A Robust Algorithm for Earthquake Detector

Wenxiang Jiang, Haiying Yu, Li Li & Lei Huang
Institute of Engineering Mechanics, China Earthquake Administration

SUMMARY:
A robust algorithm has been developed for the automatic earthquake detector. It processes the real-time acceleration data recorded by strong-motion seismograph and detects earthquakes. First, an event detector compares short-term average (STA)/long-term average (LTA) with a threshold value (THR) to sniff events. When the acceleration fallowing an event trigger exceeds a preconfigured value, the algorithm checks the characters of the data after event trigger. The characters include significant frequency, increase speed, duration and so on. If the characters pass predefined criteria, an earthquake event is reported. The algorithm is robust enough to work in complicate environments with kinds of noise, such as explosion, lightning, fallen weight and traffic. Several kinds of noise and earthquake data sets were used to test the detector and it got 0% false-trigger-rate and 0% false-report-rate. The results show the algorithm could serve high-speed train, nuclear power station and special factory, which cannot bear false triggers. This algorithm is simple enough that could be employed in low-performance computer such as embedded system.

Correspondence to: Wenxiang. Jiang, Institute of Engineering Mechanics, China Earthquake Administration, Harbin, 150080, China
Tel: 86-0451-86652976
Email:jwx_iem@163.com
Supported by: China Earthquake Specialty Science Foundation under Grant No. 201008006; National Natural Science Foundation No. 51178152; CEA,IEM Science Foundation No. 2010C02

Keywords: earthquake detector; robust algorithm; strong motion; noise;

1. INTRODUCTION

In this paper, an earthquake detector refers to an algorithm or a program used to recognize the arrival of a seismic wave in the presence of background noise. It is different from earthquake picker, which must also perform the more precise measurements of pick time required for earthquake location and further study of the earthquake(Allen 1982).

Many projects, such as high-speed train, nuclear power station and semiconductor plant, are vulnerable to earthquakes. So, many of them have regional or private warning systems with strong-motion networks comprise of strong-motion seismograph, communicating network and processing center. Generally, the strong-motion seismograph records the ground acceleration and send it to the processing center instantly. And an earthquake detector is used to sniff earthquake in the processing center.

When the ground acceleration generated by nature earthquake exceed one predefined Report

Value(RV), an earthquake alarm is reported to the control center. And then the control center take emergency action before the stronger shake come.

Report Value is different in different application(Reed and Kassawara 1990). The time when an event is triggered is called Trigger Time(TT) and the time when acceleration first reach RV is called Report Time(RT).

Generally, strong-motion station are constructed in quiet place far away from human activities. But in some cases, strong-motion stations are located in noise environment. They are often influenced by chemical explosions like quarry blasts (Ruud and Husebye 1992), fallen weight, wind, vehicular traffic, and thunder storm. For example, the stations along high-speed railway will influenced by the tremor from passing train and the stations in urban might influenced by heavy machinery doing works nearby. Furthermore, electromagnetic interference from lightning will influence kilometers, it might trigger several station at the same time. Waveform of four kinds typical noises are shown in Figure 1.

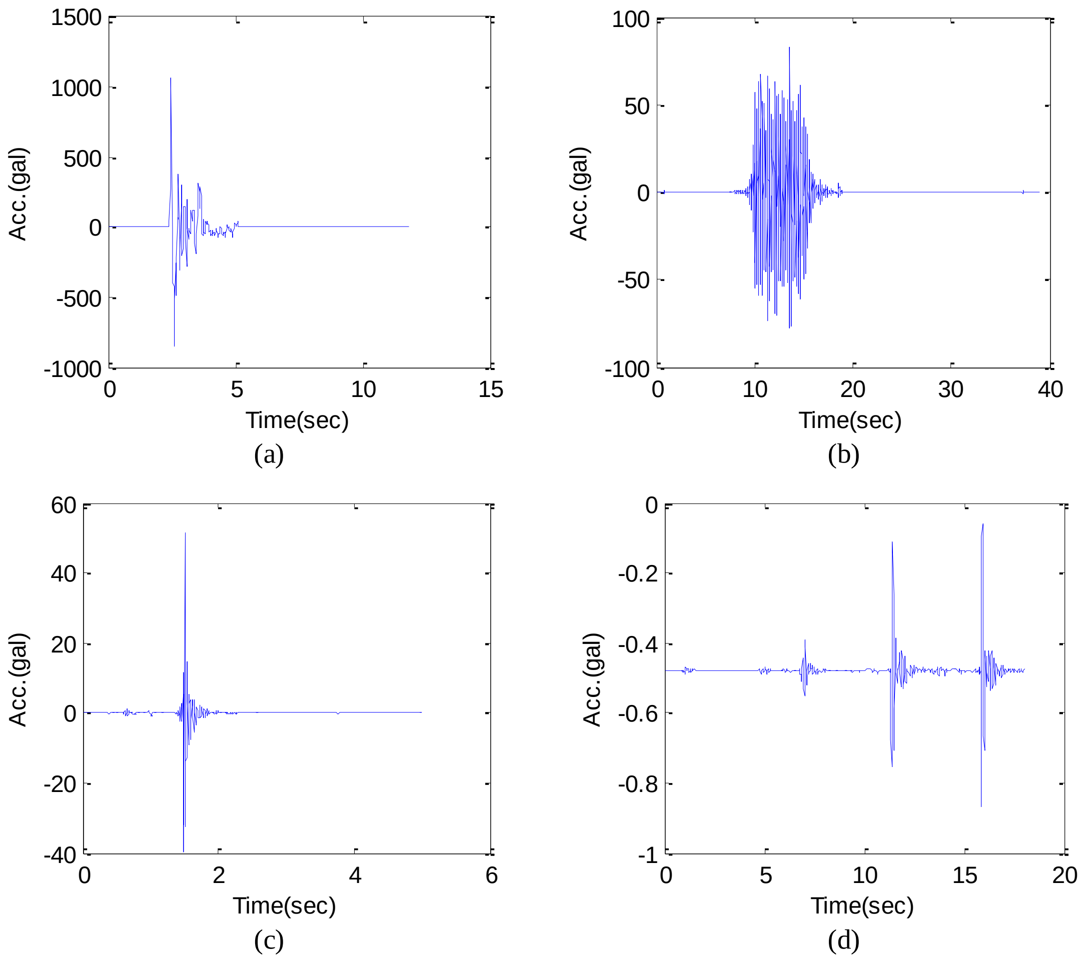


Figure 1. wave form of four kinds of typical noise: a, quarry blasts; b, high speed train; c, heavy machinery; d, thunder storm

Previous algorithms(Allen 1982; Cichowicz 1993; Ma 2008) are designed to work in quiet environment, so, they would falsely yield triggers in noise environment. So, they are not suitable to serve as detector algorithms in noise environment.

Another drawback of previous algorithms is that they would miss earthquakes. Most picker or detector algorithm use STA/LTA of character function to detect events(Allen 1978; Allen 1982). In some cases, STA/LTA would failed to trigger events.

Allen’s approach processes each sample sequentially, and the program is not allowed to access earlier points because of the limitation of the microprocessor and memory capacity. It first computes the characteristic function(CF) of current sample point and then computes the LTA / STA using two moving windows.

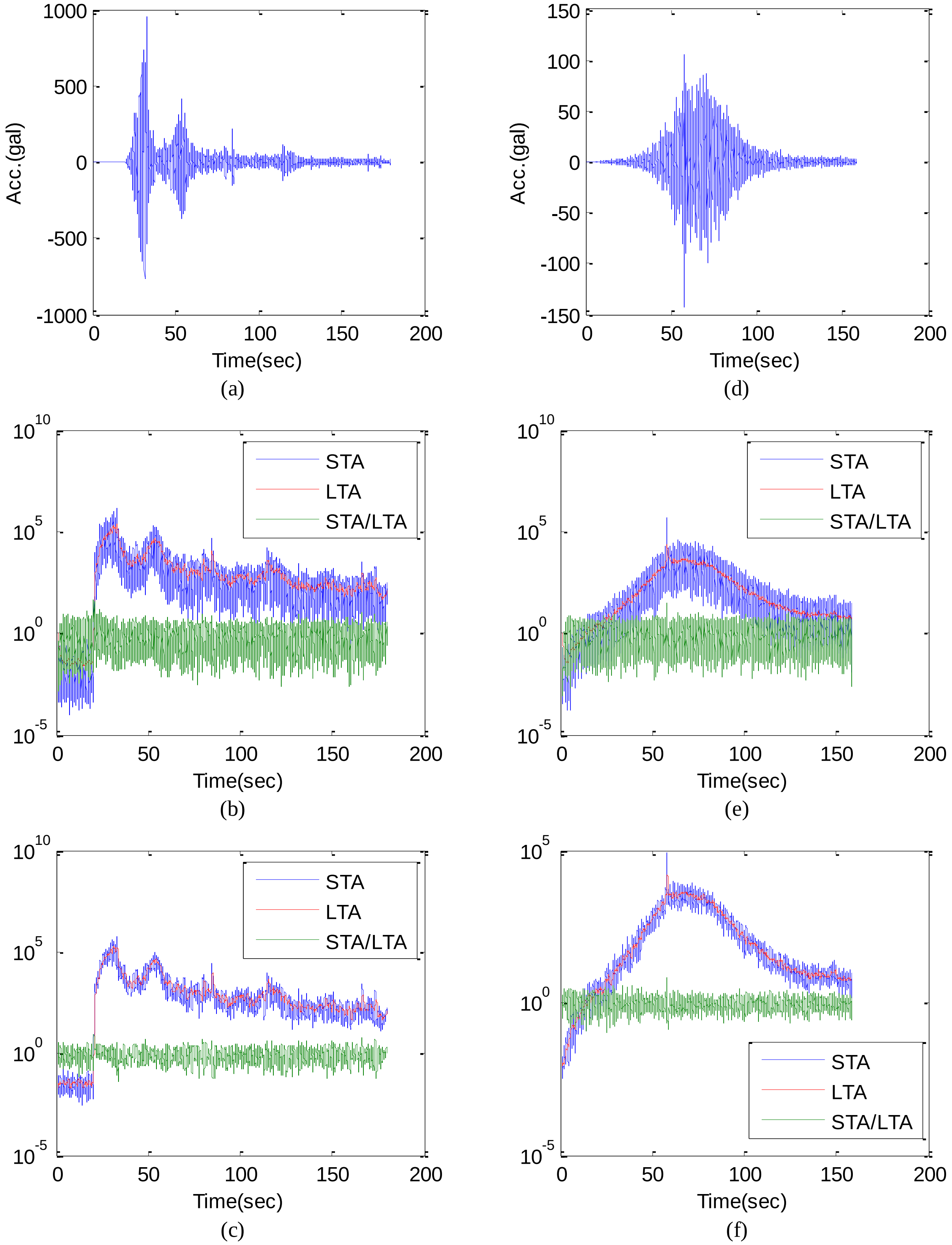


Figure 2. (a) is EW component in WCW station from WenChuan earthquake; (b) STA/LTA of WCW according to equation (1.2); (c) STA/LTA of WCW according to equation (1.3); (d) is EW component in WIX station from WenChuan earthquake. (e) STA/LTA of WIX according to equation (1.2); (f) STA/LTA of WIX according to equation (1.3); Long window is 1 second and short window is 0.1 second.

$$CF = y^2 + C2 * (y(i) - y(i-1))^2 \tag{1.1}$$

$$\frac{STA(i)}{LTA(i)} = \frac{STA(i) + C3 * (CF(i) - STA(i-1))}{LTA(i) + C4 * (CF(i) - LTA(i-1))} \tag{1.2}$$

Above equation essentially have two single-pole, low-pass filters implemented in the time domain. The filter constants C3 and C4 control the time constant of the low-pass filter function(Baer and Kradolfer 1987). Next, the algorithm compares STA/LTA and the constant THR to determine if there is an event.

Another more simple realization of STA/LTA is compute the mean value of trace data in two moving windows(Ma 2008).

$$\frac{STA(i)}{LTA(i)} = \frac{\sum_{i-k1}^{i} CF(i)\,/(i - k1 + 1)}{\sum_{i-k2}^{i} CF(i)\,/(i - k1 + 1)} \tag{1.3}$$

The two realization of STA/LTA is shown in Figure 2. It can be seen that STA/LTA is not protruding when the earthquake wave come. Unfortunately, these two realization of STA/LTA are prone to miss earthquake event when the ground motion increase slowly. Because the LTA is contributed by much data of earthquake wave in this situation,. LTA and STA increase together, there ratio keep in a low level when the earthquake wave increase slowly.

As shown in Figure 2(f), max value of STA/LTA is 6, if the THR is set to 7, the STA/LTA would never reach the THR, so it will not initiate an event trigger even the Peak Ground Acceleration exceeds 100gal. If the THR is set lower, then more background noise will trigger events in the algorithm, and this might influence the working of detector.

2. Proposed methodology

LTA should only reflect the shake level of background noise level and STA should reflect the shake of earthquake event. In order to prevent the algorithm from missing any event, LTA should get rid of the influence of events. In this paper, the proposed algorithm renews the LTA only using the data without event in a long period, saying 20 seconds. This is more reliable, because the LTA is a constant and STA increase gradually when earthquake wave come.

Table 1. Variable and corresponding description

Sequence	Variable	Description
1	CF	Character function
2	LTA	Short term average
3	STA	Long term average
4	thresh	Threshold to trigger an event
5	countZC	Number of zero-cross
6	theta	Theta is the max absolute value in acc used to compute the STA, which generate a event trigger. Zero-cross small than theta is small zero-cross
7	RV	Report value, report an earthquake when acceleration exceeds this value and pass criterion check.
8	evfFlag	Event flag, used to mark the current state of event. 0, no event;1, event triggered; 2, event reported.
9	S	Number of successive small zero cross Small count register
10	L	L=startL+countZC/2
11	peak	Store peak value of zero-cross
12	startL	Usually set to 3

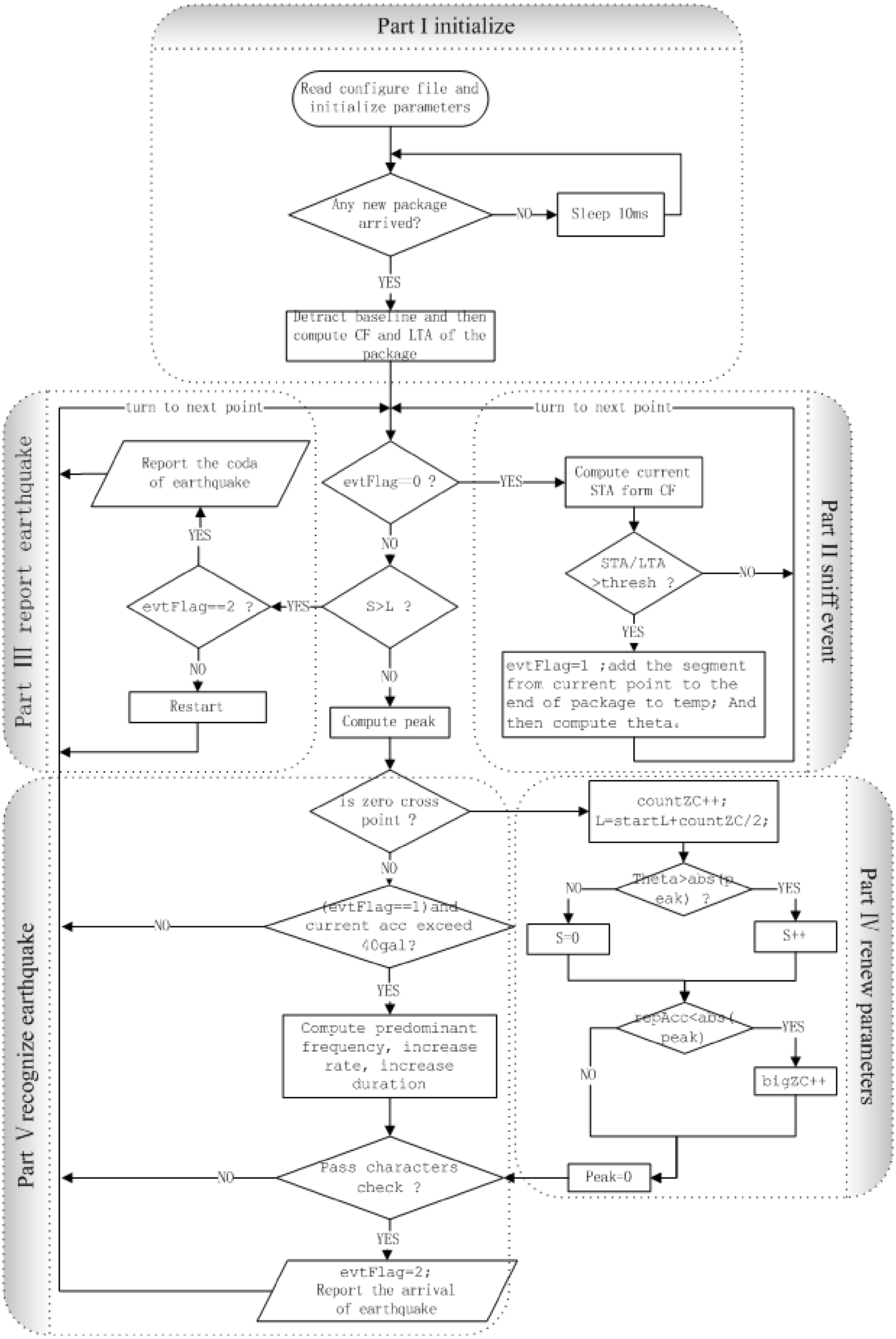


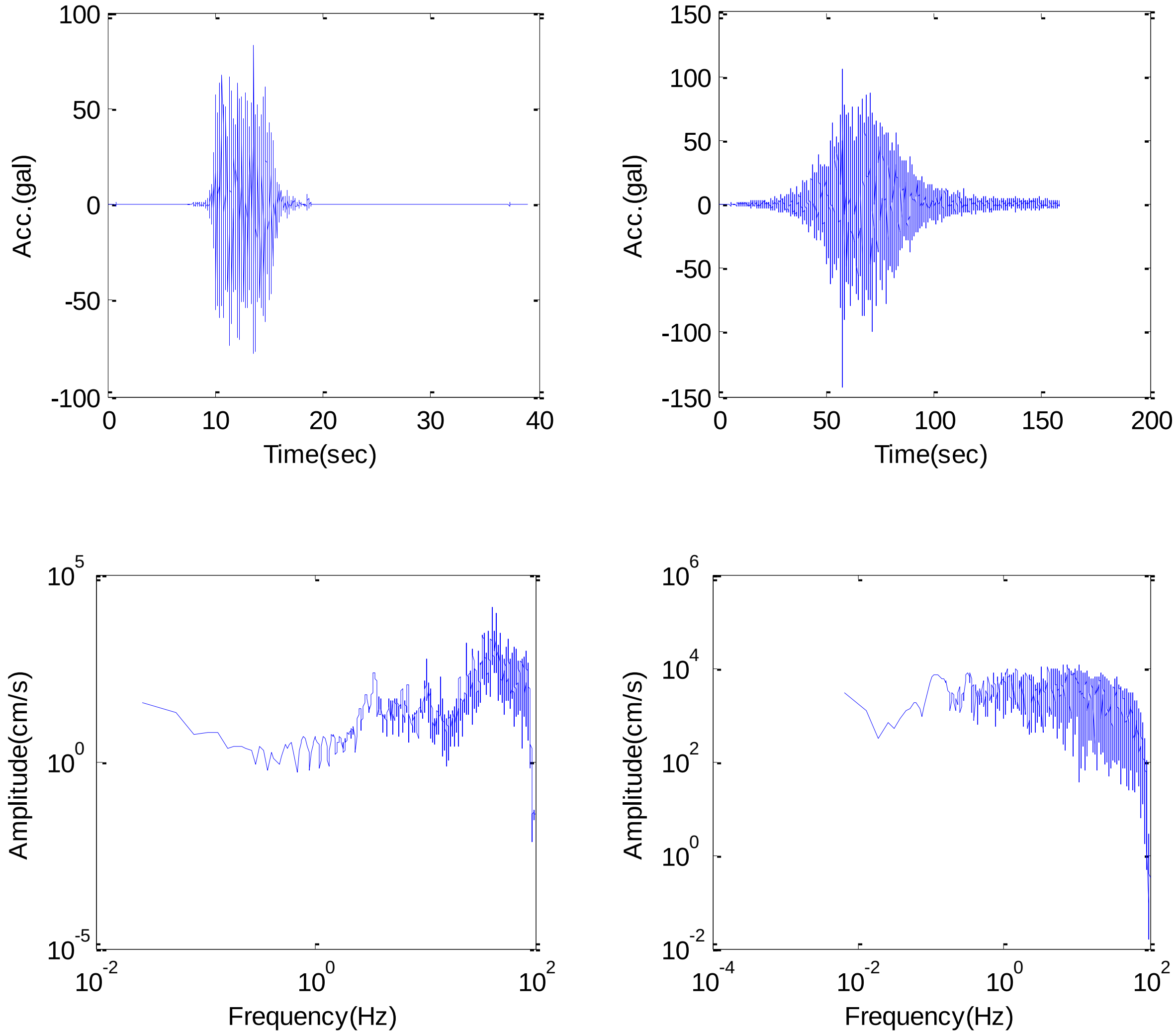
Figure 3. Flow chart of proposed algorithm

After the acceleration of an triggered event exceeds Report Value(RV), the algorithm check the characters of the acceleration trace between Trigger Time(TT) and Report Time (RT).

As shown in Figure 1(a), the acceleration increase sharply at the just beginning. The duration is very short, lasting only 2 seconds and the acceleration reach report acceleration in only 10 milliseconds. As shown in Figure 1(b), the envelope of the wave is similar to a real that of an earthquake. But Figure 4 shows the frequency spectrum is distinct from that of an earthquake.

So, in order to discriminate earthquake and noise, 4 character are used to form a criterion Characters include predominant frequency, increase rate, increase duration, number of zero-cross between TT and RT. Flow chart of the proposed algorithm is shown in Figure 3 and description of variable is listed in Table 1.

When shake intensity drop to a stable and low level, compare S and L to determine coda(Allen 1982).



(a) (b)

Figure 4 Frequency spectra of train noise(a) and earthquake(b)

3. TEST AND RESULTS

Four kinds of noise were used to test the algorithm, including quarry blasts, heavy machinery, vehicular traffic, and ElectroMagnetic Interference(EMI) from lightning. Typical wave forms are shown in Figure 1. Because the EMI from lightning recorded by strong-motion seismograph is rare, the lightning records used in this paper is artificial records according to the characters of records in strong-motion seismograph influenced by EMI from lightning (Jiang, D. Zou, D, et al. 2009).
The value of parameters used in the test are shown in Table 2

Table 2. Parameter value used in the test

Sequence	Parameter	Value
1	C2	3
2	thresh	11
3	startL	3
4	minZC	10
5	mintime	0.2
6	STAp	20
7	STAp	200
8	maxFreq	20
9	minFreq	0.05

Table 3. results of test

Noise type	Number of records	Number of false report
Quarry blast	82	0
heavy machinery	18	0
High-Speed train	22	0
EMI	6	0

Also, strong-motion records from the Wenchuan Great Earthquake, ChiChi Earthquake and other earthquake records in China Strong-Motion Network Center are used to test the algorithm, and the algorithm correctly report earthquake alarms when the acceleration exceeds RV.

4. CONCLUSIONS

This paper analyzed the STA/LTA method and proposed a new method to compute LTA. This method renew the LTA only in quiet period and it is more reliable. Also, predominant frequency, increase rate, increase duration, number of zero-cross are used to discriminate earthquake and noise. The results using these characters to design a robust detector algorithm is effect method. After an earthquake event is detected, the more precise phase arrive time could picked using additional methods(Baer and Kradolfer 1987; Cichowicz 1993; Diehl, Deichmann et al. 2009). So, this algorithm could serve as one part of picker.

ACKNOWLEDGEMENT
The authors would like to give thanks to CSMNC for providing strong motion data. Thanks to the strong motion observed personnel from the Seismological Bureau of Sichuan, Yunnan, Gansu, Shaanxi, Ningxia, Qinghai, Shanxi, Shandong, Henan, Hebei, Beijing, Tianjin, Inner Mongolia, Jiangsu, Shanghai, Fujian, Guangdong, Hubei and Anhui provinces/municipalities. Special thanks give to the Central Weather Bureau in Taiwan for providing the strong-motion records in ChiChi earthquake.

REFERENCES

Allen (1978). "AUTOMATIC EARTHQUAKE RECOGNITION AND TIMING FROM SINGLE TRACE." Bulletin of Seismic Society of America.

Allen, R. (1982). "Automatic phase pickers: Their present use and future prospects." Bulletin of the

Seismological Society of America 72(6B): S225-S242.
Baer, M. and U. Kradolfer (1987). "An automatic phase picker for local and teleseismic events." Bulletin of the Seismological Society of America 77(4): 1437-1445.
Cichowicz, A. (1993). "An automatic S-phase picker." Bulletin of the Seismological Society of America 83(1): 180-189.
Diehl, T., N. Deichmann, et al. (2009). "Automatic S-Wave Picker for Local Earthquake Tomography." Bulletin of the Seismological Society of America 99(3): 1906-1920.
Reed, J. W. and R. P. Kassawara (1990). "A criterion for determining exceedance of the operating basis earthquake." Nuclear Engineering and Design 123(2–3): 387-396.
Ruud, B. O. and E. S. Husebye (1992). "A new three-component detector and automatic single-station bulletin production." Bulletin of the Seismological Society of America 82(1): 221-237.
Jiang, D. Zou, D, et al. (2009). "On recognition and elimination method of electromagnetic interference in earthquake instrument system." Journal of Geodesy and Geodynamics 29(8):128-130.
Ma, Q (2008). Study and Application on Earthquake Early Warning . Doctor thesis.