Design of multi-parameter auto-detecting instrument system for hydrological hole pumping test based on single-chip microcomputer

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Abstract. In order to meet the requirements of modern hydrogeo-logic investigation, one multi-parameter auto-detecting instrument system for hydrological hole pumping test based on single-chip microcomputer is designed. The pumping test system contains one lower computer module and one upper computer module. The lower computer module uses the STM32 single chip microcomputer as the central module of the controller, supplemented by the sensor module, the power module, the communication module and the display module to realize the automatic detection of the multi-parameters of the hydrological hole pumping test. It can display the information of pumping speed, water level, water temperature and water flow in real time and realize the function of pumping timing switch. The upper computer module allows users to check hydrological hole pumping test information and control the whole system operation. The information transmission between the lower computer module and the upper computer module is completed by Narrow Band Internet of Things (NB-Iot). By analyzing the data of pumping test system after compensation, the max relative error of liquid level is all less than 1%. All these data confirm that the pumping test system proposed in this paper has certain application value.

1. Introduction

In the traditional pumping test, the measurement of test parameters is mostly done by hand [1-3]. This backward detection method not only has errors, but also wastes a lot of manpower and material resources, and the information is not easy to save. Therefore, it is necessary to develop and use the modern computer detection technology to realize the multi-parameter automatic detection instrument of water output, water level and water temperature in hydrological hole pumping test.

In this paper, one multi-parameter automatic measuring instrument system of hydrological hole pumping test based on single chip microcomputer is designed. The pumping test system contains one lower computer module and one upper computer module. The lower computer module uses the STM32 [4] single chip microcomputer as the central module of the controller, supplemented by the sensor module, the power module, the communication module and the display module to realize the automatic detection of the multi-parameters of the hydrological hole pumping test. It can display the information of pumping speed, water level, water temperature and water flow in real time and realize the function of pumping timing switch. In the sensor module, air pressure and density sensors are led to counteract the influence of air pressure and liquid density changes on liquid level measurement.
results. The upper computer module allows users to check hydrological hole pumping test information and control the whole system operation. The information transmission between the lower computer module and the upper computer module is completed by Narrow Band Internet of Things (NB-Iot) [5]. By analyzing the data of pumping test system after compensation, the relative errors of liquid level are all less than 1%. All these data confirm that the pumping test system proposed in this paper has certain application value.

2. System framework
The pumping test system contains one lower computer module and one upper computer module. The lower computer module is mainly composed of controller center module, sensor module, power module, communication module and display module, as shown in Figure 1.

![System framework of the lower computer module.](image1)

The upper computer module is mainly the development of APP software, which is used to realize the information exchange, processing, display with the lower computer module and the pumping test system remote control by the user.

3. Lower computer module design
In the lower computer module, the controller center module adopts STM32F429IGT6 chip, the power module uses 12V lithium battery, the communication module uses SIM7020C module [6], the display module ATK-4.3 TFT LCD capacitive touch screen. The sensor module contains one air pressure sensor BMP280, one flow sensor YF-S201, one water temperature sensor DS18B20, one density sensor GB-DMR and one water level sensor QD-136.

3.1. Controller center module
The main functions of the controller center module are as follows: It provides hardware platform for the software of the lower computer, it collects information from the water level sensor, the air pressure sensor, the water temperature sensor, the density sensor and the flow sensor, it achieves information analyses, storing, displaying and exchanging with the communication module, it receives the information of the communication module; it sends the control signal to the power module.

![Circuit diagram of sensor module.](image2)
3.2. Sensor module
The sensor module includes many kinds of sensors, such as air pressure sensor, water temperature sensor, flow sensor and water level sensor. Detection accuracy of the air pressure sensor BMP280 is 1Pa within 300-1100hPa. The flow sensor YF-S201 flow sensor produces 450 pulses per 1000ml with flow rate ranging from 1 to 30 L/min. The detection accuracy of the water temperature sensor DS18B20 is 0.5 °C within -10°C~+85 °C, and its circuit diagram is shown in Figure 2. The measuring range of density sensor GB-DMR is 500 – 2500 kg/m3 with accuracy 0.5%. The water level sensor QD-136 with input voltage 12V and output voltage 0-5V can realize 0-500m water level measurement.

3.3. Power module
The power module is mainly composed of power supply, water pump and water pump controller. For the convenience of carrying and long service life, 12V lithium battery is selected as the power supply. The battery has the advantages of small volume, large capacity, light weight and no memory effect. The pump controller selected in the design can convert the PWM control signal of microprocessor into electrical signal, and control the speed of DC motor by changing the current.

3.4. Communication module
The communication module SIM7020C is a multi-band NB-Iot chip controlled by AT command. Based on NB-Iot technology, the maximum uplink speed of data transmission standard is 62.5 KBPS, and the maximum downlink speed is 26.15 KBPS. In the pumping test system, the communication module uses four pins, namely VCC, Gnd, RXD and TXD.

3.5. Display module
The display module ATK-4.3 TFT LCD is a high performance 4.3-inch capacitive touch screen module. The display module is used to display the completed graphical interface, including control button, pump speed, actual pump water volume, IoT platform connection status, and so on.

![Software overall design flow](image)

**Figure 3.** Software overall design flow.
3.6. Software design
Software design of the lower computer module can be divided into several parts, such as system initialization, sensor part, communication part, pump control, graphic interface display part, and so on. The overall design flow of the lower computer module software is shown in Figure 3.

After controller center module, sensor module, power module, communication module and display module design, the physical map of the lower computer module is shown in Figure 4.

![Figure 4. Physical map of the lower computer module.](image)

4. Upper computer module
The upper computer module APP software should be able to save the SIM7020C data in the IoT cloud server [7], real-time display the current detection signal of the sensor module, and send the control Information of the pumping test system to the communication module. Figure 5 shows the main interface of the upper computer module.

![Figure 5. APP software main interface.](image)
5. Test experiment and data analyses

To achieve detection performance of the pumping test system, test experiment is carried out which is shown in Figure 6. In the experiment, the QD-136 type water level sensor is placed at the bottom of graduated cylinder which is introduced to act as a water container. The capacity of the graduated cylinder is 500ml and the height is 2.43cm/50ml. Further, the water level change can be simulated by filling and draining the liquid in the graduated cylinder. Change range of the water level in the test experiment is 0-24.3cm with change interval 50ml. The liquid in the graduated uses water and alcohol separately during different tests.

![Figure 6. Test experiment platform.](image)

After the test experiment, experiment data is shown in Figure 7.

![Figure 7. Experiment data chart.](image)

When the liquid uses water and alcohol, the liquid pressure $P$ in the test experiment is different evidently just as shown in Figure 7. So, liquid density can cause the accuracy of water level measurement in the pumping test system. After considering the influence of the density of water and alcohol, the measured liquid level is calculated through equation $P - P_{\text{air}} = \rho gh$, as shown in Figure 8 [8-9]. In the calculation process, standard atmospheric pressure $P_{\text{air}}$ is 101325Pa, acceleration of gravity $g$ is 9.8N/kg, and the density of water and alcohol is $10^3$kg/m³ and $0.8 \times 10^3$kg/m³, respectively [10].

![Table 1: Liquid Pressure and Water Level](image)

After considering the influence of density and standard atmospheric pressure, the difference between the measured liquid level and the liquid level is close to an order of magnitude. Therefore, in addition to the influence of density, the influence of gas pressure change on the test results should also be considered. When the liquid uses water and alcohol, the experiment data of air pressure sensor is shown in Table 1.
Figure 8. Measured liquid level under standard atmospheric pressure.

Table 1. Experiment data of air pressure sensor.

| Height/cm | Water/Pa | Alcohol/Pa |
|-----------|----------|------------|
| 2.43      | 102925   | 102673     |
| 4.86      | 102925   | 102666     |
| 7.29      | 102929   | 102662     |
| 9.72      | 102936   | 102663     |
| 12.15     | 102939   | 102662     |
| 14.58     | 102945   | 102664     |
| 17.01     | 102938   | 102657     |
| 19.44     | 102941   | 102657     |
| 21.87     | 102948   | 102665     |
| 24.3      | 102946   | 102659     |

After replace the standard atmospheric pressure with the experiment data of air pressure sensor, the recalculated measured liquid level is shown in Figure 9.

Figure 9. Recalculated measured liquid level.
After compensating the test experiment data by density and air pressure sensors, the max relative errors [11] between the recalculated measured liquid level and the liquid level are 0.95% and 0.83% when the liquid uses water and alcohol respectively, and both less than 1%. So, adding density and air pressure sensor can obviously improve the measurement accuracy and make sure that measurement result is not affected by the change of liquid density and air pressure. Through the above experiment data analyses, the pumping test system can realize the effective measurement of water level with high application value.

6. Conclusions
To realize the multi-parameter automatic detection instrument of water output, water level and water temperature in hydrological hole pumping test, one multi-parameter automatic measuring instrument system based on single chip microcomputer designed. The pumping test system contains one lower computer module and one upper computer module. The lower computer module uses the STM32 single chip microcomputer as the central module of the controller, supplemented by the sensor module, the power module, the communication module and the display module to realize the automatic detection of the multi-parameters of the hydrological hole pumping test. It can display the information of pumping speed, water level, water temperature and water flow in real time and realize the function of pumping timing switch. In the sensor module, air pressure and density sensors are led to counteract the influence of air pressure and liquid density changes on liquid level measurement results. To achieve detection performance of the pumping test system, test experiment is carried out on one pumping test system prototype. Through test experiment data analyses, the difference between the measured liquid level and the liquid level is close to an order of magnitude without considering the influence of density and air pressure. After compensating the test experiment data by density and air pressure sensors, the max relative errors between the recalculated measured liquid level and the liquid level are 0.95% and 0.83% when the liquid uses water and alcohol respectively, and both less than 1%. All these data confirm that the pumping test system can realize water level automatic detection without influence of air pressure and liquid density, and has certain application value in the aspect of high precision liquid level automatic measurement.

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References
[1] Song W, Ni L and Yao Y 2020 Energy & Buildings 208 109660
[2] Zhu Y G, Zhai Y Z and Teng Y G 2019 Science of the Total Environment 2019 135141
[3] Liang X, Ye M and Xu Y X 2019 Ground water 57(6) 962-968
[4] Guang T, Huang W Z and Xu N X 2019 Sensors and Actuators B: Chemical 294 132-140
[5] Abdulkadir K, Enri D and Pieter C 2019 Pervasive and Mobile Computing 59 101044
[6] http://www.waveshare.net/wiki/SIM7020C_NB-IoT_HAT
[7] Chang C C, Wu H L and Sun C Y 2017 Pervasive and Mobile Computing 38(1) 275-278
[8] Yin A and Xie Z M 2019 Tectonophysics 751 229-244
[9] Zheng Y, Lai Y and Hu Y H 2019 Journal of the Mechanics and Physics of Solids 131 221-229
[10] Majid M, Mohammad Amin A and Fariborz S 2018 Journal of Molecular Liquids 264 88-97
[11] Xiao L Q and Wang W Y 2017 Journal of the Korean Statistical Society 46(3) 375-389