The Research and Development of High-precision Measuring Instrument Based on ARM Embedded System

Shuo Yang¹ and Guofeng Qin¹*
¹College of Electronics and Information Engineering, Tongji University, Shanghai 201804, China

Abstract. This paper focuses on the research and development of high-precision measurement instruments based on ARM, which is a kind of AC (Alternating Current) and DC (Direct Current) resistance measuring instruments for cables and wires. The instrument has a good human machine interface, can automatically collect data of temperature, voltage and other parameters through sensors. After the collected data is transmitted to the CPU for processing and calculation, the resistance, inductance, phase angle are obtained and displayed on the screen. The instrument has the ability to automatically switch ranges, perform complex calculations and automatically compensate for errors, and can flexibly change functions and expansion modules for use in electronics and industrial applications.

1 Introduction

Embedded system technology has developed very well and the application of high-speed microprocessors and large-capacity flash memory technologies have created a huge space for instrument development in information processing and system functions. In reference 1, an intelligent system for monitoring grain condition is designed for real-time monitoring of grain conditions in grain storage bins, which saves labor costs. The system can measure data information such as temperature, humidity, and carbon dioxide concentration through sensors, which increase the convenience of grain storage management and reduce safety risks[1]. In reference 2, in order to detect the damage and resistance attenuation of bridge structures during long-term operation, an ARM-based embedded bridge inspection instrument is designed for detecting the bridge load pressure, bridge stress, strain, and settlement parameters for a long time, which achieves the goal of unattended and long-term monitoring[2]. In reference 3, Pengxiang Jin and others develop a multi-function health detection instrument, which is based on ARM embedded system, collecting body temperature, blood pressure, heart rate and other information of human body through Bluetooth or wireless[3]. Embedded systems also be applied to facial recognition[4], reading auxiliary system[5], and interconnection of different bus protocol[6]. This paper mainly focuses on proposing a high-precision measuring instrument based on ARM microprocessors. It uses the embedded system’s advantages of low cost, low power consumption, small size, and fast response speed to change the phenomenon that traditional analog instruments are needed to measure and calculate manually.

2 System architecture

In this paper, the system architecture is mainly composed of ARM processor, digital-analog conversion module, human-computer interaction interface, control relay module, and range selection module. It is shown as in Fig. 1.
The AT91RM9200 is chosen as the main processor of the entire system, run the Linux operating system, responsible for issuing control signals, reading data and calculation. PT1000 platinum thermal resistance sensor is chosen as temperature sensor. AD7710 is chosen as analog to digital conversion chip. The display screen selects YL_LCD70_v1.1 produced by Shenzhen Youlong Technology, which is a 7-inch TFT color universal type with resolution of 800×480. The human-computer interaction function is realized through the matrix keyboard and the display screen, and the interface is written by QT.

3 Hardware Structure

3.1 AT91RM9200

AT91RM9200 is a 32-bit embedded chip that ATMEL Company introduces, adopts ARMv4T framework and ARM9TDMI kernel, built entirely around ARM920T ARM Thumb processor[7]. The AT91RM9200 includes SRAM, interrupt controllers, peripheral data controllers, parallel I/O controllers, power management controllers, and integrates USB 2.0 and 10/100Base-T Ethernet media access controllers (MAC).

3.2 PT1000 Platinum Resistance

The PT1000 platinum resistance is used as temperature sensor, and a constant current source of 1mA is used as measurement current. Low current value can reduce the measurement error caused by resistance self-heating. The resistance of PT1000 increases at constant rate as the temperature increases. The PT1000 has resistance of 1000Ω at 0℃, when the temperature is 100℃, its resistance is 1385.005Ω. Measuring the resistance $R_T$ in the current temperature environment and put it into the formula (1), then the corresponding temperature $T$ is calculated.

$$T = \frac{3.9083 - \sqrt{17.58480889 - 0.00231 \times R_T}}{0.001155}$$

(1)

3.3 74LVC16374

The 74LVC16374 is a 16-bit edge-triggered flip-flop with latching capability. It can temporarily store the signal to maintain some level state, only two values of 0 and 1. Because the pin current value of AT91RM9200 is too small to drive the relay to close, we need to connect AT91RM9200 with 74LVC16374. When changing the state of the register, the pin on the other side of 74LVC16374 output a stable high and low levels to achieve the purpose of closing the control relay.

3.4 AD7710

The AD7710 is a complete analog front end chip that can be used for low-frequency measurement equipment. It uses Sigma-Delta conversion technology to achieve no missing of code under 24-bit accuracy. The AD7710 has control registers that control the filter's cutoff frequency, input gain, channel selection, signal polarity, and calibration mode. The error within a 23-bit dynamic range is only 0.0015%. The effects of temperature drift effects can be eliminated by Self-calibration mode, which also eliminate zero span and full-scale errors.

In this paper, AD7710 work in external clock, bipolar input, self-calibration mode, the cutoff frequency is 2000HZ. The pins $DRDY, TFS, RFS, SCLK, SDATA, A_0$ of AD7710 are connected to the IOs pin of the AT91RM9200.
4 Software Algorithms

The workflow of the entire system is that after the system is powered on, input the current value, frequency, and other parameters in the interactive interface. The data such as voltage and temperature of the cable will be collected and analog-digital converted, then compared with the selected range. Selecting the appropriate range automatically by controlling the driver of relay, the voltage data in the appropriate range is obtained. After the error calibration process, the measurement data is obtained. The processor uses the previously written formula to calculate the resistance value and other information. Then information will be transmitted to result interface designed by QT and displayed on the screen.

4.1 QT Interface and Calculations

At the level that users directly contact, using QT to develop the application interface by C++. Qt/Embedded Free Edition is an embedded version provided by Qt for the development of free software[8]. The data read from the driver module is calculated and calibrated in the QT application program and only the final result is displayed in the interface. The main interface design is shown in Fig. 2. There are two calculations to choose.

![Fig.2. The main interface](image)

4.1.1 Default Mode and Straight Conductor Mode. Firstly, AC current value I and frequency value \( f_1 = 50 \text{Hz} \) of AC constant current source is selected as input source. The voltage value \( U_1 \) is measured and substituted into equation (2) to calculate the equivalent AC resistance value \( R_1 \).

\[
R_1 = \frac{U_1}{I} \quad (2)
\]

Secondly, AC current value I and frequency value \( f_2 = 60 \text{Hz} \) of AC constant current source is selected as input source. The voltage value \( U_2 \) is measured and substituted into equation (3) to calculate the equivalent AC resistance value \( R_2 \).

\[
R_2 = \frac{U_2}{I} \quad (3)
\]

The equivalent AC resistance formula is as follows:

\[
R_1^2 = R_0^2 + R_L^2 = R_0^2 + 4\pi^2 f_1^2 L^2 \quad (4)
\]

\[
R_2^2 = R_0^2 + R_L^2 = R_0^2 + 4\pi^2 f_2^2 L^2 \quad (5)
\]

\( R_0 \) represents the DC resistance, \( R_L \) represents the inductive reactance and \( L \) represents the inductance. In practice, the inductance value \( L \) is always fixed. According to formulas (4) and (5), the formula (6) for the inductance \( L \) is obtained:

\[
L = \sqrt{\frac{R_1^2 - R_2^2}{4\pi^2(f_1^2 - f_2^2)}} \quad (6)
\]
Substitut inductance value $L$ into equation (4), and get the formula (7) for calculating the DC resistance $R_0$:

$$R_0 = \sqrt{R_1^2 - 4\pi^2f_1^2L^2} \quad (7)$$

4.1.2 Customize Mode. The Customize conductor customize mode and disc conductor customize can be selected through the keyboard. The input parameters and calculation formula are different from the default mode.

Input the known inductance value $L$ of the straight conductor or disc conductor and length value, AC current value $I$ and frequency value $f$ of AC constant current source is selected as input source. Then measure voltage value $U$, and get the equivalent AC resistance value $R_Z$.

$$R_Z = \frac{U}{I} \quad (8)$$

Calculate DC resistance $R_0$, inductive reactance $R_L$ and phase angle $\phi$ as follows:

$$R_0 = \sqrt{R_Z^2 - R_L^2} \quad (9)$$

$$R_L = 2\pi fL \quad (10)$$

$$\phi = \tan^{-1} \frac{R_L}{R_0} \quad (11)$$

4.2 Character Device Driver

This system needs to write two character device drivers: control relay module and analog-to-digital conversion module. Drivers run directly in the kernel space, and provides an interface to the user. The user's operation on the kernel needs to implement the open, read, write, and release methods. These are encapsulated in the file_operations structure[9], as follows:

```c
struct file_operations cardout_fops = {
    owner:   THIS_MODULE,
    open:      cardout_open,
    release: cardout_release,
    read:   cardout_read,
    write:      cardout_write,
};
```

Open: open the device for I/O operation, and module counter add one;

Release: release device, and module counter minus one;

Read: read data from the device;

Write: write data to the device.

The A/D conversion driver provides two external interfaces: open and read. Open is used to open the device file. In this process, the AD7710 chip is automatically initialized and its operating mode is set by writing a control word. Read is used to read the AD conversion value. In order to reduce the measurement error, each time the read interface is called, 12 sets of data are obtained from the driver module. After removing the maximum and minimum, return from the average of the remaining 10 sets of data, and convert it to the corresponding 24-bit binary data. In order to prevent the voltage jitter from affecting the accuracy too much, each reading judcges the difference between the maximum and the minimum. If the difference is less than 0xff, the voltage jitter is stable and the result can be returned, otherwise read data again. The process is shown as Fig.3.
4.3 Adaptive Range

The range is divided into three levels: range1:1x, range2:10x and range3:100x. Represents the magnification of the measured voltage, which is 1x, 10x, 100x. The AD7710 has an analog input voltage range of -2.5V to +2.5V. The range1 is the default selection range. In order to ensure measurement accuracy, if the voltage is less than 0.1V, switch to range2 for measurement. Under range2, if the voltage is less than 0.1V, switch to range3 for measurement.

4.4 Calibration Algorithm

Inevitably, instrumentation systems have measurement deviation in hardware and the analog-to-digital conversion process. In addition to using the self-calibration method of the AD7710, it is also necessary to reduce deviation in software algorithms. Using a standard resistor, input different current values and record the measurement results. In different voltage ranges, such as 0-0.5V, 0.5-1.0V, etc. the fitting coefficient is calculated according to the least square method. Each subsequent measurement result is corrected by the coefficient of the corresponding voltage interval so that the sum of the squared errors of the actual data and the measured data is minimized. The accuracy of measurement after the calibration algorithm can be maintained within 0.04mΩ. Table 1 shows the data of the standard DC resistance 10mΩ before and after calibration with different input current. Experiments show that the deviation is greatly reduced after the algorithm calibration, as shown in Fig.4.

| Input current /A | Resistance before calibration /mΩ | Resistance after calibration /mΩ | Deviation before calibration /mΩ | Deviation after calibration /mΩ |
|------------------|----------------------------------|---------------------------------|---------------------------------|-------------------------------|
| 0.8              | 8.06582                          | 9.99635                         | 1.93418                         | 0.00365                       |
| 1.0              | 8.06352                          | 9.97867                         | 1.93648                         | 0.02133                       |
| 1.2              | 8.08928                          | 9.99926                         | 1.91072                         | 0.00074                       |
| 1.4              | 8.17503                          | 10.0305                         | 1.82497                         | -0.0305                       |
| 1.6              | 8.16224                          | 9.96321                         | 1.83776                         | 0.03679                       |
| 1.8              | 8.22627                          | 9.99789                         | 1.77373                         | 0.00211                       |
| 2.0              | 8.26458                          | 10.0105                         | 1.73542                         | -0.0105                       |
5 Conclusion
This paper introduces a high-precision measurement instrument based on ARM processor, and uses embedded Linux operating system manages software and hardware resources. It uses QT to design an interactive interface for a convenient graphical user interface, and reduce measurement error by hardware and software calibration techniques. The experimental results show that the entire system realizes the functions of automatic measurement and calibration deviation. The system can modify and upgrade the system software according to different usage scenarios. It has the advantages of high efficiency and easy expansion and has a good application prospect in the industrial field.

6 References
[1] Q. Zhao, Y. Liu, Y. Yu, J. Song, G. Zhou. Intelligent system for monitoring and controlling of the Grain condition based on ARM9. The 26th Chinese Control and Decision Conference (CCDC), 4117-4121 (2014).
[2] X. Zhuang, L. Zhang, M. Fang, H. Wang. An Embedded System of Bridge Stress Monitoring Based on ARM9 and Zigbee. International Conference on Electrical and Control Engineering, 5007-5010 (2010).
[3] P. Jin, C. Hu, W. Lin. Interface design for multi-parameter health monitoring instrument based on ARM-9 embedded system. IEEE International Conference on Information and Automation (ICIA), 908-913 (2014).
[4] F. Ru, X. Peng, L. Hou, J. Wang, S. Geng, C. Song. The design of face recognition system based on ARM9 embedded platform. IEEE, International Conference on Asic, 1-4 (2016).
[5] K. Xiao, L.K. Su, F.F. Zeng. Reading Auxiliary Equipment based on ARM Embedded System. International Conference on Information System and Artificial Intelligence, 519-522 (2016).
[6] Q. Zhu. Research and application of industrial field bus gateway based on AT91RM900. IEEE International Conference on Software Engineering and Service Sciences, 579-583 (2010).
[7] S. SEGARS. The ARM9 family-high performance microprocessors for embedded applications. Proceedings-IEEE International Conference on Computer Design: VLSI in Computers and Processors, 230-235 (1998).
[8] Information on http://doc.qt.io
[9] J. Blanchette, M. Summerfield. C++ GUI Programming with Qt 4.10-92 (2006).

Fig. 4. DC Resistance deviation comparison