Development of Strong Motion Seismograph based on TMS320F2812 Control

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SUMMARY:
For the need of strong motion observation, a new type seismograph is developed based on TMS3202812 DSP chip. Instrument applies 24-bit Σ-ΔA/D converter and digital filter as three channel data acquisition system, CF card as data logger, net chip AX88796B as communication interface, build-in GSM module to send and receive SMS. Instrument intensity algorithm and trigger filter are designed and analyzed in detail. The characteristics of seismograph were tested. Results show that dynamic range of three channels is above 120dB, and system resolution is exceed 19-bits.

Key words: seismograph; instrument intensity; trigger filter; TMS320F2812

1. INTRODUCTION

The process of ground motion and the reaction of the building structure can be recorded with strong motion observation instruments. By analyzing the strong motion records, we can understand the strong motion and structure response characteristics, and make clear the relationship of the ground motion parameters and structure damage (Hu Y X, 2006). Strong motion observation mainly used in earthquake engineering and near-field seismology. With the strong motion observation networks, we gather information of earthquake, make the intensity report, give the quantitative estimate of the earthquake damage, and provide reference for earthquake emergency rescue. In order to meet the requirements of the strong motion observation, the new seismograph must have broadband response, large dynamic range, low noise, low power consumption and high reliability characteristics.

2. ALOGRITHM OF INSTRUMENT INTENSITY AND TRIGGER FILTER DESIGN

2.1. Instrument intensity

The instrument intensity standard has always been the focus on the field of earthquake engineering (Hao M et al., 2005) . Professer Huixian Liu suggested that the sesmic intensity should be defined as the average scale of shake strength on the designated location of the ground (LIU H X, 1978). It still has a guiding significance for the reaserch seismic intensity and the formulation of the instrumnet intensity. The currnet definition of the seismic intensity used in digital seismograph derived from the GB/T17742-2008 seismic intensity scale, in which the seismic intensity was divided from one degree to twelve degree. The different intensity degrees could be described by the people feeling on the ground, the building damage features by the earthquak, earthquake disaster phenomena, the value of horizontatal ground peak acceleration and peak velocity. Because the seismic intensity was evalueated by the strength of ground motion and the earthquake damage, the seismic assesment standard was uncertainty, subjectivity and complexity. For instance, the seismic intensity reported by the instrument were not necessarily coincide with the assessmental intensity. So we should find a effective method for determination the instrument intensity, which was not depend on the people's feeling, and directly reflected the intensity of the ground motion. Due to the complexity of field conditions, the instrument intensity value was not exactly correspond with the build damage level. At the same time, we need study on the shake table calibration method and standard for the seismic intensity measuring instrument.

There are several kinds of instrument intensity algorithms used in strong motion observation: 1) The Japan Meteorological Agency (JMA) has adopted the instrument intensity scales for the strong motion observation network and seismic information system. In order to distinguish the instrument intensity scales from the seismic intensity scales, JMA called the intensity measured by intensity meters as JMA intensity. 2) The method used in the Federal Seismic Survey (USGC) earthquake observation stations. 3) Professor Yifan Yuan, Institute of Engineering Mechanics (IEM), proposed another intensity algorithm. In view of complexity and uncertainty relationship between earthquake three elements(PGA, spectrum, duration time) with seismic intensity, Professor Yifan Yuan think that the fuzzy judging method for seismic intensity has a better consistency with the intensity assessment in earthquake field than the statistical regression method. And the corresponding intensity algorithm was developed based on the ground motion parameters, which was used in GDQJ-I and GDQJ-II strong motion seismograph developed by IEM (Gao F, et al., 2003.), the strong motion observation network around Beijing and Sichuan province (ZHU J G, et al.,2005). Reference those intensity algorithms; the new type seismograph applied the new method as follows (JIN X, et al., 2010):

1) Filtering the three components acceleration data with amplitude filter (see Fig. 1). The expression of the filter is illustrated in Eqn. 2.1.

$$H(f)=\frac{\alpha f^4[(f_1^2-f_2^2)^2+4f^2(\xi_1 f_1-\xi_2 f_2)^2]}{[(f^2-f_1^2)^2+4\xi_1^2 f_1^2 f^2][(f^2-f_2^2)^2+4\xi_2^2 f_2^2 f^2]} \tag{2.1}$$

$\alpha=0.8064$, $\xi_1=0.54$， $f_1=0.28\,\text{Hz}$， $\xi_2=1.00$， $f_2=2.15\,\text{Hz}$, passband of the filter is 0.28-3.00Hz.

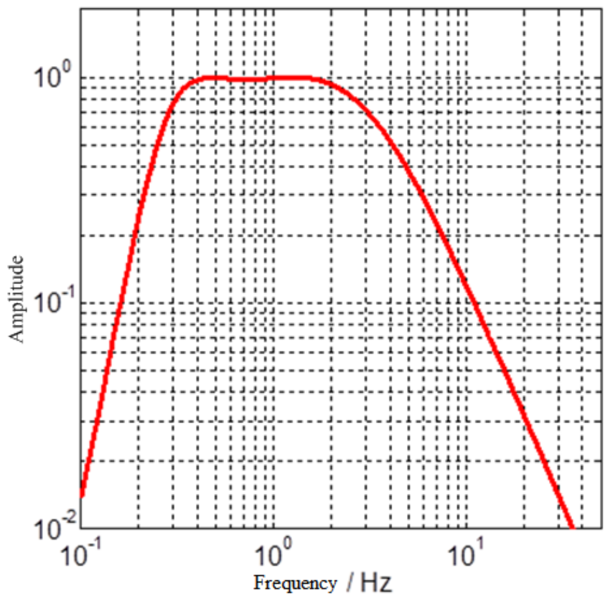

Figure 1. Trigger filter applied in intensity caculation

The synthetic acceleration was caculated by filterring three components acceleration time histories data using Eqn. 2.2.

$$a=\sqrt{a_{ew}^2+a_{ns}^2+a_{ud}^2} \tag{2.2}$$

Where: a —synthetic acceleration;

a_{ew}—filtered east-west acceleration;

a_{ns}—filtered north-south acceleration;

a_{ud}—filterd vertical acceleration time.

Select the amplitude in synthetic acceleration which duration time is greater than 0.5 seconds as the effective acceleration $A_{0.5}$(cm/s^2), take the effective PGA $A_{0.5}$ to equation 3 in one deciaml precision, the I_I is the seismic instrument intensity of the position(Eqn. 2.3).

$$I_I = 2.71 \times \log_{10}(A_{0.5}) + 2.39 \tag{2.3}$$

2.2. The trigger filter and trigger algorithm

The finite impulse response (FIR) filter and infinite impulse response (IIR) filter are generally used digital filter implementation types. The order of IIR filter is commonly less than the FIR filter at the same performance and the IIR filter runs faster and consumes less RAM than FIR filter. Therefore, the trigger filter used in seismograph commonly applied pass-band IIR filter. The trigger filter design principle usually make the pass band including seismic event energy band, while make the noise energy spectrum outside the pass band. Its main purpose is to minimize false trigger record by means of eliminating the data acquisition zero-offset, DC component and background noise of ground motion.

Trigger filter is designed in the form of the cascade Butterworth band-pass filter. High order IIR filter can be constructed by several cascade second-order IIR filters, which use less delay units and can be adjusted independently without affecting the other pole-zero characteristics (Emmanuel C I, 2004). The equation of high order filter is like Eqn. 2.4 and Eqn. 2.5. The trigger filter used in strong motion record take the form of two-stage second-order cascade filter. The coefficient of the filter is: $b_{01} = 0.192518$, $b_{11} = 0$, $b_{21} = -0.192518$, $a_{11} = -1.613746$, $a_{21} = 0.6149635$, $b_{02} = 0.192518$, $b_{12} = 0$, $b_{22} = -0.192518$, $a_{12} = -1.613746$, $a_{22} = 0.6149635$. The filter pass-band ($F_L - F_H$) at different sample rate was showed in Table 1.

$$H(z) = H_1(z) \times H_2(z) \times H_3(z) \times H_4(z) \cdots \quad) \tag{2.4}$$

$$H_k(z) = \frac{b_{0k} + b_{1k}z^{-1} + b_{2k}z^{-2}}{1 - a_{1k}z^{-1} - a_{2k}z^{-2}} \quad (k = 1, 2, \cdots \quad) \tag{2.5}$$

Where: $H(z)$ —cascade filter;
$H_k(z)$ —second order filter.

Table 1. Pass-band frequency of IIR filter

Sample rate/Hz	50	100	200
Pass band F_L-F_H /Hz	0.025-3.75	0.05-7.5	0.1-15

2.3. STA/LTA trigger algorithm

There are two trigger algorithms used in seismograph, the amplitude threshold trigger algorithm and short-time average/long-time average (STA/LTA) trigger algorithm. STA/LTA trigger algorithm significantly increases the instrument's trigger sensitivity and make it more robust to false triggers in many, particularly weak motion, seismological applications. Calculation methods of STA and LTA are set the number of sample data to N_{STA} and N_{LTA} respectively, then $STA = \frac{1}{N_{STA}} \sum_{i=1}^{N_{STA}} |x(i)|$, and $LTA = \frac{1}{N_{LTA}} \sum_{i=1}^{N_{LTA}} |x(i)|$. Usually set $N_{LTA} \geq 10 N_{STA}$. ST and LTA can be regarded as a sliding average of the different sampling signal length. The physical meaning of LTA can be looked as the reference value of the background noise of the sampling signal, while the STA represents a sudden change in the sampling signal. When the acquisition signal changes quickly, the change ratio of STA is much large than LTA. When the value of STA-LTA or STA/LTA reach the threshold, strong motion record start to record the signal as trigger event.

3. HARDWARE AND SOFTWARE DESIGN OF STRONG MOTION SEISMOGRAPH

3.1. Strong motion seismograph working states

Strong motion seismograph working states can be divided into standby mode, trigger mode, monitoring mode, real-time transmission mode and short message sending mode (see Fig. 2). Instrument automatically enter standby mode after loading self-test program and pre-set instrument and sensor parameters. The collected data were compared with the trigger threshold continuously at running time. When the value of data meet the trigger condition, the working status of seismograph turn to trigger mode, and it records the trigger data into CF card until the data value under the trigger threshold. The seismograph returns to standby mode after recording the trigger data, and waiting for the next trigger event. Seismograph sends a short message to the pre-set mobile phone if intensity report was set on.

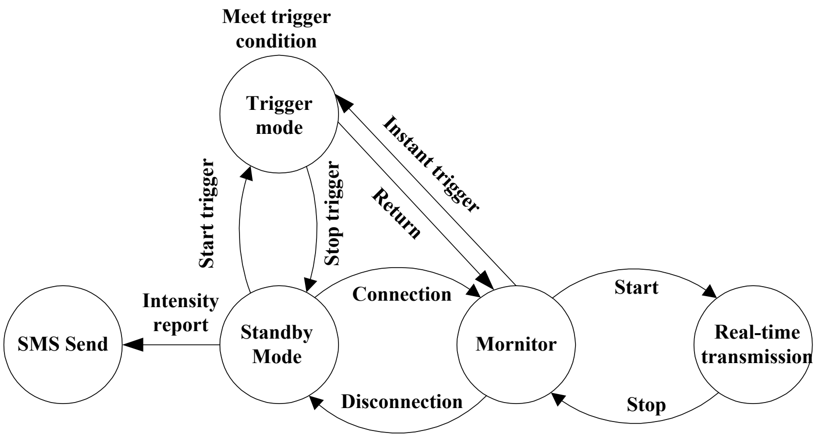

Figure 2. Strong motion seismograph working state diagram

3.2. The hardware of seismograph

Digital signal processor TMS320F2812 is the centre controller to achieve signal acquisition and logical control, which is equipped with 512KB SRAM as the data and program cache. In order to meet the continuous data acquisition and storage, the seismograph is equipped with 8GB CF card. Every half hour, the instrument corrects the internal clock with GPS module to keep the precision of time system. While the instrument is turned off, the clock chip DS1302 can hold the real time information. TMS320F2812 transmits data or command with single-chip microcomputer W77LE51 through serial interface. Instrument is provided with industry standard RS232/RS485 serial interface, TCP/IP protocol network interface, and builds in GSM communication module. System hardware structure is shown in Fig. 3.

CF card connects with TMS320F2812 through data bus D0-D15 and address bus A0-A2 by true IDE mode. Chip select terminal of CF card, CS0 and CS1, connects with 74HC138 address decoder，Y1 and Y2, and the CF card resister address is 0x2100-0x2200. TMS320F2812 calls the read and write function to record data file in CF card, and file functions call low-level CF card driver to complete the file operation. For the convenient for processing and reading record file on the personal computer, the format of record files on CF card adopted the embedded FAT32 file system.

The system uses 24-bit A/D convert CS5371/72 and digital filter CS5376A to constitute a 3-channel signal acquisition circuit. The full-scale output voltage of three-component accelerometer is ±2.5V, which is converted to 512K 1-bit data stream by A/D convert, and digital filter change the data stream into 24-bits three channels signal. TMS320F2812 connects with digital filter with serial peripheral interface (SPI). Depending on different monitoring requirements, the signal-sampling rate can be set to 500Hz, 200Hz, 100Hz or 50Hz. 24 bits signal is first stored into circular data buffer, at the same time it is filtered by IIR trigger filter and compared with trigger threshold. Instrument starts to record data in CF card if it was exceeded the pre-set value. Therefore, a complete strong motion record should include pre-event time data, trigger time data and post-event time data.

Seismograph sends and receives data based on TCP/IP network protocol. In the server mode, it is waiting to be connected with monitoring software in the client mode. After connected, monitoring software could operate multiple seismographs at the same time. Using the mobile phone, operator can send or receive SMS to instrument for checking instrument status, calibrating the sensor, receiving intensity quick reporting.

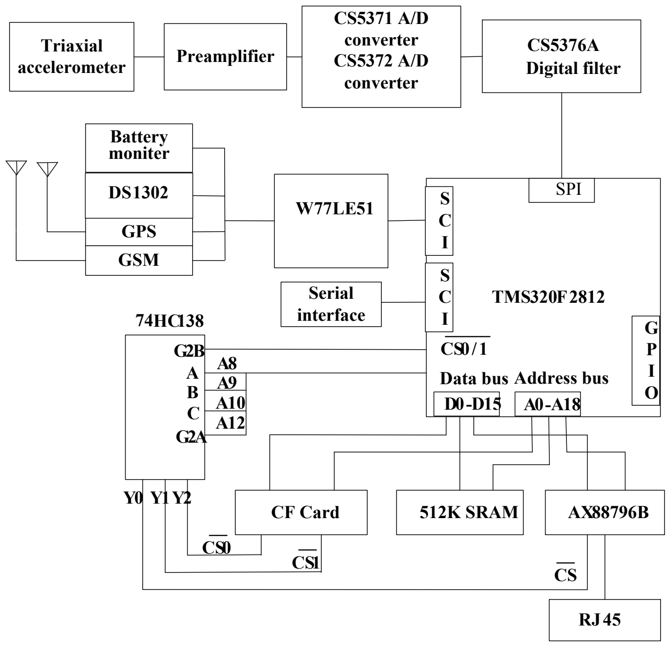

Figure 3. Digram of system hardware

4. PERFORMANCE TESTING

A/D resolution bits, amplifier circuit's characteristics, and digital signal processor mainly determine the data acquisition performance.

4.1. Signal-noise rate and dynamic range testing

The key performance indicators of seismograph are signal-noise rate and dynamic range. For testing, we should ground the signal input, record at least 4000 sample data, and upload the data to monitor PC for procession. The root mean square value of noise n_R is calculated according to Eqn. 4.1, in units of volt.

$$n_R = \sqrt{\frac{\sum (X_i - X_0)^2}{N-1}} \tag{4.1}$$

$$D_R = 20\lg(A_e / n_R) \tag{4.2}$$

Where: n_R —the root mean square value of noise;

X_i —the sample date value;

X_0 —the sample date average;

A_e —effective value of sample data;

A_m —amplitude of sampling data, $A_e = 0.707A_m$.

Calculating the dynamic range according to Eqn. 4.2, Noise characteristics and dynamic range of test data are given in Tab. 2. Test data show that the noise RMS value of seismograph is less than $2\mu V$; dynamic range in different sampling frequency is all greater than 120dB.

Table 1. Noise factor and dymamic range of tested data

Sample rate/Hz	Noise rms value/mV			Dynamic range/dB		
	Channel 1	Channel 2	Channel 3	Channel 1	Channel 2	Channel 3
50	0.000499	0.001227	0.001484	130.98	123.17	121.52
100	0.000579	0.001244	0.001506	129.69	123.04	121.38
200	0.000704	0.001676	0.001634	127.99	120.46	120.68

4.2 Resolution test

The A/D converter and amplifier circuit characteristics play a key role on the data resolution. Resolution test is executed under the condition of each channel grounded and 200 sampling rate, and recorded at least 4000 sample data, calculated the maximum and minimum values of data, got the resolution from Eqn. 4.3.

$$\mu = \log_2\left(\frac{2A_{mc}}{X_{max} - X_{min}}\right) \tag{4.3}$$

Where: μ —resolution;

A_{mc} —full scale input;

X_{max} —maximum value of data;

X_{min} —minimum value of data.

Test results: the first channel minimum value is 0.0778mV, 0.9636mV and 0.4598mV respectively. The maximum value is 0.0823mV, 0.9726mV and 0.4564mV respectively. The corresponding resolutions are 20.08, 19.08 and 19.76 bits.

5. CONCLUSIONS

The core technology of seismograph is applying the 24 bits A/D and digital filter in data acquisition system to ensure the high accuracy of data and low noise rate. The hardware and embedded software of instrument are developed with the functional modular, which can be upgraded easily. There is no definitely conception of instrument intensity, so the calculation algorithms of intensity are not uniform in different instruments. Designing an objective and rational instrument intensity algorithm is the primary goal for seismograph research.

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