towards curve fitting. We draw a summary and make a comparison among them. Results are shown in Table 1.
Table 1: Comparison of curve fit method.

| Method | Description                                                                                      | Characteristics                                                                 |
|--------|-------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| SIM    | Has simple principles; is easy to learn; go through each data point accurately.                 | Large error; curve is discontinuous and rough; great dependence on some calibrated points. |
| NNM    | Has strong non-linear description ability; can process multiple sets of curve fitting concurrently. | The model structure is difficult to build; slow or over-coincidence training convergence rate; the selection and processing of the network structure are subjective partly. |
| LSM    | Reflect the trend of discrete data; make sums of squared errors smallest.                       | In practical problems, we must choose the fitting relation carefully, if the choice is not correct, it will have a direct impact on the calculation and conclusion. |

Considering the comparison of the three methods above and the actual situation [11], we select the least squares method to do the experiment.

The data corresponding to each sampling point are optimized by CID algorithm. Results are shown in Table 2.

Table 2: Data after CID algorithm optimization.

| Liquid level/cm | 0  | 5  | 10 | 15 | 20 |
|-----------------|----|----|----|----|----|
| AD value        | 1147 | 1256 | 1330 | 1409 | 1458 |
| Liquid level/cm | 30 | 40 | 50 | 60 | 70 |
| AD value        | 1585 | 1725 | 1863 | 2143 | 2293 |
| Liquid level/cm | 80 | 90 | 100 | 110 | 120 |
| AD value        | 2350 | 2471 | 2581 | 2750 | 2979 |
| Liquid level/cm | 130 | 140 | 150 | 160 | 170 |
| AD value        | 3101 | 3192 | 3270 | 3337 | 3369 |
| Liquid level/cm | 180 | 190 | 200 |     |    |
| AD value        | 3400 | 3460 | 3507 |     |    |

The curve fitted by Matlab software is shown in Figure 7. Taking accuracy of the curve fitting into account, we select the five order polynomial fitting curve.

Finally, we obtain the five order polynomial fitting function:
\[ y = 0.000000002x^5 - 0.00001200x^4 + 0.00187980x^3 - 0.11375029x^2 + 17.25710988x + 1157.05589791; \]

Ideal curve function:
\[ y = 11.80000000x + 1147.00000000. \]

We need to do compensation handling for the curve fitted because the five order polynomial is not an ideal curve. For example, when the liquid level is 100 cm, we put it into the ideal curve function and get A1 as value of AD, then we put it into the five order polynomial and get A2. The compensation coefficient equals A1 divided by A2. In this way, the compensation coefficient (CC for short) are shown in Table 3.

Table 3: Diagram of the compensation coefficients.

| Liquid level/cm | 0  | 5  | 10 | 15 | 20 |
|-----------------|----|----|----|----|----|
| CC              | 0.9913 | 0.9720 | 0.9583 | 0.9484 |     |
| Liquid level/cm | 20 | 30 | 40 | 50 |     |
| CC              | 0.9409 | 0.9300 | 0.9213 | 0.9128 |     |
| Liquid level/cm | 60 | 70 | 80 | 90 |     |
| CC              | 0.9040 | 0.8952 | 0.8867 | 0.8795 |     |
| Liquid level/cm | 100 | 110 | 120 | 130 |     |
| CC              | 0.8742 | 0.8714 | 0.8718 | 0.8758 |     |
| Liquid level/cm | 140 | 150 | 160 | 170 |     |
The compensation coefficient curve fitted by Matlab software is shown in Figure 8. We can obtain the five order polynomial function of compensation coefficient:

\[ y = -0.0000081x^3 + 0.0006597x^2 - 0.00333942x + 0.98815937. \]

Figure 7: AD value five times nonlinear fitting curve diagram

Figure 8: Compensation coefficient five times nonlinear fitting curve diagram

5 Conclusion and Prospect

This paper designs a static calibration system for liquid level sensor based on CID algorithm, and it also puts forward a kind of self-adaptable ID algorithm for this system. The data handled by this algorithm have obvious optimization effects and strong stability and practicability.

Because of the limited conditions of the laboratory, the collection of experimental data is a little imperfect. There are many points that could be done further research in the experimental process, such as the online real dynamic calibration system research of liquid level sensor, it has a major research significance and its application will be broader.

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