Design and implementation of strain testing system based on Qt

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Abstract. Strain testing system is an important research direction in the field of engineering testing, which is widely used in structural health monitoring, motion detection, civil engineering, and other fields. Aiming at the shortcomings of the traditional strain testing system, a strain testing system based on Qt is designed and developed independently, which can collect 8 channels of strain data at the same time and realize the interaction between software and hardware of the system. The system software is developed by Qt, integrated with signal filtering and spectrum analysis algorithms, and designed with a friendly graphical user interface, which is easy to operate. Through the test, the system can reliably measure the strain data and display the waveform of the signal in real-time. It has the advantages of high acquisition efficiency, stable running, good real-time performance and good scalability, which can provide a technical reference for the improvement of the strain test system.

1. Introduction
Strain monitoring is an important content in structural health monitoring, as well as one of the important means to analyze the stress state of parts or structures and evaluate the mechanical properties of materials [1]. The resistive strain gage is a cheap and common sensor, which can convert strain signals into electrical signals, can work in a harsh environment, does not require a high working environment, and can respond to strain signals at low frequency [2]. On the one hand, the traditional strain data acquisition system needs to design the strain signal amplifying circuit and filtering circuit, etc, which has a complex structure. On the other hand, it lacks intuitive user interface and is inconvenient to operate. Therefore, it is very important to design a simple and reliable strain testing system.

LiangCheng Su [3] pointed out that the traditional hardware strain detector was limited by the working frequency of the single-chip microcomputer itself, and the measurement accuracy was not high and the dynamic measurement could not be realized. FangYi Li [4] pointed out that the quality of the strain testing system is directly related to the reliability of the experimental results. To better measure the strain, it is necessary to design a strain test system. In related studies, DingZhen Li [5] designed and implemented a dynamic strain testing system based on the embedded Linux operating system, and realized parameter setting, data collection, data viewing curve through the Web. The disadvantages of this system are complex system structure and discrete data curve. Aiming at the complex signal conditioning circuit of the traditional strain acquisition system and low collection accuracy, BingLi Shi [6] used FPAA signal conditioning circuit to realize a multi-channel strain data acquisition system and improved the strain signal conditioning circuit, but there was no design available operational user interface. In view of the complex structure and inconvenient operation of the traditional strain...
acquisition system, Ting Lv\cite{7} used the LabView8.2 test platform to realize the design of the strain signal acquisition system. However, the encapsulation of LabVIEW is relatively high, and the application interface designed by LabVIEW is relatively poor in portability, low in program development efficiency, and not easy to expand. Therefore, the performance of the strain testing system needs to be improved.

Qt is a cross-platform application development framework, and as a multi-platform graphical user interface development framework, it is one of the best choices for human-computer interaction system development\cite{8}. The test system software is developed using Qt Creator5.9, which can meet the development needs.

This paper designs a strain testing system based on Qt, introduces the principle of strain data measurement, realizes the dynamic acquisition of strain signals, waveform display, processing and analysis of strain signals, designs a friendly man-machine interface for the system, and can provide a technical reference for improving the performance of the strain testing system.

2. Principle of strain measurement

When the resistance strain gauge is used to measure the strain, because the strain value is small, the Wheatstone bridge circuit is usually used to measure such a small resistance change value\cite{9}. In order to accurately measure the strain data, the system adopts the Wheatstone full-bridge circuit for measurement, which can increase the sensitivity of the system by four times. The Wheatstone full bridge circuit is shown in Figure 1.

Where $R_1$ and $R_3$ are the effective strain gauge elements for measuring compression Poisson effect ($-\varepsilon$), $R_2$ and $R_4$ are the effective strain gauge elements for measuring tensile Poisson effect ($+\varepsilon$), $V_{EX}$ is the excitation voltage and $V_{CH}$ is the measuring voltage. The measured voltage is shown in Equation (1).

$$V_{CH} = V_{EX} \left( \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} \right)$$  \hspace{1cm} (1)

When the bridge is balanced, $R_1 R_3 = R_2 R_4$, when the resistance values of each arm of the whole bridge vary by $\Delta R_1, \Delta R_2, \Delta R_3$ and $\Delta R_4$ respectively, for the equal bridge arm, that is $R_1 = R_2 = R_3 = R_4$, with sufficient precision, the higher order trace is omitted, the output voltage is Equation (2).

$$\Delta U = \frac{V_{EX}}{4} \left( \frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4} \right)$$  \hspace{1cm} (2)

Strain $\varepsilon = K \frac{\Delta R}{R}$ put in Equation (2) to obtain the strain as Equation (3), where $K$ is the sensitivity coefficient of the resistance strain gage. The full bridge resistance strain gage arrangement is shown in Figure 2.

$$\varepsilon = \frac{\Delta U}{K V_{EX}} = \varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4$$  \hspace{1cm} (3)
Taking the full-bridge circuit as an example, the principle of collecting strain data is as follows: When there is no external force, the strain of the equal-strain cantilever beam is zero, and the output voltage of the full-bridge circuit is zero. After loading, the cantilever beam produces strain and the resistance value of the resistance strain gauge changes. At this time, the signal is very weak, which needs to be adjusted and amplified by the dynamic strain resistance gauge, then connected to the PCI-6143 data acquisition card through the BNC-2120 noise-resistant shielded junction box. Through A/D card converted into a discrete digital signal, and the collected data is stored to the computer by the interface of DAQmx API driven of the data acquisition card. The strain value is processed and analyzed in the computer, and finally displayed on the software interface.

3. System architecture
This system uses NI company PCI-6143 acquisition card as data acquisition equipment, and uses Qt C++ to develop data acquisition software to realize high-speed data acquisition and data processing and analysis. The system is mainly composed of three parts: test system software, device driver, and system hardware. Each part transmits information based on Qt signal and slot mechanism. The system architecture is shown in Figure 3.

3.1. Data acquisition card selection
This system uses PCI-6143 high performance multi-function data acquisition card produced by American NI company, as is shown in Figure 4. The acquisition card has 8 16-bit analog input channels A10-A17, which can collect multiple channels at the same time. The acquisition card can be used for analog signal input, analog signal output, digital I/O, at the same time has two 24 bit counters and digital trigger, the maximum update rate of 250KS/s, ADC resolution of 16bits, the input range is ±5V, the maximum operating voltage of all analog input channels is ±7V, the time base frequency is 10MHz. It is connected with its accessory BNC-2120 through 68 pin connecting wire.
As is shown in the Figure 5, the BNC-2120 junction box is equipped with special wiring accessories for PCI-6143, which can be used with the data acquisition card PCI-6143.

3.2. Selection of resistance strain gauge
The resistance strain gauge is selected from the BF20-3AA high-precision resistance strain gauge produced by China Avionics Measurement Company, and its main performance parameters are shown in Table 1.

| The performance parameters | Performance indicators |
|---------------------------|------------------------|
| Resistance value          | 120 ± 1Ω               |
| Sensitivity coefficient   | 2.0 ± 1%               |
| Power supply voltage      | 3~10V                  |
| Strain limit              | 20000um/m              |
| Basal material            | Constantan             |
| Base length * base width  | 56 * 5.2mm             |
| Gate length * gate width  | 50 * 3.0mm             |
| Insulation resistance     | 1000MΩ                 |
| Temperature range         | -10~60℃                |
| Mechanical hysteresis     | 1.2um/m                |

3.3. Selection of dynamic strain gauge and bridge box
The TS3828 dynamic resistance strain gauge manufactured by Jiangsu TaiSi Electronic Co., Ltd. The dynamic strain gauge is mainly used to adjust and amplify the strain signal, balance the bridge voltage and provide bridge voltage for the Wheatstone bridge. The TS3800 type bridge box is selected as the bridge junction box, which is mainly used to connect the resistance strain gauge to the bridge and convert the change of resistance into the change of voltage.

4. System software design

4.1. Software development process of strain test system based on QT
The test software must have a user-friendly graphical user interface (GUI) to facilitate user operation, and at the same time, it requires fast response and good real-time performance. Qt is the mainstream cross-platform application development platform, and use C++ language to develop programs. Because the program developed by C++ language is fast and efficient, C++ language is the first choice for the development of software combining hardware and software, Qt has the advantages of both sides, so this test software chooses Qt as the development kit. Qt adopts signal and slot to achieve event processing, when the user clicks on any widget in the UI interface, will produce the
corresponding signal, such as button is clicked, released, etc. The key steps for Qt to develop data acquisition software are as follows:

1) Use Qt Creator to create a project with UI interface.
2) Design various widgets needed by the system on the *.ui graphical interface generated by the project.
3) Call the hardware device driver LIB or DLL. During development, static link library *.Lib or dynamic link library *.Dll file and related header files need to be placed in the same level directory of the project.
4) Develop the response slot function of the widget. The slot function is the core of the whole measurement software development, all functions are completed by various slot functions. All API calls and data operations should take place in the slot function.

4.2. User interface design of data acquisition system
This system user interface mainly contains strain data acquisition module, waveform display module, sampling data filtering, signal spectrum analysis module and storage module. The system interface is designed by Qt Designer visualization designer software, system UI function structure is shown in Figure 6.

4.3. Waveform chart development
In order to observe the characteristics of the strain signal, it is necessary to develop the signal waveform diagram. Qt provides the base class Qt Charts for the development of two-dimensional graphics[10], which can easily develop various two-dimensional graphics. To use the Qt Charts module in the project, you must add the following statement in the project management file *.pro file: Qt += charts. The key steps for Qt to develop a two-dimensional chart are as follows:

1) Create a QChart
2) Create a data sequence
3) Add data to a data sequence
4) Data Sequences are added to the chart
5) Create an Axis
6) Data sequence is added to the coordinate
7) Show the QChartView
5. System testing and analysis

5.1. System workflow analysis
After the PCI-6143 data acquisition card and its driver software NI-DAQmx are installed, the industrial control computer will automatically set the I/O address and interrupt number, allocate memory resources, and realize the interaction between software and hardware of the test system through the NI-DAQmx driver API and Qt program. In the interface of the test system, necessary parameters such as analog input channel, sampling frequency, bridge information and strain gauge information can be set. Users can complete real-time collection of strain data through simple operations and store the data in the computer memory for subsequent processing and analysis.

The working process of the test system is as follows: start the system test software, set the necessary test parameters according to the requirements of the strain test system, and start data acquisition. The driver NI DAQmx communicates with the board to complete data acquisition. The board uses its own on-board memory to buffer the data. When certain conditions are met, the data is read into the computer hard disk by DMA, and the data acquisition module completes high-speed continuous data acquisition. The sampling signal is displayed in real time by waveform display module.

5.2. Setting of experimental parameters
In the experiment, Dev/AI0 was selected as the analog input channel, and the signal input range was $0.5 \sim 0.5 \mu \varepsilon$. Full Bridge II was selected as the Full Bridge type, which was suitable for measuring bending strain, and the initial bridge voltage was 0V after being balanced by the dynamic resistance strain gauge. The voltage excitation source is external excitation, and its value is 5V, the strain gage factor is 2.00, the rated resistance of the strain gage is 120Ω, the Poisson's ratio is 0.30, the sampling rate is 5120, the number of samples is 32768, and the sampling clock source is the board clock OnboardClock.

5.3. Strain data acquisition
According to the above parameter Settings, patch wiring is carried out in the manner shown in Figure 1 and 2. Excitation voltage is supplied to the electric bridge through a dynamic resistance strain gauge, the data acquisition card is connected to the BNC-2120 junction box, using system test software to automatically collect data, and draw the signal waveform diagram. The original strain signal waveform diagram is shown in the Figure 7.

![Figure 7. The original strain signal curve.](image-url)
5.4. Data processing

The moving average filter is the easiest digital filter to understand and apply, so it is the most common filter in digital signal processing\[^{11}\]. The moving average filter is to take the average value of the input signal to generate the output signal, and its mathematical expression is shown in Equation (4), where \(x[i]\) represents the input signal, \(y[i]\) represents the output signal, and \(M\) represents the number of points used in the moving average. The curve of the strain signal after moving average filtering is shown in Figure 8, in which the red curve is the original strain signal before filtering, and the blue curve is the strain curve after filtering.

\[
y[i] = \frac{1}{M} \sum_{j=0}^{M-1} x[i+j]
\]  

\[\text{(4)}\]

![Figure 8. The curve of the strain signal after moving average filtering.](image)

5.5. Spectrum analysis

Perform fast Fourier transform (FFT) on the collected strain data to calculate the amplitude spectrum of the time domain signal. The amplitude spectrum of the strain signal is shown in Figure 9.

![Figure 9. Spectrum diagram of strain signal.](image)
6. Conclusion

This paper designs a set of strain test system based on Qt, completes the system hardware construction and system software development, which can quickly collect strain signals, and realize signal filtering and spectrum analysis. Experiments verify that the system's software and hardware have high reliability, can meet the accuracy requirements of the strain test system, and can provide a technical reference for the development and testing of the strain test system. It has certain practical value and can be applied to the test of the strain system in the fields of civil engineering and mechanical engineering and so on.

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