High Performance Seismic Sensor Requirements for Military and Security Applications

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ABSTRACT

General Sensing Systems (GSS) has been developing seismic sensors for different security and military applications for the past several years. Research and development in this area does not have a single-value purpose as security and military applications are of a broad variety. Many of the requirements for seismic sensors are well known. Herein we describe additional requirements for seismic sensors that are not at the center of common attention and associated with high performance seismic sensors. We find that the hard issues related to "remote" deployment/installation methods can be solved, given the seismic sensor does not have the usual single-axis sensitivity, but sensitivity to arbitrary oriented impact/vibrations. Our results show that such a sensor can be designed, in particular based on electret materials. We report that traditional frequency response curve linearity is not always the appropriate goal. Such issues as useful signal frequency band and an interference immunity should be directly taken into account. In addition, the mechanical oscillator of the seismic sensor should have a very broad dynamic range about 120dB, or an adjustable sensitivity for use in various tactical applications. We find that increasing sensitivity is not so much needed as is reducing of the seismic sensor sensitivity threshold. The lower sensitivity threshold in higher target detection range can be obtained in low noise environmental conditions. We will also show that the attempt to design and manufacture a universal seismic sensor for every possible application seems unreasonable. In every respect it makes sense to design a seismic sensor set, which can fit and satisfy all plurality of the applications and multi objective requirements.

Keywords: Intruder detection, seismic sensor, homeland security and military seismic systems

1. INTRODUCTION

Seismic surveillance systems are very important for various homeland security and military applications. Performance and usefulness of such systems strongly depends on the characteristics of the seismic sensors. At the present time, traditional commercial seismic sensors/geophones are used for military application. These geophones have common characteristics, which were typically set for scientific geophysics purposes, in particular for seismic exploration.

However, military applications have a strongly specific character and need seismic sensors with other significant characteristics. A sensor for military applications is not a sensor for precise seismic signal characteristics exploration, its measurement or metrological examination. First of all, the sensor for military applications is one that allows to make a reliable decision about the presence of a target in its deployment area. It should also be convenient for use in military systems with heavy environment conditions. Today, military systems have very strict requirements for small size, low mass/weight, low price of the sensors, etc. In addition, military systems have requirement that are not as common and well known.

In this paper, we report on the additional requirements for seismic sensors that are not at the center of common attention. We illustrate our results with the new GSS electret based seismic sensor data [1] and with the broadband laboratory and field seismic testing in various conditions.

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Unattended Ground Sensor Technologies and Applications VII,
edited by Edward M. Carapezza, Proceedings of SPIE Vol. 5796
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.604358

2. RESULTS AND DISCUSSION

2.1 Sensitivity to arbitrary oriented impact/vibrations lead to better applicability to "remote" deployment

Typically, seismic sensors respond only to impact/vibrations oriented in the same direction as a sensor axis (single axis geophone). Some sensors can work only by their vertical orientation and detect vertical oriented vibration (for example, the GS-20DX geophone produced by Geo Space Corporation [2]). Some sensors can detect signal by their arbitrary orientation, but they respond only to vibrations oriented in the same direction as the sensor axis (for example, GS-14-L3 geophone produced by Geo Space Corporation [2].) Such performance leads to many issues linked to deployment/installation methods.

When a sensor is deployed from the air, for example by UAV, it will almost certainly not enter the ground vertically. (See Figure 1, quoted from [3])

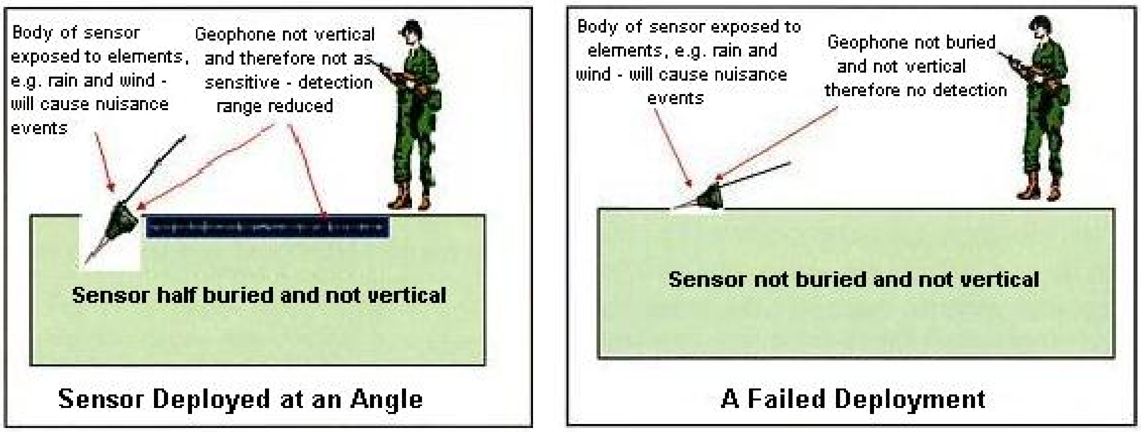

Figure 1. Issues of the angular deployment of seismic sensor.

Therefore a single axis geophone could have reduced response signal and consequently reduced detection range of vertical vibration with respect to a sensor deployed vertically. Automatic seismic calibration, which is recommended in [3], cannot lead to providing identical responses of a sensor deployed at an angle and a vertically deployed sensor. In real environment conditions, seismic vibrations are a result of the presence in deployment point of various oriented seismic vibrations/waves. Therefore the sensor's ability to respond to arbitrary oriented impact/vibrations will lead to better applicability in "remote" deployment.

We described in [1] the new GSS electret based seismic sensor, which is shown below in Figure 2.

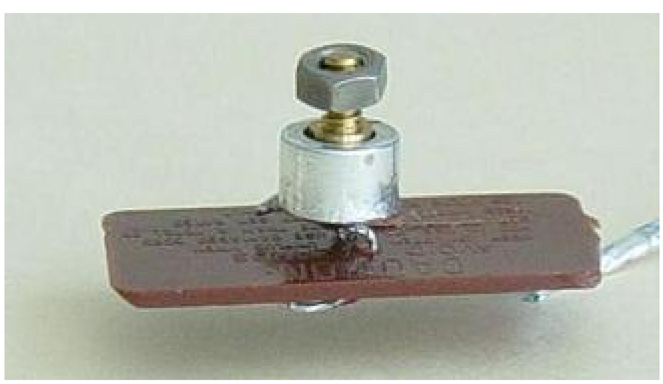

Figure 2. GSS sensor on a board for securely attaching to a vibration stand (lab test) or to a land case of a standard geophone (field test).

This sensor is the first step in the creation of a final version of the sensor, which has sensitivity to arbitrary oriented impact/vibrations. The presented sensor was placed for testing in different orientation (vertical, horizontal, and at 45˚ angle) on the vertically vibrating surface, as shown in Figure 3.

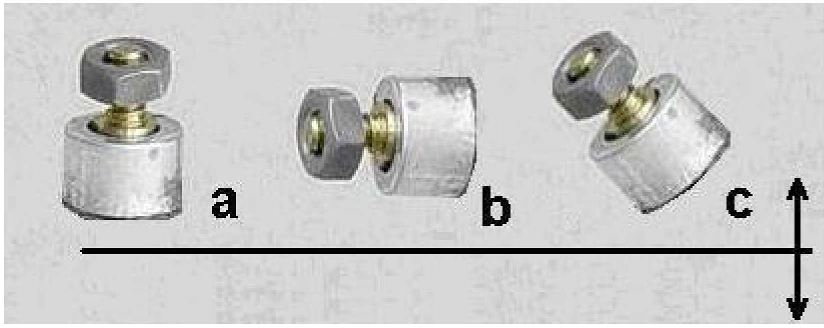

Figure 3. GSS's sensor testing by its different orientation on a vibration stand.

Output of all sensors was connected to an analog-to-digital converter (ADC) without additional amplification. Equal strong impacts were exerted on the sensor by different orientation during recordings. Figure 4 below shows these recordings.

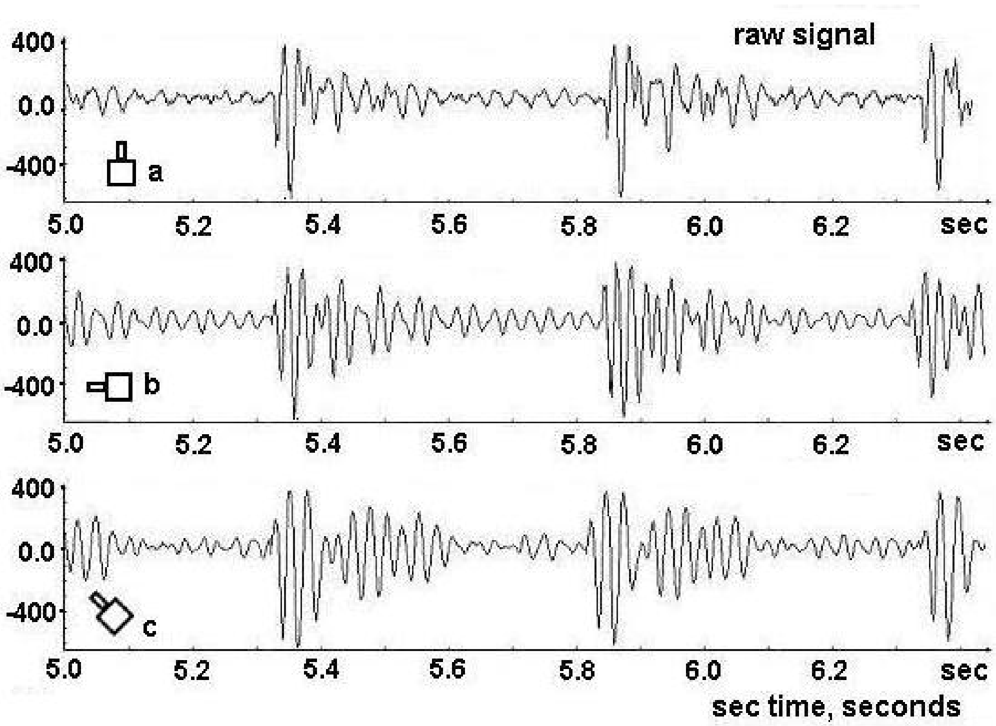

Figure 4. Records of the same seismic signal by the different sensor orientation as shown in Figure 3.

In all orientations, the new sensor actually shows the same high response signal level. We plan to fix the small signal damping different between the 45˚ angle and the vertical orientation. The amplitude spectrum of the signals from Figure 4 is shown in Figure 5 below.

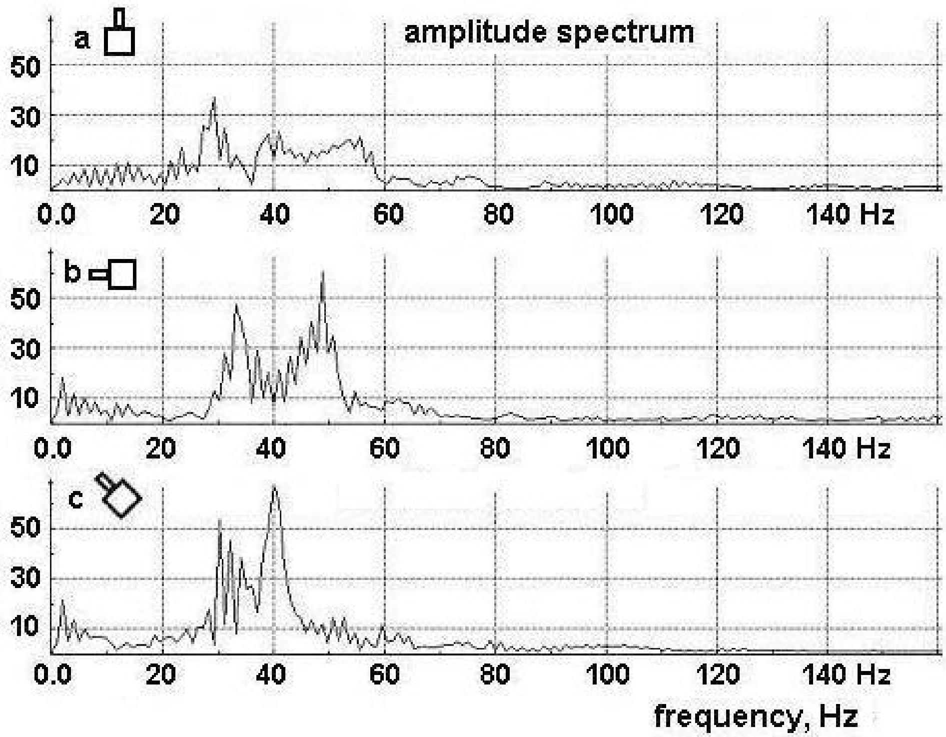

Figure 5. The amplitude spectrum of the seismic signals recorded by the GSS sensor and shown in Figure 4.

Figure 5 shows that in the vertical orientation, the GSS sensor has a more flat response curve. But as it will be shown, a non-flat response curve may not create a problem in target detection. In fact, a non-flat response curve can create an additional advantage for the seismic sensor in military applications. Figure 5 also shows that resonance frequency does not much depend on sensor orientation. It changes its value not more than at 20-25%. The horizontal and at an angle oriented sensor shows the stronger resonance properties than the vertical oriented sensor, but this fact does not change the general frequency band.

The above results illustrate that it is possible to create a seismic sensor for military applications, which has actually the same response/sensitivity in arbitrary orientation, leading to much better applicability for "remote" deployment.

2.2 Frequency response curve linearity is not always the right goal

Manufacturers traditionally attempt to create seismic sensors that have a linear response curve. This makes sense for many scientific applications, but not for many military and homeland security applications. In real environment conditions, in particular on the battlefield, environmental seismic noise can be more powerful than, for example, a footstep signal. For reducing the interference, a bypass filtering is usually employed. If the bypass filtering is used after amplification of the seismic signal or even after analog-to-digital conversion, very large signal distortions can be obtained. If bypass filtering is used between the seismic sensor and amplifier, there is the question of why we try to create a seismic sensor with a linear response curve. It is more reasonable to have a sensor with a nonlinear response curve that can automatically reject the main part of the interfering noise. In this case, the useful low signal (for example, footstep signal) can be amplified and processed with the lowest signal distortions, providing the maximum target detection range with the lowest false alarm.

An example of the footstep signal amplitude spectrum for different distances between a walking human person and the seismic sensor is shown below in Figure 6.

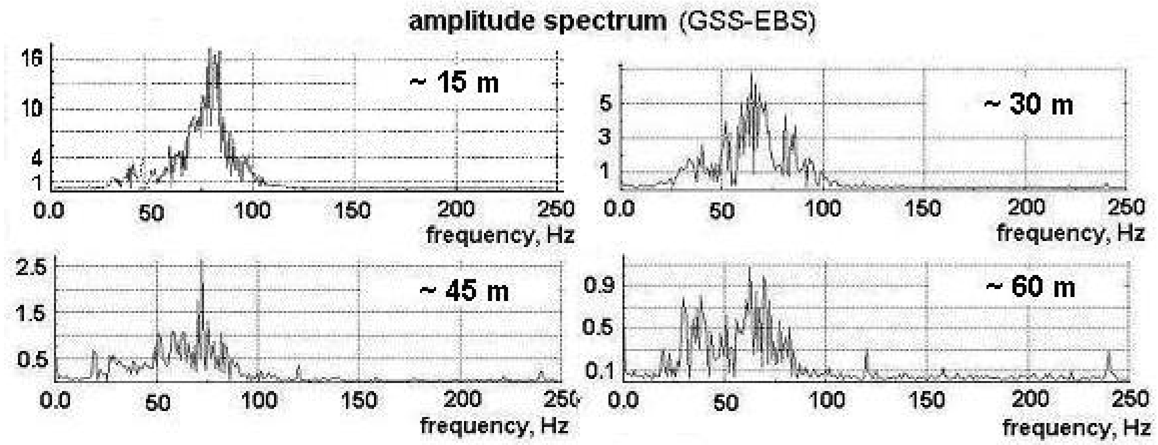

Figure 6. The amplitude spectrum of the footstep signals for different distances between a walking person and seismic sensor.

Figure 6 shows that for various reasonable distances (not for about 1m) the footstep seismic signal has a specific frequency band, 10-15Hz up to 80-100Hz. It makes sense for footstep detection to create and to use a seismic sensor with a corresponding frequency band and a corresponding frequency response curve. The use of a sensor with, for example, a flat response curve from DC to 5kHz [4] actually gives a worse result than the use of an existing commercial geophone and a much worse result than the use of the military applications oriented GSS sensor [5]. Figure 7 (quoted from [4]) shows a signal recorded in the vertical axis as the test subject approached the broadband MEMS Accelerometer.

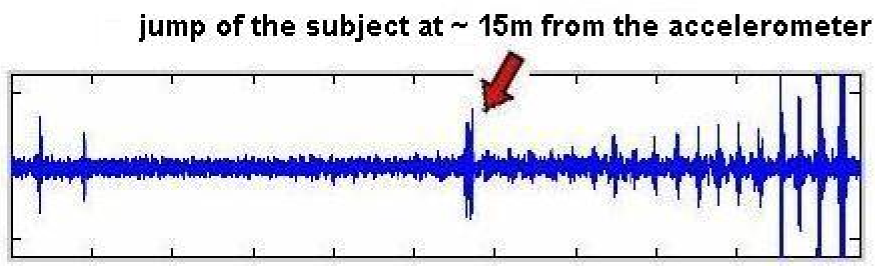

Figure 7. Footstep data measured with the MEMS Accelerometer (quoted from [4]).

According to [4], "minimal processing was used to produce" Figure 7. Therefore relatively short footstep detection range, as seen in Figure 7 above, can be obtained by using such broadband seismic sensor without fitting to the useful signal.

While choosing the sensor frequency band, it is also useful to take into account real tactical application. For example, for detection of the same footstep seismic signal, we can use for perimeter detection systems the sensor with a narrower frequency band and shorter detection range, than a sensor that must be used for an area detection system—which requires the highest detection range and correspondingly broader frequency band. Thus, frequency band, frequency response curve, and interference immunity should be taken into account.

2.3 Broad dynamic range and adjustable sensitivity

Seismic sensors are used for various target detection from very light walking person to very heavy military vehicles such as tanks, armored troop carriers and mobile missile launchers. In one situation, a human person can walk far away from sensor and produce very weak sensor response. In another situation, a heavy tank can rush close to the sensor and produce very strong sensor response. In both these contrary situations, the sensor must produce enough correct response signal which can be processed for decision making about the corresponding target presence.

Taking into account the possible mass and speed of targets, the assessment shows that the seismic sensor, which is capable to detect the above-mentioned various targets, should have a very broad dynamic range of about 120dB, i.e. it should give correct response to signals which differ from one another at million times. An automatic gain control during analog preprocessing or digital processing signal cannot help, because in any case the input signal should have the right shape. Therefore, the mechanical oscillator of the seismic sensor should have the above-mentioned broad dynamic range of about 120dB, or should have adjustable sensitivity for use in various tactical applications. This is not always taken into consideration by the design of the new sensors.

2.4 Lower sensitivity threshold

The seismic sensor manufacturer's data includes so-called sensitivity. This means a transformation/conversion ratio and shows the relation between output electrical signal (as usual in Volts) and input mechanical vibration velocity or acceleration. Of course, this characteristic is important and its higher level allows to simplify a signal preprocessing problem, because in this case a lower amplification is needed before analog to digital converting. Therefore, a design of all new sensors is oriented at increasing sensitivity. But for improving the sensor's tactical applicability, it is more critical to reduce the sensitivity threshold. This threshold can be defined as the lowest vibration value (vibration velocity or acceleration) that is able to generate a correct output electrical signal. The lower the sensitivity threshold, the higher the target detection range can be obtained in low noise environmental conditions.

Unfortunately, both the published testing results [4, 6, 7, 8] and our lab and field testing results [1, 5] show that many up-to-date sensors have unsatisfactory high sensitivity threshold, leading to signal missing by weak input vibration from the distant targets and to reduction of the detection range. Figure 8 from [7] shows an example of such a situation.

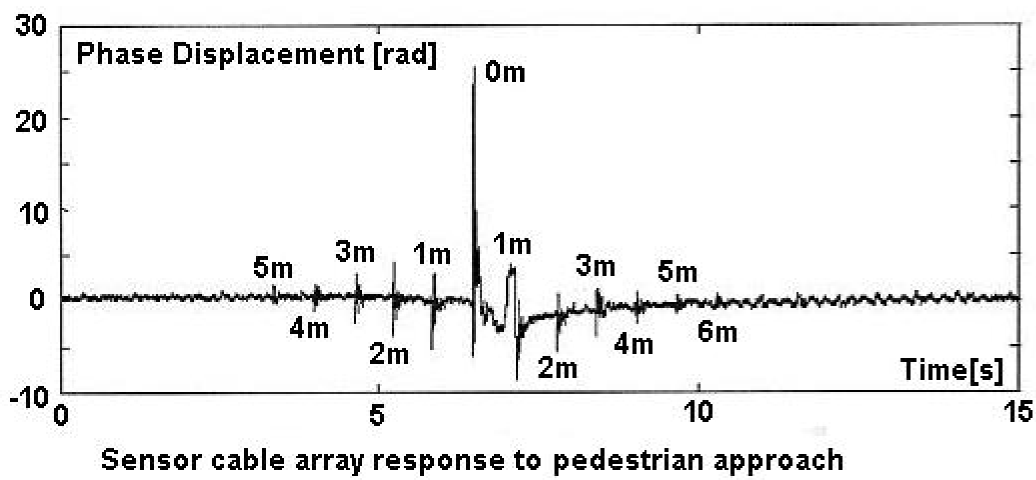

Figure 8. Footstep data measured with the fiber-optic security array during land deployment (quoted from [7]).

Even for perimeter protection systems, the detection range shown in Figure 8 is not high enough. For area reconnaissance systems, the 5m-detection range is even more impractical. In fact, at present time, as shown in [1, 5], the GSS electret based seismic sensor shows the lower sensitivity threshold especially in low and high frequency bands. Figure 9 shows in correct comparison qualitative scale advantages of the GSS sensor in terms of the sensitivity and sensitivity threshold versus the most popular and broadly used geophones (GS-14-L3 and GS-20DX) produced by Geo Space Corporation or by other companies.

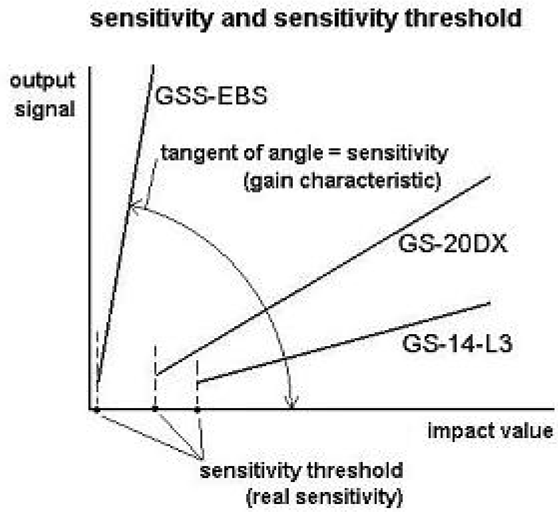

Figure 9. Higher sensitivity and lower sensitivity threshold of the GSS electret based sensor in comparison with commercial geophones.

2.5 Plurality of the applications and multi objective requirements may justify the set of sensors choices

There are a large number of various military, homeland security and other physical protection applications where seismic sensors can be used. As usual, all these applications differ from one another in many characteristics. These differences include:

- Type of detected targets (heavy or light, mechanical or human)
- Type of arrangements (inside area or along the line/border, full or partial covering of the controlled zone)
- The specific deployment method (hand-placed, airdrop, launching the sensors from a mortar, grenade launcher, submunition dispenser)
- The stationary or mobile type of seismic system
- The autonomous or non-autonomous power supply
- Disposable sensor for short-term working or reliable and durable sensor for long term working

All these differences require certain performances of the seismic sensors, which are very often incompatible. In addition, we should remember the seismic and technical specificity that has been mentioned. Therefore, the attempt to design and manufacture a universal seismic sensor for every possible application seems unreasonable. In every respect, it makes sense to design a seismic sensor set, which can fit and satisfy the plurality of applications and multi objective requirements.

3. CONCLUSIONS

The design and development of new seismic sensors for military and security applications is very popular at the present time. But success can be achieved only if the new sensors can fit to the very broad variety of the specific requirements. We discussed above some non-traditional requirements, which today are not so well known and common. The possible ways to fit these requirements is shown. We believe that the requirements and recommendations reported in this paper will contribute to research and development connected with seismic sensors and seismic security systems.

ACNOWLEDGEMENTS

Dr. Ed Carapezza of DARPA is acknowledged for technical discussions of the presented results. Mr. Al Sicignano of GSS is acknowledged for his help in manufacturing the new sensor. Mr. Matt Sandy of GSS is acknowledged for his contribution in editing this manuscript. This work is supported by DARPA under contract number HR0011-04-C-0108.

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