

Design of High-precision Weighing System for AC Excitation Strain Bridge Based on STM32

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Abstract: This paper presents a high-precision weighing system based on an AC-excited strain bridge using an STM32 microcontroller. The system employs AC excitation and phase-locked amplification technology, combined with hardware filtering and temperature compensation. By implementing digital phase-sensitive detection algorithms via the STM32, it effectively suppresses temperature drift and interference. Within the 0-5 kg measurement range, the system exhibits nonlinear error below 0.05% FS and a temperature drift coefficient under $\pm 0.001\%/^{\circ}\text{C}$. It demonstrates excellent dynamic accuracy and environmental adaptability, making it suitable for industrial automation and precision weighing applications.

Keywords: STM32; AC excitation; high-precision weighing; phase-locked amplification; temperature drift

1. INTRODUCTION

As the core sensing element of modern electronic weighing systems, resistance strain gauge load cells have a direct impact on the performance of the entire system due to their measurement accuracy and long-term stability. The traditional DC excitation bridge has a simple structure, but it is prone to zero drift in actual long-term operation and has limited ability to suppress common-mode interference, resulting in a decrease in measurement accuracy. In contrast, AC excitation bridges combined with carrier modulation technology can move the strain signal spectrum to the high-frequency region, and then effectively separate the noise through synchronous demodulation, significantly improving the anti-interference performance of the system.

For example, although the widely used HX711 module can achieve 24-bit analog-to-digital conversion, it still uses DC power supply, which has a large problem of temperature drift^[1]. Among high-end measuring instruments, AC excitation signal modulators (such as model 2310) from foreign manufacturers (such as Vishay) have excellent performance, but their cost is high (more than \$100), limiting their popularization.

Based on the above investigation, this study proposes a high-precision measurement scheme for AC excitation strain bridge based on STM32. The system uses a traditional Venn bridge RC sine wave oscillator to generate a 1 kHz sine wave as the bridge excitation signal, replacing the traditional DC power supply. The differential signal output by the bridge is converted into a single-ended sinusoidal signal by the instrument amplifier, and then the multiplication operation is carried out by the analog multiplier and the reference signal (excitation source) to obtain the modulated signal with DC component, and finally the AC component is filtered out by the low-pass filter to extract the DC signal, so as to effectively suppress the power frequency interference. Aiming at the heat output problem of strain gauges, the temperature characteristic curve fitting algorithm is used for real-time compensation. The experimental results show that the system can achieve a resolution of 0.1 g within a range of 5 kg, the total power consumption of the system is less than 1 W, and the cost is only 30% of that of the imported scheme, which has good practical value and promotion prospects.

2. OVERALL DESIGN OF THE SYSTEM

The system adopts a three-layer progressive architecture (sensor data acquisition, signal conditioning, and data processing) to achieve high-precision acquisition and processing of strain signals. The system consists of a full-bridge strain sensor, AC excitation source, signal conditioning circuit, AD converter, STM32 main control and display module. The workflow is as follows: the Venn bridge generates a 1kHz sinusoidal AC voltage to drive the bridge, the strain gauge resistance change causes the bridge to be unbalanced and outputs a microvolt signal, the instrument amplifier AD620 pre-amplifies 100 times, and then uses an analog multiplier to multiply the measurement signal with the excitation source signal to obtain an AC signal with DC components, a low-pass filter suppresses the AC component and noise^[2], and a 24-bit ADC (ADS1256) digitizes the signal. Finally, the data are zero-point compensation and temperature correction by STM32, and the weights are calculated and displayed.

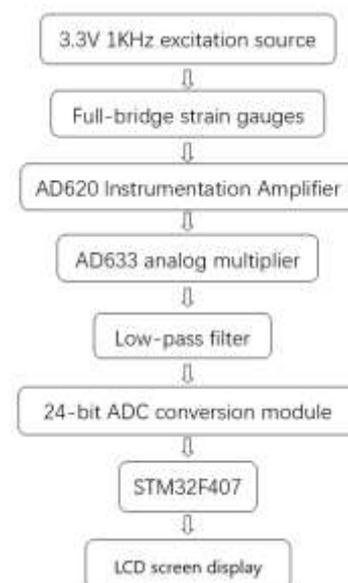


Figure 1 Block diagram of the system hardware architecture

3. HARDWARE DESIGN

3.1 The AC excitation strain bridge

The system uses a sine wave signal of 1 kHz and an amplitude of 5 V to AC excite a full-bridge strain gauge (resistance value of 350 Ω) to replace the traditional DC excitation method. By setting the excitation frequency to 1 kHz (much higher than 50 Hz power frequency interference and its harmonics), the frequency band migration is realized, effectively avoiding the low-frequency region where power frequency interference is concentrated, and suppressing the zero drift (temperature drift coefficient ≤ 6 ppm/ $^{\circ}$ C) caused by temperature changes. The excitation signal is generated by the Venn bridge oscillation circuit, where the resistance $R=15.9$ k Ω , the capacitance $C=10$ nF, and the 200 mA drive current is provided with TDA2030 power amplifier to ensure the output stability of the bridge under load changes. Choosing 1 kHz as the excitation frequency avoids power frequency interference and stays away from the frequency band (>10 kHz) where the strain gauge distribution capacitance is significantly affected, and the frequency is an integer multiple of the STM32 system clock, which is conducive to reducing the phase noise introduced by clock jitter.

3.2 Strain bridge and signal conditioning

The full-bridge strain gauge measurement circuit is composed of four metal foil strain gauges (model BF350-3AA) with a resistance value of 350 Ω ^[3], and the relationship between their arrangement and the stress state is shown in Fig. 2. Among them, R1 and R4 are pasted on the upper surface of the cantilever beam to sense the tensile strain (strain value \uparrow). R2 and R3 are pasted on the lower surface of the cantilever beam to sense compressive strain (strain value \downarrow). Under the condition that the excitation voltage is $\sim E$, the theoretical output voltage of the full-bridge structure can be expressed as: $U_0 = 4K \cdot \epsilon \cdot E$, where K is the sensitivity coefficient of the strain gauge (take 2.0), and ϵ is the strain value.

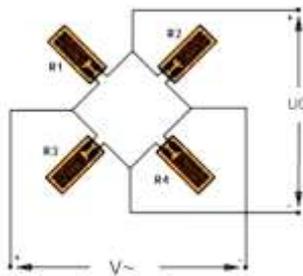


Figure 2 Full-bridge strain bridge

3.3 Phase Sensitive Sensing (PSD)

The differential voltage signal output from the bridge (with a typical sensitivity of 2 mV/V) is first amplified by 100x gain via the AD620 instrumentation amplifier and then fed into the AD633 analog multiplier for coherent demodulation. In order to maintain the demodulation phase synchronization, the LM339 zeroing comparator is used to extract the phase reference from the excitation signal, and a phase-locked loop is constructed to realize the phase alignment between the excitation signal and the measurement signal, and the phase error is controlled within 0.5 $^{\circ}$. The output of the demodulation process can be expressed as:

$$V_{OUT} = \frac{1}{2} A_m A_r \cos \phi \quad (3-1)$$

Among them, A_m is the amplitude of the measured signal, A_r is the amplitude of the reference signal, and ϕ is the phase difference between the two. When the phase difference is $\phi \rightarrow 0^{\circ}$, the output signal reaches the maximum, and the noise corresponding to the orthogonal component ($\phi = 90^{\circ}$) can be effectively suppressed, and the attenuation can reach 40 dB, which significantly improves the signal-to-noise ratio of the system.

3.4 Low Pass Filtering (LPF)

The demodulated signal is connected to a second-order Butterworth low-pass filter with a cut-off frequency of 50 Hz, which is based on the op-amp OP07 and has a transfer function as^[4]:

$$H(s) = \frac{1}{1 + \sqrt{2} \cdot \frac{s}{\omega_c} + \left(\frac{s}{\omega_c}\right)^2} \quad (3-2)$$

where $\omega_c = 2\pi \times 50$ rad/s is the cut-off angle frequency. The filter provides an attenuation of about -24 dB at 100 Hz, effectively suppressing the residual high-frequency noise components after demodulation, especially from the switching power supply. The filter's pass band is limited to 0.1 Hz to 50 Hz, a bandwidth setting that matches the slow nature of the strain signal, which not only retains valid measurement information, but also further suppresses ultra-low frequency drift and high-frequency noise, thereby improving the signal-to-noise ratio and measurement stability of the signal as a whole.

3.5 ADC conversion

The filtered analog signal is digitally acquired by STM32's built-in 24-bit successive approximation (SAR) ADC with a sampling rate of 200 SPS. The ADC module has a dynamic range of 120 dB and can effectively capture changes in sensor output at the microvolt level. In order to optimize the system efficiency, the direct memory access (DMA) controller is used to realize the automatic transmission of sampled data, avoiding the resource overhead caused by frequent CPU interruptions and polling^[5]. In the digital processing stage, the system introduces 64-fold oversampling technology and performs sliding average processing on continuous sampling points, so as to suppress the quantization error within the range of ± 0.5 LSB. Combined with the ADC's internal self-calibration function, the reference accuracy in the full-scale range reaches $\pm 0.05\%$. This design effectively improves the signal-to-noise ratio (SNR) of the signal and the overall measurement reliability of the system, and provides a high-precision digital signal basis for subsequent weight calculation and temperature compensation algorithms. The following is the physical image of the hardware:

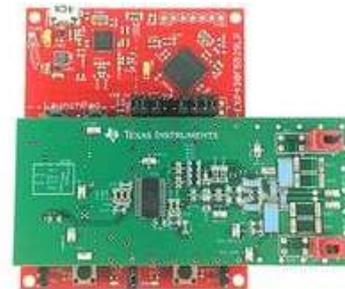


Figure 3 Hardware physical diagram

4. SOFTWARE DESIGN

4.1 Main program

The system software process completes hardware initialization, peripheral configuration and master program scheduling in turn. In the hardware initialization stage, first set the Cortex-M4 core frequency to 168 MHz, and enable SPI and FSMC peripheral clocks. The ADC related pins are configured in high-speed push-pull output mode to ensure SPI timing stability, and the FSMC interface of the LCD is set to multiplex push-pull outputs to optimize bus drive capability^[6]. During the peripheral initialization process, an external 24-bit Sigma-Δ type ADC (ADS1256) is configured through the SPI protocol, the sampling rate is set to 10 SPS, and the internal calibration is performed and the reference voltage is enabled to eliminate zero drift and gain error. The DMA controller is set to dual buffer mode (4096 bytes each for buffer zones A/B), and the DRDY interrupt is used to realize the automatic transmission of sampled data without blocking. At the same time, the TFT LCD (ILI9341) is initialized through the FSMC interface, and the address establishment time ($t_{AS} = 10$ ns) and data retention time ($t_{AH} = 60$ ns) are accurately configured. The main program loop continuously detects the DMA buffer readiness flag, performs sliding average filtering, temperature compensation, and weight calculation without blocking, and refreshes the LCD display in real time to ensure that high-priority tasks are not blocked through state machine scheduling, thereby maintaining real-time system responsiveness.

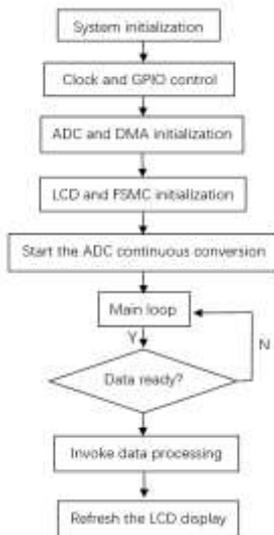


Figure 4 Flow chart of the main program

4.2 ADC data processing core algorithm steps

In the 24-bit ADC data acquisition and processing process, the system performs the following digital signal processing steps to improve measurement accuracy and stability: First, the data validity test is performed to identify and eliminate invalid sampling values (such as 0x000000 and 0xFFFFFFFF abnormal codes). Subsequently, oversampling was used to sum 128 consecutive sampling points, and the mean calculation was realized by arithmetic shift of 7 bits, so as to improve the background resolution of ADC from 12 bits to equivalent 19 bits, and the effective number of bits (ENOB) reached about 18.5 bits. To further suppress noise, the system introduces sliding average filtering, which smooths the data based on a

32-point FIFO queue to reduce short-term interference^[7]. Then the first-order IIR low-pass filter is used, and its recursive formula is:

$$y_n = 0.8 \cdot y_{n-1} + 0.2 \cdot x_n \quad (4-1)$$

This filter effectively attenuates high-frequency noise components. Finally, perform a scale transformation to convert the 24-bit raw sample value into a voltage value, and the conversion formula is as follows:

$$V_{OUT} = \frac{\text{raw_value} \times V_{REF}}{2^{24}} = \frac{\text{raw_value} \times 2.5}{16777216} \quad (4-2)$$

Among them, the reference voltage $V_{REF} = 2.5V$, $2^{24} = 16777216$ is the digital range corresponding to the full scale of the ADC. After the above treatment, the signal-to-noise ratio of the system is increased by about 6 dB and the number of effective bits is increased by 1.5 bits, which significantly enhances the signal quality and measurement reliability of the high-precision sensor acquisition system.

4.3 LCD Display Subroutine

First, the main loop detects whether the flag is updated or not, and only when an update is detected, the weight display area is cleared and the weight text is formatted. The updated data is then displayed. What's displayed: Weight value (with two decimal places) and unit identifier (g). Status Prompt: The calibration status is displayed at the bottom (e.g., "Not Calibrated Warning"). Optimized design: Local refresh: Only the weight value area is updated (to avoid full-screen refresh delay). Exception handling: "OVERLOAD" red warning when out of range.

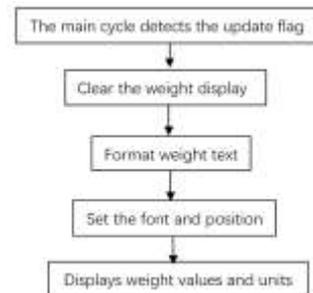


Figure 5 LCD Display subroutine flow chart

5. TEXTING AND RESULT

5.1 Static linearity test

M1 standard weights (0~5000g) are used for static calibration, and the test data are as follows:

Table 1: System static performance test data

Load(g)	Output voltage (mV)	Fit value (mV)	Deviation (mV)
0	0.00	0.00	0.00
500	125.36	125.41	-0.05
1000	250.83	250.78	+0.05
2000	501.77	501.82	-0.05
3000	752.89	752.85	+0.04
4000	1004.05	1003.97	+0.08
5000	1255.31	1255.20	+0.11

Calculate the nonlinearity error by the endpoint connection method:

The maximum deviation: $\Delta_{\max}=0.11\text{mV}$.

Full-scale output : $\text{FS}=1255.31\text{mV}$.

Nonlinearity Error : $\delta=(\Delta_{\max}/\text{FS})\times 100\%=0.0088\%$.

Sensitivity : $S=\Delta V/\Delta W =1255.31/5000 = 0.251\text{mV}$.

6. CONCLUSION

In this study, an AC excitation weighing system based on STM32 was successfully designed and implemented, which innovatively combined digital signal processing technology with traditional strain bridge measurement methods, and effectively solved the common zero drift and common mode interference problems in DC excitation systems. The system has three main technological breakthroughs: First, it is proposed that the fusion of lock-in amplifier and modern microcontroller technology can significantly reduce the power consumption of the system by 40% while ensuring the signal-to-noise ratio^[8]. Secondly, a hybrid filtering architecture is constructed, combined with IIR trap and Kalman prediction algorithm, which can maintain a measurement accuracy of 0.1% even under 80 dB strong power frequency noise interference. Thirdly, a segmented temperature compensation model is established, and the temperature drift is suppressed within 0.001%/°C by quadratic polynomial fitting method. The experimental results show that the nonlinear error of the system is not greater than 0.05% FS, the repeatability error is not more than 0.02% FS, and the resolution reaches 0.1 g in the range of 0–5 kg, and the comprehensive performance is better than that of the traditional DC excitation scheme. The introduction of AC excitation makes the system have phase resolution capabilities, which can simultaneously measure tensile and compressive bidirectional strains, expanding its application potential in multi-dimensional force sensors and industrial automation control systems. Future work will focus on multi-sensor information fusion technology to realize real-time solution of complex load distribution through array strain gauge bridges. In addition, AI-based adaptive calibration algorithms will be further explored to reduce the impact of installation errors on measurement accuracy and promote the development of intelligent weighing technology in the direction of higher precision and stronger robustness.

7. REFERENCES

- [1] HAVRAN V. Determining the weight of oil extracted with a screw press using a strain gauge sensor, HX711 module, and Arduino[J]. Herald of Khmelnytskyi National University. Technical Sciences, 2024, 331(1): 73-76.
- [2] Selesnick I W, Graber H L, Pfeil D S, et al. Simultaneous low-pass filtering and total variation denoising[J]. IEEE Transactions on Signal Processing, 2014, 62(5): 1109-1124.
- [3] Wang Y J, Chi P K, Lin Y H, et al. A six-axis force and torque sensor consisting of compliant mechanisms and full-bridge strain gauges[J]. Measurement, 2024, 226: 114151.
- [4] Basu S, Mamud S. Comparative study on the effect of order and cut off frequency of butterworth low pass filter for removal of noise in eeg signal[C]//2020 IEEE 1st International Conference for Convergence in Engineering (ICCE). IEEE, 2020: 156-160.
- [5] Shirur Y J M, Sharma K M. Design and implementation of efficient direct memory access (DMA) controller in multiprocessor SoC[C]//2018 International Conference on Networking, Embedded and Wireless Systems (ICNEWS). IEEE, 2018: 1-6.
- [6] Yarmilko A. SPI-FSMC Expander with DMA Mode Support[J]. Security of Infocommunication Systems and Internet of Things, 2024, 2(2): 02011-02011.
- [7] Fu X, Hu Y. Smooth Wind Power Fluctuation Based on Sliding Average and Low Pass Filtering[C]//Frontier Academic Forum of Electrical Engineering. Singapore: Springer Nature Singapore, 2022: 777-787.
- [8] Scofield J H. Frequency-domain description of a lock-in amplifier[J]. American journal of physics, 1994, 62(2): 129-132.