Seismic Signal Warning and Classification Algorithm Based on Noise and Improved Zero Crossing

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Abstract. Seismic signal generated by moving on ground by person and vehicle target is sensed by MEMS accelerometer, then collected and processed by MSP430, achieving early-warming and target identification of ground targets. A seismic signal warning algorithm based on the characteristics of noise is proposed as to early-warming and a seismic signal target classification algorithm based on improved zero crossing is used to identify different kind of targets. The results show that person within 8 meters and vehicles within 20 meters away from the accelerometer can be detected and identified effectively. The correct identification rate can reach 85% or more. This algorithm is very simple and practical when processing signal collected by sensors with digital output.

Introduction

Sensor system for battlefield surveillance is a high-tech system, including electronics, acoustics of geological science, sensor technology, microelectronics technology, computer science, signal processing technology and so on. Among them, the sensor is the basis for the development of ground sensor battlefield reconnaissance system, the signal processing technology is an important guarantee to improve the performance of the system detection.

Personnel, vehicles and other ground targets' motion can cause the ground vibration, so vibration signals are generated. The accelerometers are sensitive to vibration signal and able to record acceleration information. As a result of the staff walking on the ground, the incentive is discontinuous, in the time domain performs a pulse signal, and the impact of vehicle targets on the ground is continuous, in the time domain performs a continuous seismic wave, mainly because of the frame suspension system vibration, engine and transmission system vibration, and the undulating ground excitation of vehicles [1]. For the two different targets vibration signals generated on the ground, Duan Junfeng put forward the method of fuzzy set theory and fuzzy logic reasoning, fuzzy logic inference system to achieve [2] target detection and classification; Nie Weirong proposed zero analysis and a time domain method based on spectrum analysis, summarized the classification [3] of ground target by using artificial neural network. Since the war the real-time requirement is very high, the fuzzy logic, spectrum analysis, artificial neural network recognition algorithm require excellent processor performance and power, a much easier and more effective method is necessary. And it is what this paper has done.

Seismic signal warning algorithm based on the characteristics of noise

When the target appears, compared with the noise signal detected by the sensor, the signal has an increasing trend. So we can set a threshold value, when the signal strength is beyond the threshold value, we can get the conclusion that the target appears. However, some information can't be ignored.

First: The seismic signal strength caused by persons and vehicles are not the same at the same distance;

Second: The sensitivity of the different sensors are not the same;

Third: Battlefield environment is not available to know clearly in advance;

Forth: Noise signal is uncertain, large outliers value may occur while the target does not appear, leading to false alarms.

Therefore, it is impossible to set a fixed amplitude threshold value in advance to determine whether the target appears.

To solve the above problem, based on the noise characteristics, seismic signal warning algorithm is proposed. Without the need for filtering noise and other complex process, the algorithm simply need a period of real-time signals. When the target does not appear, the sensor can only get the background noise, background noise can be considered as Gaussian white noise, so three-sigma rule can be used in our algorithm.

As is shown in Figure 1, nearly all (99.73%) of the values lie within three standard deviations of the mean.

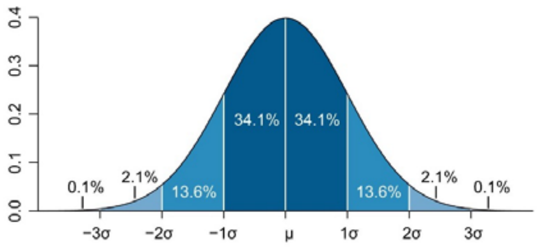

Figure 1. Gaussian distribution

$$\Pr(\mu-3\sigma<X\leq\mu+3\sigma)\approx 0.9973 \quad (1)$$

The process of seismic signal warning algorithm is shown in Figure 2.

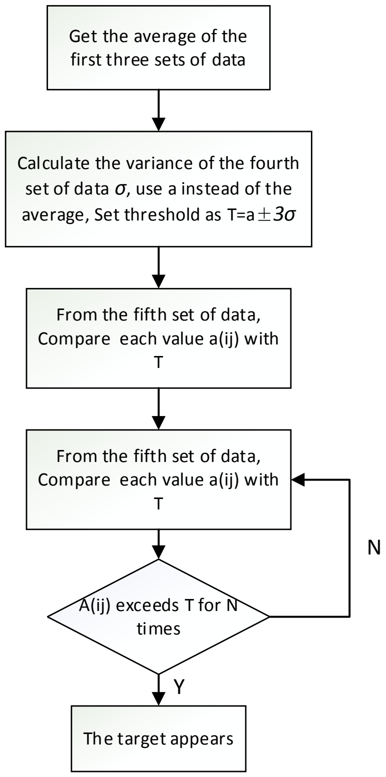

Figure 1. The process of warning algorithm

N must meet:

$$N > T_a \times f_s \times 0.3\% \quad (2)$$

f_s is the length of the sampling frequency, T_a is the sampling time of each data.

The expectation of ideal Gaussian white noise should be 0, to obtain the average of the first three sets of data, mainly based on the selected sensor in the gravitational field of random position, there is a DC output. Based on the three-sigma rule, the threshold value is T = a±3σ, noise amplitude in the interval X (a-3σ, a +3σ) is Pr (a-3σ<X≤a+3σ) = 99.7%, when the target enters into the effective detection area of the sensor, the possibility of signal amplitude exceeding the threshold will be gradually increased, so as to achieve the purpose of warning

Seismic signal target classification algorithm based on improved zero crossing

Ground targets personnel, vehicles and other ground motion at the time, the impact on the ground will make the ground shake, generate seismic signals. Acceleration sensor can be sensitive to seismic acceleration signal information. Since the person walking on the ground excitation is intermittent, and in the time domain representation of the intermittent pulse signal, while the impact on the ground of the vehicle target is continuous in the time domain of a continuous wave, depending frame suspension system vibration, the engine and transmission vibration, as well as vehicles and other incentives for undulating ground, through the domain zero crossing algorithm to distinguish these two goals [4].

The zero-crossing analysis principle

Zero crossing analysis principles Zero-crossing signal refers to the phenomenon that the amplitude of the time-domain signal moves from the positive to negative or negative to positive. Zero-crossing rate (ZCR) [5] refers to the frequency of zero crossing. ZCR is formally defined as:

$$zcr = \frac{1}{T-1}\sum_{t=1}^{T-1} F\left\{s_t s_{t-1} < 0\right\} \tag{3}$$

In this expression, s is a signal with the length of T, the result of the function $F\{A\}$ is true when the parameter A is 1 and otherwise the result is 0. In some scenarios, only positive zero crossing or negative zero crossing signal is recorded, rather than in all directions. Because logically, between two consecutive positive zero crossing, there is only one negative zero crossing. This feature has been widely used in voice recognition and music information retrieval [6].

Zero-crossing analysis is a process that compare the amplitude of the domain signal with the set threshold value in a determined period of time, and calculates the times of signal cross the threshold, which is a signal processing method in the time domain and it essentially characterizes the baseband of the signal. In certain sampling rate, the number of zero-crossing are closely related with the signal spectrum. If the signal is a sinusoidal signal with a frequency of f, the number of the zero-crossing is [7]

$$N = kf. \tag{4}$$

In this expression, k is a proportionality factor, which is also proportional to the number of zero crossing and the frequency of the signal. For Gaussian stationary random signal with the frequency range from f_1 to f_2, per unit power spectrum $G(f)$ and the number of zero-crossings have the relation:

$$N = 2\sqrt{\frac{\int_{f_1}^{f_2} f^2 G(f)\mathrm{d}f}{\int_{f_1}^{f_2} G(f)\mathrm{d}f}}. \tag{5}$$

This formula shows that if the frequency of the signal in the main band is high, the number of zero-crossing would be large in a certain period of time.

The Improved Zero-Crossing Algorithm

Based on the three-sigma rule and zero crossing analysis above, an improved zero crossing algorithm set the sum of the mean value of the noise signal amplitude value in the first three groups and three times of the variance as the threshold value, as below:

$$T = a \pm 3\sigma \tag{6}$$

When the signal amplitude changes between $a \pm 3\sigma$, we consider that no zero- crossing occurs .If the amplitude exceeds the threshold value, zero-crossing number increase by one. Compared with setting the sub-maximum value or the maximum value as the threshold value, it is more effective to avoid large floating thresholds caused by accidental error, the algorithm is very good at immunity and high reliability.

In actual the seismic signal processing is carried out section by section, which means we can choose a reasonable length of time to process the signal.

Calculate the zero-crossing rate is intended to distinguish the footsteps of personnel and vehicles signal. Personnel pace signal is discrete , this frequency is determined by the time between two feet touch the ground ; vehicles' signal is continuous , vibration signal can be detected only when the vehicle is in the detection range of the sensor . In the actual process of collecting seismic signals of different types of vehicles, it is founded that, due to the damping design the seismic signals of common commercial cars is very week, so the detection range is very limited, this phenomenon is far from the military armored vehicles. When such goals accelerate from far to near seismic sensor is effective in very short time, so it is not appropriate to adopt the zero-crossing algorithm for target classification. And because of the limited experimental conditions, no wheeled armored vehicles for seismic signal acquisition, the seismic signals zero-crossing analysis mainly base on the tank target. However, based on the theoretical analysis and related data, armored vehicles targets can also be distinguished from the staff by the zero-crossing analysis algorithms.

When the vehicle enters the detection range of the sensor, no matter what the size of the window is, the zero rate will keep bigger than zero. If the vibration signal is relatively stable, zero-rate will change continuously in the process. For personnel pace, the width of the window has a big impact on the zero rate. Assume stable personal pace, namely the time interval between the two paces is equal set as T. Different time intervals will produce different zero-crossing rate. Here are two different calculation methods of the zero crossing.

At least one full pace signal is in the time window. After a lot of research before and observation of the actual collected seismic signal repeatly, it is founded that when people have a normal walking speed, personnel pace seismic signal duration time (this time refers to the interval between the beginning of the current pace and the arrival of the next footstep) is about 150 ~ 350ms. In order to get at least one full pace signal, the length of the time window can be taken by 0.4s. Providing the sampling frequency is 800Hz, the number of data points is $0.4 \times 800 = 320$. If the number of zero-crossing is N, the zero-crossing rate is

$$\eta = N / 320 \tag{7}$$

Figure 3 and Figure 4, respectively, shows personnel pace and tanks seismic signal zero-crossing rate distribution at different distances. As can be seen from the figure, the zero-crossing rate of the personal pace at close distance is no more than 5%, while in the more remote, less than 1%. While the tank moves from far to near, the zero rate grows soon, even at the maximum distance of 20m, its zero-crossing rate will soon exceed the zero-crossing rate of personal pace.

Based on these rules, under certain circumstances, we can set a threshold to distinct people and tank targets.

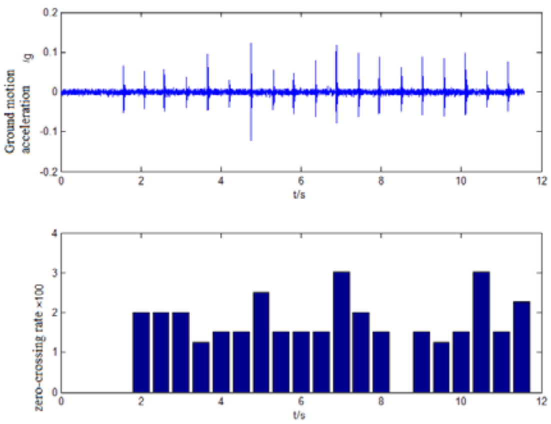

Figure 2. Zero-crossing rate of pace signal in 1 meter

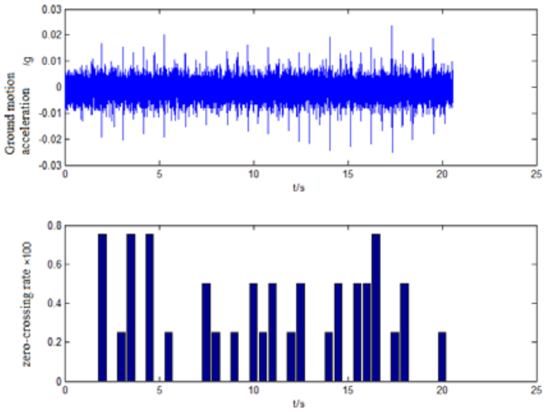

Figure 3 Zero-crossing rate of pace signal in 5 meter

Narrow time window. Under normal circumstances mentioned above, the duration of the personal pace is 150 ~ 350ms. If the selected time window is very narrow, such as 0.1s, because of the intermittent personnel pace signal, there must be some windows that the calculated zero-crossing rate is 0, the phenomenon is intermittent zero-crossing. The tank's seismic signal is continuous, the zero crossing rate in the narrow time window will never be zero, showing a continuous zero-crossing phenomenon.

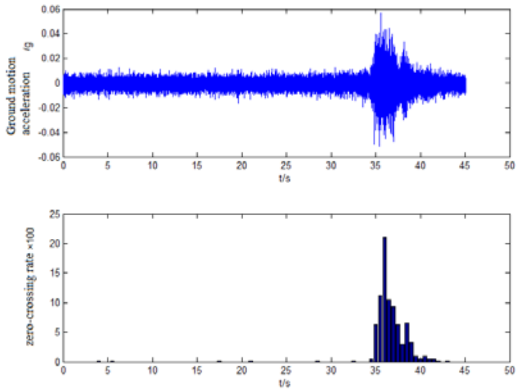

Figure 5. Zero-crossing rate of tank signal in 20 meters

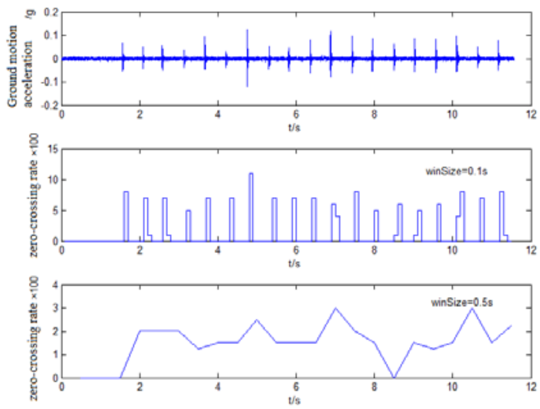

Figure 6. Zero-crossing rate of pace signal under different time window

The first part of Figure 5 shows the seismic signal of footsteps, the interval between the paces is about 0.5s. The second part shows the zero-crossing rate with a window width of 0.1s, the zero-crossing rate is not zero when footsteps signal occurs, otherwise the zero-crossing rate is zero. The last part shows the zero-crossing rate with a window width of 0.5s. We can learn from the figure that the zero-crossing rate characteristics of people are the same with vehicle, and the continuous value is always non-zero, but zero-crossing rate is relatively small.

Figure 6, the first picture shows a vibration signal of the tank in the time domain, the middle picture shows the zero-crossing rate with a window width of 0.1s. The third picture shows the zero-crossing rate with a window width of 0.5s. As can be seen from the figure, although the window width is not the same, the zero-crossing rate is always bigger than zero, while the value is continuously changing.

The two methods selected above to calculate the zero-crossing rate use different width of windows, but the windows are not overlap in time, that means the data are not overlap. In fact we can also use partly overlapped windows to calculate the zero-crossing rate. Providing the amount of data is N, M is the number of data contained within the window, so 0 <N <M. The curve generated using this method to calculate zero crossing rate is much smoother than above, but the corresponding calculation is more complex. In practical applications, we can choose different approaches based on the performance of the processor.

Conclusion

In order to test whether our algorithm is available, we conduct some experiment outdoors. The result shows that Seismic signal warning algorithm based on the characteristics of noise is effective even if the persons are 5meters away, or the vehicles are 18meters away from our sensors. And the false warning rate is less than 5%. Based on the seismic signal target classification algorithm based on improved zero crossing, the false rate of persons is about 8%, while vehicles is about 9%. So our algorithm is proved to be right and reasonable.

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