

## Detection of Unobserved Ground Targets by Use of Seismic Location Stations

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### **Abstract:**

*The detection method of moving unobserved ground military heavy trucks is considered in paper. The 3D coordinates detection set and the seismic location method are used in our study. The computational algorithm of determination of the bearing angle and distance to unobserved ground target are presented, the computational uncertainties are estimated. The triangular form of 3D detectors in one seismic location cell is offered. It allows minimizing distance and angle uncertainties in target direction. To improve the detection effectiveness, the optimal geometry disposition of 3D detectors in seismic location cells is determined. The offered method is effective in case of terrain relief where seismic-acoustic signal is propagated by approximately straight line. Therefore, this method can be applied only to homogenous medium, for example, to mountainous, solid rocky soil.*

### **Keywords:**

*bearing angle, computational algorithm, seismic location cells, seismic-acoustic signal, unobserved target*

### **1. Introduction**

For successful planning of a military operation the battle field commanders have to know full information about battle space [1]. But there could be such a critical situation during military operations that it might not be possible to observe terrestrial targets, particularly unobserved enemy ground military heavy trucks located on mountainous terrain. In this situation, there is indefinity in information, thus the risk of wrong decision making under uncertainty on destroying of the targets is rised, the probability of unexpected attack is increased. Therefore, the detection of faraway moving unobserved military heavy trucks is very important.

To solve this problem, the passive (hidden) means is offered to reveal the heavy trucks movement. The advantages of passive means are noiselessness and low energy

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consumption ( $< 0.01$  W). This power is provided by autonomous energy sources (battery, accumulator, solar cells), which is very important during war operations at the field conditions.

Firstly, this problem of the secretive revealing of unobserved military heavy machineries (tank or other armoured trucks) in mountainous or forestry regions has been considered in [2, 3]. The offered method cannot directly be applied in complex conditions of landscape (serially located mountains, hills and valleys). This method is effective in case of terrain relief when seismic-acoustic signal is propagated by approximately straight line. Therefore, this algorithm can be applied only to homogenous medium, that is, to mountainous, solid rocky soil.

The location parameters of unobserved target can be determined by seismic and acoustic methods, and by their combination [4-7]. Each of them has advantages and lacks. The application of the combination of these methods raises the reliability of detection because noise factors for various physical effects phenomena are negligibly correlated [8]. The application of detection seismic-acoustic means is caused by neighbourhood of physical processes, which occur during longitudinal seismic and acoustic wave propagation along of soil-air interface with various densities.

We can see in frequency range of surface seismic waves (5-200 Hz) that there is a sufficiently high and stable acoustic electric sensitivity of piezoelectric detectors [3]. At that, the range of a low frequency (1-10 Hz) is of a special interest, and subsurface seismic vibrations are weakly depended on climate factors.

Permanent seismic-acoustic waves arise in the surface soil owing to not only the movement of heavy armoured trucks, but also trains, aircraft, helicopters, rain, wind and processes in Earth interior. By application of space-separated 3D detectors and seismic location cells of triangular form [9] we can determine a bearing angle (azimuth) of the source of seismic waves and a distance. Then, by use of the computer base of standard spectral seismic-acoustic data, we can determine a type of the armoured trucks.

The detection method of location of the moving unobserved ground military heavy trucks is considered in paper. The 3D coordinates detection set and the seismic location method are used in our study. The computational algorithm for determination of bearing angle and distance to unobserved ground target are presented, the computational uncertainties are estimated. The triangular form of 3D detectors in one seismic location cell is offered. It allows minimizing distance and angle uncertainties in target direction. In order to improve detection effectiveness, the optimal geometry disposition of 3D detectors in seismic location cells is determined.

The goal of this work is the development of the determination algorithm of angle parameters of unobserved target direction (bearing angle measurement) based on seismic-acoustic data, distance to target and optimal geometry of disposition of 3D detectors in seismic location cell.

## 2. Determination of Space Parameters

Let us consider the principle of seismic location station (*SLS*) operation. The chart of geometry of *SLS* components is shown in Fig. 1 [3, 10]. There are three 3D detectors in seismic location cells (*SLC<sub>i</sub>*) for detection of seismic-acoustic waves (Fig. 2): here,  $d$  is the distance between detectors;  $i, (i = 1, \dots, n)$  is the serial number of cell,  $n$  is the number of seismic location cells; *SW* is the input signal from seismic-acoustic wave. Let us suppose cells are brought into a line and the distance between them is equal to  $l$ . Then, the distance between the first cell and the last one is  $L = (n - 1) \cdot l$ .

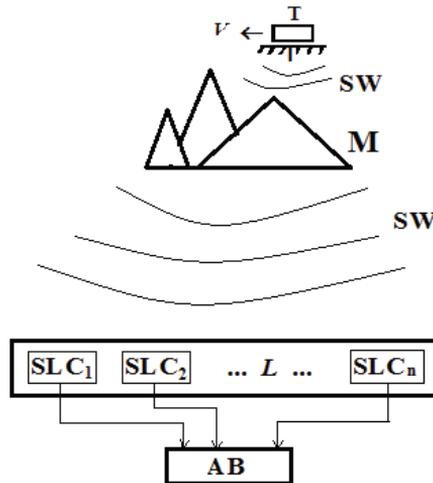


Fig. 1 Seismic location station SLS

$SLC_i$  are seismic location cells; SW is seismic-acoustic wave from moving unobserved target T; V is the speed of target; M – mountain; AB is the electronic block of processing and filtration of input information; L is the distance between first  $SLC_i$  and end  $SLC_n$  (a base of SLS)

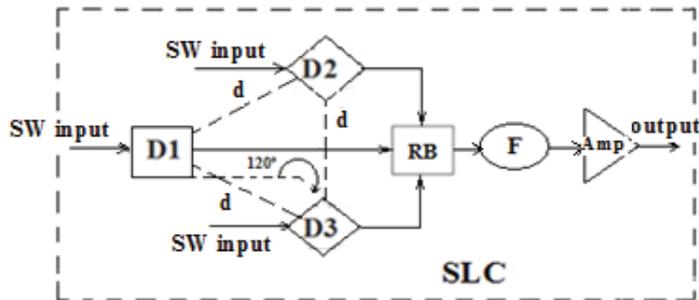


Fig. 2 The chart of seismic location cell: here, D1, D2 and D3 are 3D seismic-acoustic detectors; SW input – input signal of seismic acoustic waves; RB is the information-receiving block; F is the electronic filter block; Amp is the amplifier;  $120^\circ$  is the angle between vertical surfaces of 3D detectors

3D-detectors are made based on piezoelectric sensors. Polymer matrix PVDF +  $Pb(ZrTiO_3) + (SiO_2)_6$  and PVDF +  $Pb(ZrTiO_3) + BaTiO_3$  hybrid nanocomposites are used in these sensors as highly sensitive piezoelectric materials [11]. When we compare output power on various sides of 3D-detectors, we can determine the direction of incident wave. That is, this kind of 3D sets allows determining exactly the space position of the target. The physical principles of 3D detectors operation and of sensible piezoelectric sensors making are given in [9, 10].

The design of 3D-detectors is shown in Fig. 3 in [3, p. 187]. We can determine the direction of seismic sound source by comparing the fixed signal power from vertical sides of piezoelectric detectors (sensors). Then, we calculate an average value of the

obtained data from all 3D detectors of considered *SLS* and determine the direction of target for this station. Now, for determination of the target location we can apply the triangle method by separately considering each pair of *SLS*. We calculate the average value of the obtained average data and determine the coordinates of target.

Below, we present the calculation formulas of direction vectors, the distance to target  $R$  and the evaluation of calculations uncertainty in dependence on the distance  $l$  and the number  $n$  of *SLS*.

Let us consider angle parameters in the direction of target, the distance between the target and *SLS*, and the optimal disposition geometry of 3D detectors in seismic location cell.

Let us take the coordinate system shown in Fig. 3. Let  $SLC_1$  is situated in  $(0, 0)$  point, and  $SLC_2$  is situated in  $(l, 0)$  point. If the direction of the target with  $(x_0, y_0)$  coordinates in  $SLC_1$  sets itself by  $\alpha$  angle, and in  $SLC_2$  sets itself by  $\beta$  angle, then

$$(x_0, y_0) = \left( l \frac{\tan \beta}{\tan \beta - \tan \alpha}, l \frac{\tan \alpha \tan \beta}{\tan \beta - \tan \alpha} \right) = \left( l \frac{\cos \alpha \sin \beta}{\sin(\beta - \alpha)}, l \frac{\sin \alpha \sin \beta}{\sin(\beta - \alpha)} \right).$$

The distance to the target is

$$R = l \frac{\sin \alpha \sin \beta}{\sin(\beta - \alpha)} \quad (1)$$

The quantity  $R$  is identical with the coordinate  $y_0$  (it is clear from Fig. 3), that is  $y_0 = R$ .

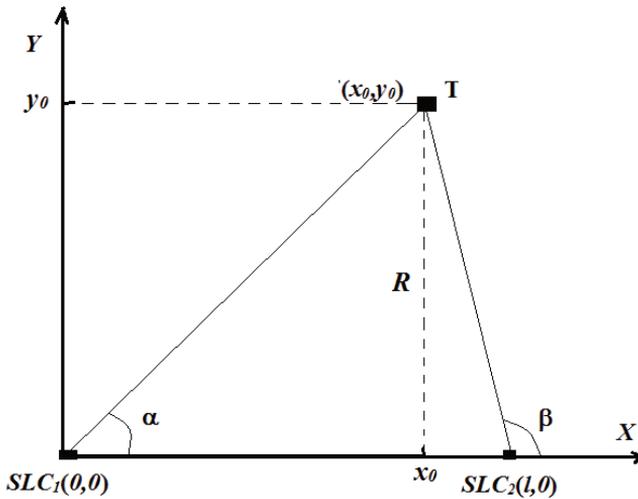


Fig. 3 Coordinate system for connection of investigated object

Let us determine increment of  $R = R(l, \alpha, \beta)$ :

$$dR = \frac{\sin \alpha \cdot \sin \beta}{\sin(\beta - \alpha)} dl + l \frac{\sin \alpha \cdot \sin \beta}{\sin^2(\beta - \alpha)} d\alpha - l \frac{\sin^2 \alpha}{\sin^2(\beta - \alpha)} d\beta \quad .$$

Therefore, the relative uncertainty of calculation of the distance to the target is

$$\left| \frac{dR}{l} \right| \leq \frac{\delta_1}{|\sin(\beta - \alpha)|} + \frac{d\alpha}{\sin^2(\beta - \alpha)} + \frac{d\beta}{\sin^2(\beta - \alpha)} = \frac{|\sin(\beta - \alpha)|\delta_1 + d\alpha + d\beta}{\sin^2(\beta - \alpha)}, \quad (2)$$

where

$$\delta_1 = \frac{dl}{l}.$$

It is clear that the larger  $|\sin(\beta - \alpha)|$ , the lower the calculation uncertainty.

To reduce the uncertainty  $dR$ , three D1, D2 and D3 3D detectors in one *SLC* are placed angularly under  $120^\circ$  to one another (see Fig. 2) [10].

So, detecting signals by piezoelectric sensors on vertical sides of 3D detectors we can determine the direction (bearing angle), the distance to the source of seismic waves (the target) and the evaluation of measurement uncertainties.

Generated on horizontal sides of 3D detectors the signals are filtered (sorted out) because they are formed by acoustic waves from flying targets (aircraft, helicopter etc.).

Let us suppose  $\delta_1 = \Delta l/l = 0.0001$  (the accuracy of a laser range finder);  $d\alpha = d\beta = 0.01^\circ \approx 0.0002$  rad (it is ordinary accuracy of geodesic, land-surveying devices is better, see [12]). Let us consider a case when  $l = 2000$  m,  $\alpha = 50^\circ$ ,  $\beta = 110^\circ$  and  $\beta - \alpha = 60^\circ = \pi/3$ .

Then, from Eq. (2) we have

$$\frac{dR}{l} \leq \frac{|\sin(\beta - \alpha)|\delta_1 + d\alpha + d\beta}{\sin^2(\beta - \alpha)} \approx \frac{0.0005}{\sin^2(\beta - \alpha)}. \quad (3)$$

From Eq. (3) we obtain the uncertainty of determination of the target space coordinates. From Eq. (3) we obtain the uncertainty of determination of the target space coordinates  $dR \approx 2$  m.

From Eq. (1) we obtain the distance of the unobserved target  $R = 1600$  m.

Various spectrums of seismic-acoustic waves (etalon spectrums) generated by moving armoured machineries (T-55, T-72, T-80, T-90 tanks: BMP-2, BMP-1, BMD, BRDM-2, BRDM, BTR-80, BTR-60 and heavy trucks) are stored in the memory of electronic block AB. Therefore, taking into account that the power of propagated seismic-acoustic waves is inversely proportional to the square of the distance, we can determine the type of target by comparison of seismic-acoustic spectrums detected by 3D detectors with etalon ones.

### 3. Conclusion

The paper deals with the determination of the hidden movement of enemy heavy armoured trucks (targets) based on seismic acoustic location. The algorithms of determination of the angle parameters and the distance to the unobserved ground target are developed based on seismic acoustic data.

The triangular form of 3D detectors in one seismic location cell is offered. It allows minimizing the distance and angle uncertainties in target direction. The optimal dislocation geometry of 3D detectors in seismic location cell for decreasing measurement uncertainty is determined.

If the width of seismic location station is  $L = 2000$  m,  $\alpha = 50^\circ$  and  $\beta = 110^\circ$  then the uncertainty of determination of the target space coordinates is  $dR \approx 2$  m in the distance of  $R \approx 1600$  m.

This method can be applied only to homogenous medium, for example, to mountainous, solid rocky soil.

In heterogeneous geological subsoil environment, there are lots of interference and diffraction processes of seismic-acoustic waves. So, we must carry out field experiments and have reference (etalon) data generated by moving of known armoured machineries.

## References

- [1] HASHIMOV, E.G., BAYRAMOV, A.A. and KHALILOV, B.M. Terrain Orthophotomap Making and Combat Control. In *Proceeding of International Conf. "Modern Call of Security and Defence"*. Sofia: Georgi Rakovski Military Academy, 2017, vol. 1, p. 68-71.
- [2] HASHIMOV, E.G. and BAYRAMOV, A.A. Detection Unobserved Moving Armored Vehicles by Seismic Method (in Azerbaijani). *National Security and Military Sciences*, 2015, vol. 1, no. 1, p. 128-132.
- [3] HASHIMOV, E.G. and BAYRAMOV, A.A. Seismic Location Station for Detection of Unobserved Moving Military Machineries. *Military and Information Sciences*, 2016, vol. 4, no. 2, p. 61-66. DOI 10.17858/jmisci.82365.
- [4] PANFILOV, A.K., KUZMENKO, I.V. and SISOYEV, S.N. Identification in Seismoacoustic Detection Systems (in Russian). *New Technologies*, 2010, vol. 4, p. 54-59.
- [5] JIN, X., SARKAR, S., RAY, A., GUPTA, S. and DAMARLA, T. Target Detection and Classification Using Seismic and PIR Sensors. *IEEE Sensors Journal*, 2012, vol. 12, no. 6, p.1709-1718. DOI 10.1109/JSEN.2011.2177257.
- [6] PAKHOMOV, A. and GOLDBURT, T. *Seismic Systems for Unconventional Target Detection and Identification. Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense V*, 2006, vol. 6201, 62011I-1. DOI 10.1117/12.668930.
- [7] CRESS D.H. *Seismic Methods of Locating Military Ground Targets*. Miscellaneous paper M-76-13. Vicksburg (MS): U.S. Army Engineer Waterways Experiment Station, 1976. 73 p.
- [8] GARCIA, M.L. *Design and Evaluation of Physical Protection Systems*. 2nd Edition. Oxford: Butterworth-Heinemann, 2008. 370 p. ISBN 978-0-7506-8352-4.
- [9] YANCHICH, V.V. *Piezoelectric Sensors of Vibrational and Shock Acceleration* (in Russian). Rostov-na-Donu, South Federal University, 2008. 77 p.
- [10] HASHIMOV, E.G., BAYRAMOV A.A. and SABZIEV E.N. Determination of the Bearing Angle of Unobserved Ground Targets by Use of Seismic Location Cells. In *IEEE Proceeding of the International Conference on Military Technologies (ICMT)*. Brno, 2017, p. 185-188. DOI 10.1109/MILTECHS.2017.7988753.
- [11] KERIMOV, M.K., KURBANOV, M.A., BAYRAMOV, A.A. and MAMEDOV, A.I. Matrix Active Micro- and Nanocomposites Based on the Polymer, Semiconductive and Ferropiezoceramic Materials. In *Nanocomposites and Polymers with Analytical Methods*. Rijeka: InTech, 2011, p. 375-404. ISBN 978-953-307-352-1.
- [12] SIAUDINYTE, L. and GRATAN, K.T.V. Uncertainty evaluation of trigonometric method for vertical angle calibration of the total station instrument. *Measurement*, 2016, vol. 86, p. 276-282. DOI 10.1016/j.measurement.2015.10.037.