Seismic Systems for Unconventional Target Detection and Identification

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ABSTRACT

Seismic detection systems for homeland defense and security applications are an important additional layer to perimeter, border and zone protection. General Sensing Systems has been developing a novel method and corresponding software for footstep detection with a near zero false alarm rate. This method has been realized in a number of detection systems. The testing of the GSS seismic systems in various environment noise conditions showed that such systems can be successfully used for other target detection. Such "unconventional" targets can include light and heavy vehicles, trains, helicopters and ships. This paper describes the signal characteristics of such targets and the preliminary experimental data on the corresponding detection range. We also report on the seismic sensor and seismic system requirements for target detection.

Keywords: Seismic security and reconnaissance systems

1. INTRODUCTION

The use of seismic systems for footstep detection and other military applications is well known [1-4]. In addition, seismic systems can be used for detection of the seismic vibration from other moving and stationary targets such as light and heavy vehicles, trains, tanks, etc. Moreover, such seismic systems can be used for detection of the acoustic-seismic and hydro acoustic-seismic vibrations from such targets as helicopters, aircrafts, ships, etc. Detection issues have been discussed in recent publications [5-8].

Some of the targets seem to be unconventional for seismic security systems, i.e a train. Many important, protected facilities, such as military bases, have a local railway. Therefore it is critical to know how the train seismic signal affects the seismic security system and how to separate the train signal from that of other dangerous targets.

The general idea of such unconventional target detection is clear. Moving or just "working" targets exerts a time changing force at the earth's surface. The earth/ground starts vibrating and the seismic/vibration sensor converts such vibrations into electrical signals. For targets operating in other mediums (helicopters and aircrafts in air, ships or underwater vehicles in water) the physical processes are more complicated. Moving targets produce acoustic (in air) or hydro acoustic (in water) waves in their corresponding medium. After propagation, these waves exert a force at the earth's surface. The earth vibrates and the seismic sensor converts such vibrations into an electrical signal.

Every target has a specific character and requires the use of seismic sensors, seismic systems and corresponding signal processing methods for its detection and discrimination. Thusly, the corresponding sensors, systems and signal processing methods may have their own requirements, which are not well known at the present time.

In this paper, we report on the signal characteristics of the above mentioned targets and on the corresponding detection range preliminary experimental data. We illustrate our results with field test

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records and with laboratory preprocessing of raw data. We also report on seismic sensor and seismic system requirements for target detection.

2. RESULTS AND DISCUSSIONS

2.1 Field test environment conditions and hardware description

2.1.1 Field test environment conditions

We investigated signal characteristics during our field tests for the following targets:
- Walking and running person
- Low and high-speed train
- Light and relatively heavy vehicle
- Helicopter
- Ship

For seismic system development, it is very important to obtain signal records of such targets in similar environment conditions. This allows an objective comparison of the various target signals and to design reliable seismic detection and discrimination systems.

We selected an area at the Hudson River bank in Yonkers, New York. Satellite photos of this area [9] are shown in Figure 1 below.

Figure 1. Selected area and environment conditions for the field tests.

The selected area allowed the recording of a seismic signal at the following distances:
- Walking and running person on grass and asphalt surface (1m and up)
- Low and high speed train – Metro-North Railroad (50m and up)
- Light and relatively heavy vehicle on asphalt surface (5m and up)
- Helicopter flying along Hudson River (700m and up)
- Ship on Hudson River (400m up)

2.1.2 Hardware description

We used the commercial GS-20DX geophone (seismic sensor) produced by Geo Space Corporation [10] for all the field tests. One of the important characteristics of this geophone is frequency bandwidth, which is 8.0-1500Hz according to manufacturer data [10]. The geophone was installed right on the ground with the grass surface about 1m from the asphalt surface area.

The output signal from the electrodynamic GS-20DX geophone is very low. Therefore, we should use a significant pre-amplification to supply the signal to an analog-to-digital converter (ADC) especially by testing low amplitude seismic signals in the real environment during field testing. The low noise amplifier was created on an Analog Device operational amplifier OP295 which has a symmetrical input and variable gain in the range of 10^3 to 10^5.

A photo of the hardware used—seismic sensor in a land case with a connecting cable, seismic amplifier, analog-to digital converter and laptop—is shown in Figure 2 below.

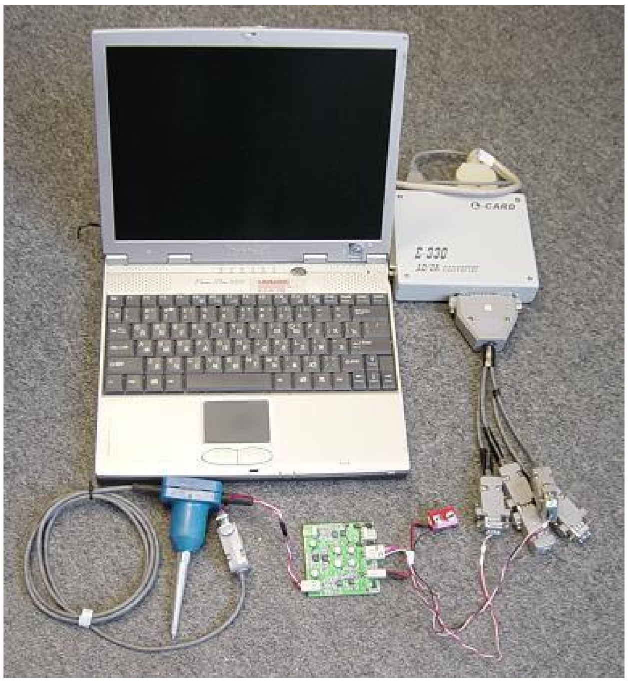


Figure 2. Seismic system components used in the field test.

2.2 Seismic signal characteristics of various targets

Recordings of the various targets' seismic signals were performed in the same place and with an identical sensor installation. Typically, only one kind of target produced the main part of the recorded seismic signal presented in this paper. This means that other targets were at a much greater distance during the records. The general background noise raw signal and its spectrum in the field test area are shown in Figure 3 below.

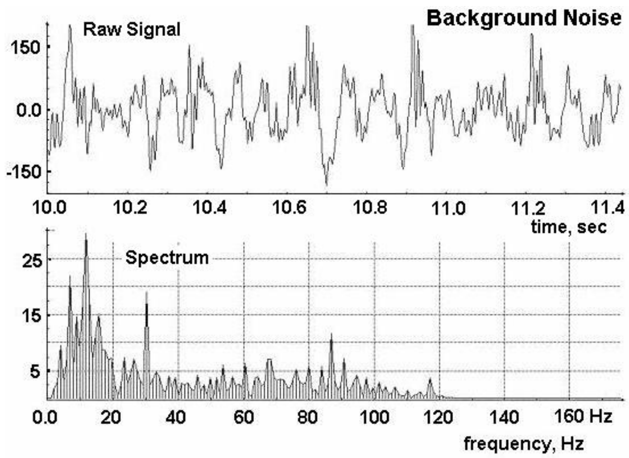


Figure 3. General background seismic noise and its spectrum in the field test area.

The spectral lines—7Hz, 12Hz, 30Hz—in Figure 3 show that our recordings were performed in an urban area, where various machinery operates at any time at a large distance and create the not-flat background noise spectrum plot. This situation is typical for a seismic security system at real functional facilities.

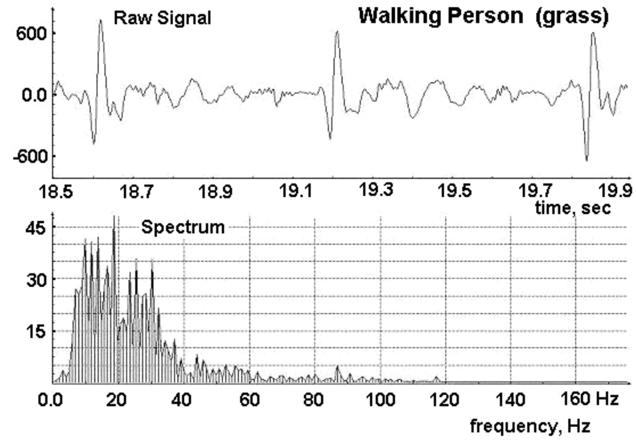
We will present results for all targets in this paper in a form similar to Figure 3. The raw signal fragments allow us to discern the presence or absence of any signal envelope pattern. The spectrum plot shows the pattern of a signal amplitude spectrum. All recordings were made during 60 seconds while the target passed by the seismic sensor. Sampling frequency was 500 Hz. We will present the short time frame recordings. This case is most interesting and important because in a real seismic security system, the signal processing duration is not more than 4-6 seconds due to many technical and tactical limitations.

2.2.1 Walking and running person

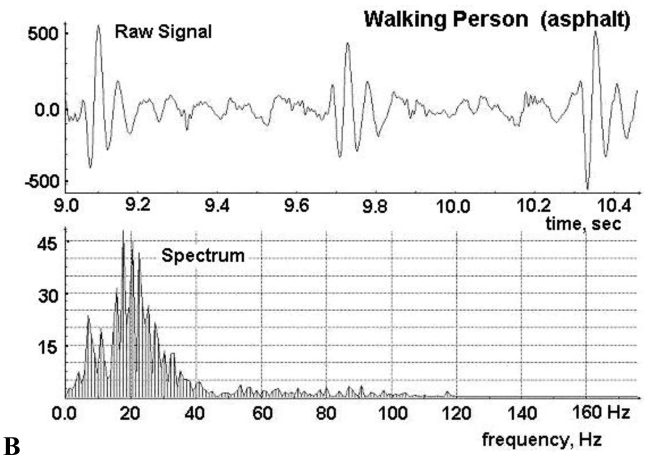
The nature of seismic footstep signals has been previously described [1-3, 11-13]. However, in the real environment, the seismic footstep signal characteristics vary significantly from case to case as was shown in [13]. In our research, it is very important to investigate the footstep signal characteristics in the same environment conditions used for other targets. This allows us to better understand how do design a reliable, near zero false alarm seismic security system for different target detection.

Examples of the raw footstep seismic signal and its spectrum for walking and running person are shown in Figure 4 below. The person was moving on the grass surface (Figure 4A and 4C) or on the asphalt surface (Figure 4B) along the separation line between grass and asphalt surface (see Figure 1). Figure 4 represents moments when the distance between the moving person and sensor was about 15-18m.

The plots in Figure 4 show that the signal from each step of the on person walking on asphalt has a lower amplitude and longer duration than the signal from each step of the person walking on grass. Low frequencies are much weaker in spectrum of the person walking on asphalt than in the spectrum of the person walking on grass. A running person generates a stronger signal with broader amplitude spectrum than a walking person. Also, there is a visible periodic envelope pattern in all three cases.



A



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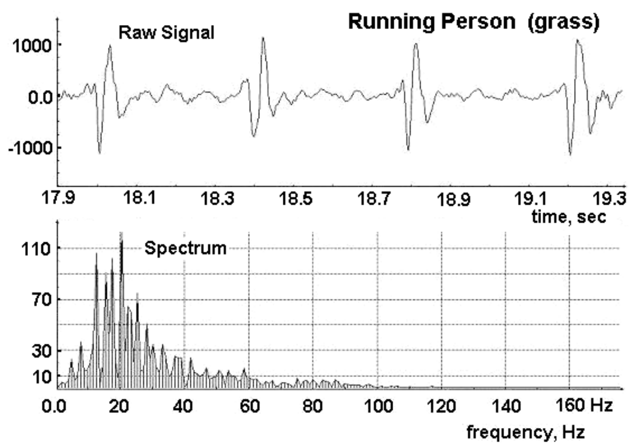


C

Figure 4. Raw signal and its spectrum for a walking (A, B) and running (C) person.

2.2.2 Low and high-speed train

The raw seismic signal and its spectrum for low and high-speed train are shown in Figure 5 below.

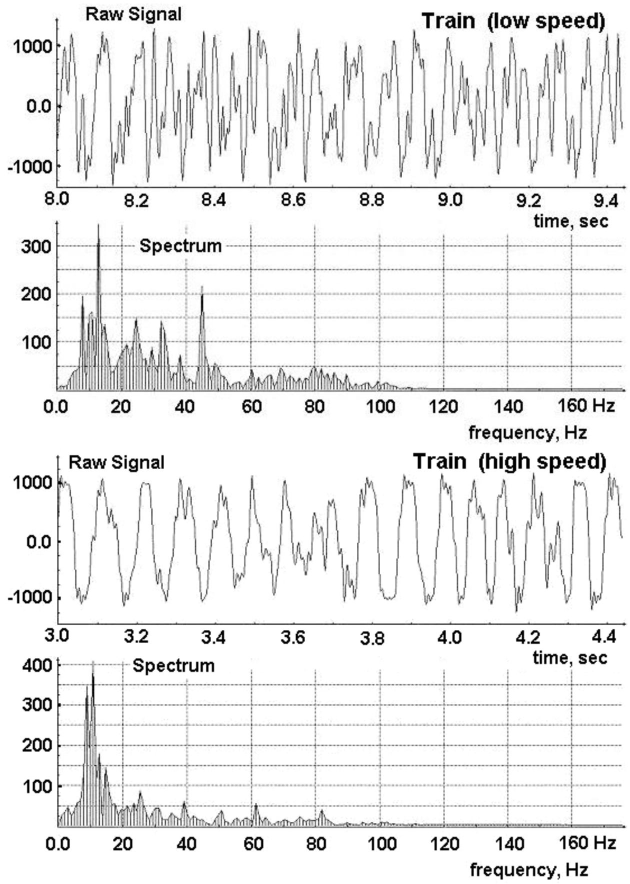
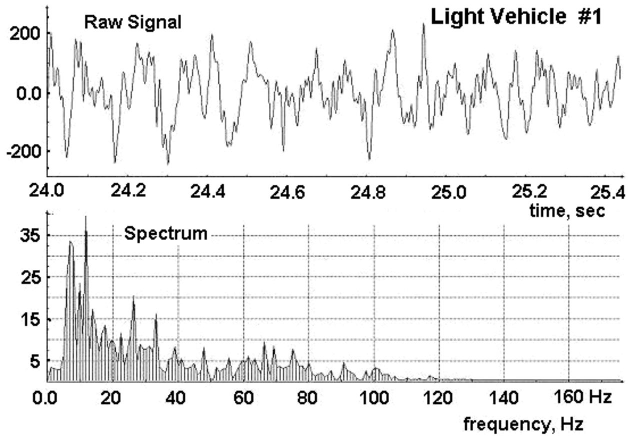


Figure 5. Raw signal and its spectrum for low and high speed train.

Figure 5 represents moments when the distance between the seismic sensor and the low and high-speed train was about 50m and 150m correspondingly. The signal from the train is very strong and has high amplitude. It also has clear and visible spectral lines, but the position and amplitude of these spectral lines strongly depends on the train's speed. Moreover, these spectral lines are broad enough because the train's parts—cars, wheels, wheel base, railing length—are not identical. The train's raw signal does not have any visible envelope pattern.

2.2.3 Light and relatively heavy vehicle

A light vehicle was represented in our field test as a mid-sized SUV. A relatively heavy vehicle was represented as a heavy truck. The raw seismic signal and its spectrum for the light and relatively heavy vehicles are shown in Figure 6 below.



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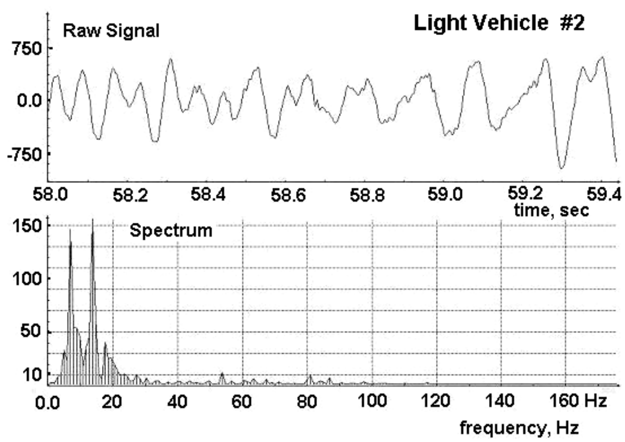

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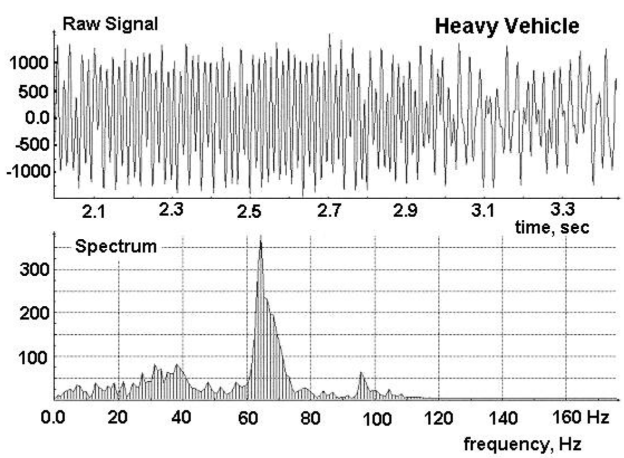

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Figure 6. Raw signal and its spectrum for light (A, B) and heavy (C) vehicle.
The records represent moments when the distance between the seismic sensor and the vehicles was about 5-15m. The speed of all vehicles was low (about 15-20km per hour). Figure 6A shows the signal from a vehicle that was moving in high gear with constant speed. Figure 6B and Figure 6C show the signals from vehicles that were moving in low gear with acceleration.

The Figure 6A shows that the quietly moving light vehicle generates a seismic spectrum close to the background noise spectrum but more powerful. The accelerating light vehicle generates much stronger seismic vibrations with specific high-level spectral lines which correspond to the engine and power train rotation speeds. The accelerating heavy vehicle generates very strong seismic vibrations with specific high-level and broad spectral lines in a frequency band of 60 to 70Hz, which corresponds to the general track vibration as a single whole. It is clear that the above shown spectral pattern allows one to reliably identify a moving vehicle for presented cases.

2.2.4 Helicopter

Helicopters were tested during their flights along the Hudson River. Their paths were actually straight above the seismic sensor. The raw seismic signal and its spectrum for the helicopter are shown in Figure 7 below. The distance to the helicopter for this record was roughly 300-700m.

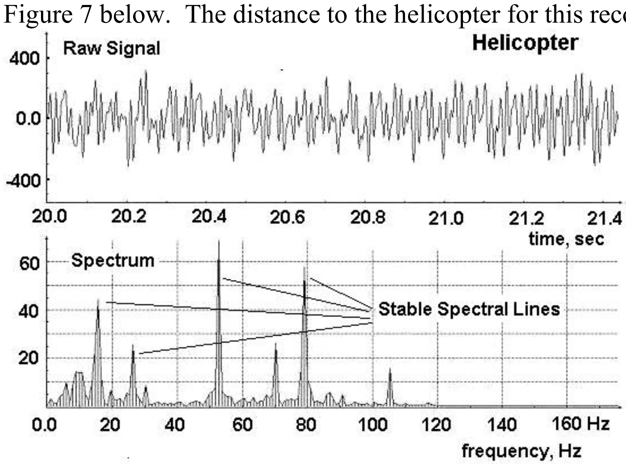

Figure 7. Raw signal and its spectrum for a helicopter.

The signal from the helicopter is strong enough and has several high amplitude and very narrow and well visible spectral lines. Some spectral lines are stable and not dependant on the distance to the helicopter during its flight. The position and amplitude of other spectral lines depend strongly on the distance to helicopter. Those “moving” spectral lines are a little broader. The helicopter’s raw signal does not have any visible envelope pattern. In general, the helicopter spectral pattern is very specific and allows one to make error-free identification of the helicopter from other targets.

2.2.5 Ship

The ship testing was performed while ships/barges moved along the Hudson River. The distance to the ship from the seismic sensor during testing was approximately 400-500m. Figure 1 shows a similar situation. The raw seismic signal and its envelope and spectrum for the ship are shown in Figure 8 below.

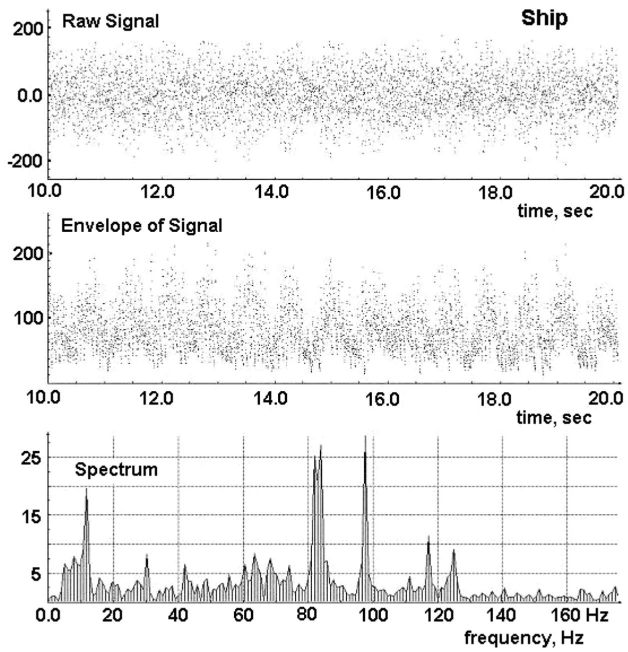

Figure 8. Raw seismic signal and its envelope and spectrum for ship.

There is a visible periodic envelope pattern in all three cases. The signal from the ship is strong enough and has several high amplitude and well visible spectral lines. Those spectral lines are broad enough. The ship's raw signal has a visible envelope periodic pattern. The combination of the broad spectral lines and the envelope periodic pattern allows one to make an error-free identification of the ship from other targets.

2.3 Seismic sensor and seismic system requirements for various target detection

2.3.1 Seismic sensor requirements

General high performance seismic sensor requirements for military and security applications were reported in our previous papers [14, 15]. The seismic signal characteristics of the various targets presented above provides additional information about such technical requirements as broad dynamic range and adjustable sensitivity.

As shown above, seismic sensors can be successfully used for various target detection from very light walking person and distant moving ship or helicopter to very heavy vehicles such as high or low speed train, tanks, and mobile missile launchers. In one situation, a person can walk far away from the sensor and produce a very weak sensor response. In other situations, a train or heavy vehicle can rush close to the sensor and produce a very strong sensor response. In both these contrary situations, the sensor must produce enough of a correct response signal to be processed for decision-making about the corresponding target presence.

Taking into account the possible mass and speed of targets, the easy assessment shows that the seismic sensor, which is capable of detecting the above discussed different targets, should have a very broad dynamic range of about 120dB—it should give correct response to signals, which differ from one another by six orders of magnitude. An automatic gain control during analog preprocessing or digital processing signal cannot actually help because in any case the input signal should have a sufficiently correct shape. Therefore, a mechanical oscillator of the seismic sensor should have the above mentioned very broad dynamic range of about 120dB, or a sensor mechanical oscillator should have adjustable sensitivity for use in various tactical applications. This is not always taken into consideration in the design of new sensors or in their use. The proprietary GSS new seismic sensor [16-19] allows to solve many of these issues.

2.3.2 Seismic system requirements

There exists a vast number of various homeland defense and security, military and other physical protection applications wherein seismic systems can be employed. These applications differ from one another in many features. The main differences include:

- Set of the detected targets
- Type of sensor arrangements (inside area or along the line/border, full or partial covering of the controlled zone, etc)
- Stationary or mobile type seismic system

Additional differences include:

- Use of autonomous or non-autonomous power supply
- Sensor deployment method—by hand, airdrop, launched from mortar, grenade launcher, etc.
- Use of disposable sensors for short-term working or reliable and durable sensors for long-term working

All these differences demand certain seismic system performance requirements which are often incompatible. In addition, we should remember the seismic and technical specificity for the seismic sensors mentioned above. Therefore, the attempt to design and manufacture a universal seismic system for every possible application seems unreasonable. In every respect it makes sense to design the number of the **seismic system base versions**, which can fit and satisfy the plurality of the applications and multi objective requirements. The main idea that should be used in the development of the base versions is a multi-sensor, a multi-processing channel and a multi-unit design. This approach allows one to solve the range of defense and security issues with the highest efficiency.

3. CONCLUSIONS

The design and practical use of seismic security systems is critical for homeland defense and security and for various military applications. The use of the seismic sensors (separate geophones or seismic strings and sensitive cables) allows one to reliably detect and effectively differentiate various targets which move not only on earth surface, but also underground, in air and in water. This opens a very broad range of security and military applications where seismic systems can be successfully used. The design of the corresponding seismic systems opens a new stage in improving long and short perimeter and border protection.

We have described in this paper signal characteristics of targets such as a walking and running person, light and relatively heavy vehicle, helicopter, ship and low and high-speed train. We have shown raw signals and amplitude spectrums for these targets. We have also reported on preliminary experimental data about the corresponding detection range of the targets. Our results demonstrate that many of mentioned above targets can not only be detected but also identified by seismic systems.

Seismic sensor and seismic system requirements for various target detection was also presented. The main requirements for seismic sensors are a broad dynamic range and an adjustable sensitivity. Seismic system development should be oriented towards the design of a number of base versions that should be multi-sensor, multi-processing channel and multi-unit systems. To achieve the highest efficiency of seismic detection, these issues should be accurately analyzed in the future.

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