Development of Flowmeter with IoT Function

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Abstract. Turbine flowmeters are now widely used as sensors in existing flow monitoring scenarios, but their traditional induction coils are susceptible to electromagnetic interference. The process of configuring, calibrating, etc. is complicated. And the interface of existing flowmeter is relatively single. Regarding these issues above, this paper develops a new type of turbine flowmeter with Internet functions replaces the traditional induction coil with AMR components, designs its preamplifier module, develops the microprocessor software functions for the secondary instrument, integrates a variety of industrial wired/wireless flexible communication interfaces in the flowmeter secondary instrument, and uses ZigBee technology to perform node networking, ID setting and routing to construct the IoT architecture of flowmeter. This intelligent flowmeter sensor can be applied to the fields of chemical industry, metallurgy and so on, which can greatly help solve the problems of current flowmeter configuration and network access difficulties, meeting the urgent needs of intelligent manufacturing.

1. Introduction

With the rapid development of intelligent manufacturing and industry 4.0, the industry has put forward higher requirements for the monitoring of production process parameters. Flow rate is a very important measured physical quantity in process control. As a sensor for a large number of applications in the existing flow monitoring scene, the turbine flowmeter has the characteristics of large-scale, high-precision and low production cost. However, since it measures the rate of change of the magnetic induction intensity, it must work in a changing magnetic field or moving in a magnetic field to work, and cannot detect static and slowly changing magnetic fields, and has low detection sensitivity to low-frequency alternating magnetic fields.

In addition to the accuracy of the flow sensor, intelligent manufacturing requires a large number of sensors, and the manual calibration, configuration and other work of the sensor also requires a huge amount of human and material resources. And the universality of flow sensor under different data interfaces also needs to be solved urgently.
Digital, intelligent, multi-functional, and networked are the inevitable trends in the future development of flow sensors [1-2]. Aiming at the problems of poor accuracy, low intelligence level and weak IoT function of existing flowmeters, it is urgent to design and develop an intelligent secondary instrument for new turbine flowmeter, which is suitable for current intelligent manufacturing. Automation and Internet of Things functions improve the intelligent level of flowmeters to solve the various shortcomings of existing flowmeters and adapt to the requirements of the new era flowmeters [3].

2. The Overall Structure of Turbine Flowmeter
This paper proposes a new type of turbine flowmeter based on AMR sensor. The overall structure is shown in Fig. 1. Through the modular design of signal sensing, adjustable signal conditioning, frequency monitoring microprocessor and ZigBee networking part of turbine flowmeter, the flow measurement, flexible configuration, and automatic calibration of turbine flowmeter are realized, and the measurement accuracy and stability of different frequency bands are improved. At the same time, develop the relevant flexible interface modules to expand the applicability and rely on ZigBee to carry out the self-organizing network of the Internet of things [4], to achieve the wireless network data transmission, node identification and remote platform centralized control functions in the traffic monitoring system.

![Overall structure of the turbine flowmeter](image)

Figure 1. Overall structure of the turbine flowmeter.

2.1. Sensor and Signal Conditioning
As shown in Fig. 2, the sensor uses Honeywell anisotropic resistance HMC1051. After magnetic saturation, the resistance is related to the direction of the current and the magnetization. Let the angle between the magnetization M and the current I be \( \varphi \). The resistivity can be calculated by (1)

\[
\rho(\varphi) = \cos 2\varphi (\rho_p - \rho_T) + \rho_T
\]
\( \rho_{y} \) is the resistivity of the anisotropic magnetic resistance when the angle between \( I \) and \( M \) is 90°, and the unit is \( \Omega \cdot m \). \( \rho_{p} \) is the resistivity of the anisotropic magnetic resistance when the angle between \( I \) and \( M \) is 0°, and the unit is \( \Omega \cdot m \).

When the value of \( M \) is small, the maximum value of the resistivity change of the anisotropic magnetic resistance is (2):

\[
\Delta \rho_{m} = \rho_{p} - \rho_{y}
\]

The resistivity of the anisotropic magnetic resistance meets the following (3):

\[
\rho(\varphi) = \rho_{p} - \Delta \rho_{m} \sin 2\varphi
\]

The sensor is internally equipped with a 4-sensor Wheatstone bridge for converting magnetic resistance changes into a voltage output. After powering the Wheatstone bridge, the resistivity of the anisotropic resistive component of the bridge follows the external magnetic field change, so the output voltage can be monitored accordingly.

The differential output voltage from the AMR is amplified by the LMV358 typical dual operational amplifier, which uses TL431 as the controllable regulator. The amplifier can implement an operational amplifier with full supply amplitude output at the voltage differential input. This amp has a high input resistance, which can effectively suppress the zero drift. The common-shot amplifier circuit is selected as the intermediate stage to obtain a lower output resistance, so the system has a strong load capacity.

The amplified DC signal of the flow signal is about 2.7V, which is introduced into the dual voltage comparator LM393. The voltage comparator determines the final output of the system by the state of the system for a while before the output. This allows the high-side switch Threshold value to be higher and the low-side switch Threshold value to be lower. When the input signal is incremented from small to large or decreasing from large to small, the high-side and low-side switches have unequal Threshold values, and thus a hysteresis curve like a hysteresis curve appears. When the Threshold value is greater than the input signal, the reverse input can output a high level and pull the corresponding Threshold value via the feedback resistor. When the input voltage reaches the rising Threshold value, the circuit then pulls down the output voltage of the output. The Threshold value is set by the adjustable resistor 3296W-1-103LF, which can determine the reference voltage and output the compared square wave signal. The square wave signal is finally denoised by a TLC04 low-pass filter.

![Figure 2. Signal conditioning process.](image)

### 2.2. Software Design of Flowmeter

The software design of the intelligent flowmeter secondary instrument is to uniformly call each hardware module of the secondary instrument to ensure the accuracy of the measurement result, realize the multi-protocol conversion of the data transmission and the correctness of the data. The development of intelligent secondary instrument software in this paper follows the development idea of gradual decomposition from top to bottom to realize the modularization of software design [7]. The software of the intelligent secondary instrument is divided into several modules, and the modules are divided again according to the specific functions. According to different functions, corresponding subprograms are developed. Some subprograms with similar functions are composed of functional modules, and then the complete program is composed of each functional module.

The software of the intelligent flowmeter secondary instrument needs to be developed separately for the monitoring node device and the wireless routing device. And the function of the wireless routing
device is relatively less than that of the monitoring node, the data relay function is mainly assumed. So the software design in this paper focuses on the software development of the node equipment.

The overall software architecture is shown in Fig. 3, which is mainly divided into the following three functional modules:

Flow measurement module. It includes frequency measurement subprogram, temperature measurement subprogram and flow algorithm subprogram. It is responsible for converting the pulse signal output by the pre sensor into flow data and processing it by other program modules.

HMI module. Including LED subprogram, key subprogram and OLED subprogram, responsible for the processing of human-machine interaction functions, intuitive display of data and the realization of humanized operation.

Output module. Including pulse output subprogram, current output subprogram, USB subprogram, RS485 subprogram, ZigBee subprogram. The traffic information is converted to other types of signal outputs or transmitted after protocol conversion.

Figure 3. Overall diagram of flowmeter software.
Figure 4. Flow chart of main program.

The main program flow chart of the intelligent flowmeter secondary instrument is shown in Fig. 4. The main program is the general scheduler which calls each function module uniformly. The basic process is: after the system is powered on, it is initialized vertically; after the initialization completed, it is processed to measure the signal frequency, and then it processes the temperature sensor signal to get the temperature data. Based on the temperature data and frequency data, the instantaneous flow and cumulative flow are calculated by using the algorithm, and the flow value is displayed on the OLED screen, then the current of 4-20mA is output according to the instantaneous flow. Then send data to each conversion chip through serial port to realize RS485 interface output and ZigBee wireless transmission. After completion, the program returns, and the signal processing and frequency measurement are restarted to enter the next cycle.

2.3.Flexible Interface Module Based on IoT
This paper combines the characteristics of intelligent manufacturing and industrial Internet to develop the IoT application functions such as automatic description, identification and networking of flow sensors, which facilitates the configuration and deployment of a large number of sensing devices in intelligent manufacturing. For difficult-to-route traffic monitoring applications, the system uses ZigBee technology for wireless data transmission, and develops a ZigBee gateway integrated universal communication module to convert sensor data into the required interface data information through wireless ZigBee data transmission and reception and protocol conversion.

Based on the ZigBee wireless sensor communication module, the subject is oriented to the industrial IoT, which develops the functions of instant, automatic description, automatic identification, automatic organization and interoperability of the turbine flow sensor [8]. The flow meter Internet of things architecture is shown in Fig. 5. And realize the IoT of the turbine flowmeter by developing the networking method, its own ID setting, and the routing method.

ZigBee adopts star networking mode and is divided into two parts: terminal node module and coordinator (router) module. The IoT software architecture development process is as follows:
The ZigBee program was developed using the ZigBee protocol stack Z-Stack. The ZigBee protocol stack is a concrete implementation of the ZigBee protocol. So first you need to study the function call in the protocol stack.

Develop a networking and data transmission program for the terminal node and the coordinator to implement the flowmeter networking function.

Develop a unified data transmission protocol, add node ID and data type, and realize automatic identification, self-organization, self-healing and other automatic functions of terminal nodes.

![Figure 5](image)

**Figure 5.** Architecture of internet of things based on ZigBee.

3. Verification of Flowmeter Function

In the experimental part, the prototype machine is made and the functions of the flowmeter are tested. The experimental data are analyzed and the disadvantages are analyzed and optimized. After the secondary instrument of intelligent flowmeter is powered on, all functions are tested.

3.1. Hardware Function Test of Flowmeter

As shown in Fig. 6, after power on initialization, the power light is on, the OLED screen shows that everything is normal, and the instrument operates well.

After the flowmeter is calibrated, further test shall be carried out and compared with the existing calibration results. The results are shown in Table 1:

![Figure 6](image)

**Figure 6.** Coordinator and flowmeter node equipment.

After calculation, the measurement error of the turbine flowmeter is 0.28%, which meets the requirements of JJG 1037-2008.
Table 1. Flowmeter Test Data

| Average flow rate (L/min) | Temperature TM average (°C) | Pressure PM average (MPa) | Frequency average (Hz) | Average value of measurement frequency (Hz) |
|--------------------------|-----------------------------|----------------------------|------------------------|--------------------------------------------|
| 50.33                    | 27.72                       | 0.25                       | 525.75                 | 524.39                                     |
| 45.28                    | 27.12                       | 0.21                       | 472.50                 | 473.12                                     |
| 35.21                    | 28.86                       | 0.14                       | 366.29                 | 365.42                                     |
| 25.17                    | 28.52                       | 0.08                       | 260.91                 | 261.87                                     |
| 16.11                    | 28.51                       | 0.04                       | 164.09                 | 163.97                                     |
| 9.03                     | 28.72                       | 0.03                       | 89.97                  | 89.78                                      |
| 2.32                     | 28.69                       | 0.02                       | 19.87                  | 19.74                                      |

3.2. ZigBee Network Test

When the ZigBee network is tested, the two node devices respectively set the IDs as 1 and 2, and send the instantaneous flow and the accumulated flow to the coordinator. The coordinator sends the received data to the host through the RS485 interface. The host monitors the data of each node in real time through graphical software.

![Serial data waveform display](image)

Figure 7. Host test results.

The host computer software is shown in Fig. 7. According to the flow data sent by each node, the waveform is generated in real time, which can directly reflect the trend of node flow. The experiment proves that the ZigBee module can automatically set up, identify and realize the Internet of things of the secondary instrument.

4. Summary

For the development of the new turbine flowmeter, the intelligent microprocessor software is used to optimize the frequency measurement algorithm and a unified wired/wireless communication port module is developed. In the specific implementation, the hardware circuit and software program of the intelligent secondary instrument are separately designed. In addition, the feasibility and practicability of hardware circuit and software design are verified by experiments. The experiment proves that each functional module works well, the frequency measurement accuracy is less than 0.28%, and the Internet of Things is tested by system debugging, which proves that the instrument has good stability, and all interfaces work normally and meet the performance indicators.
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