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Project Paper

Seismic Location Station for Detection of Unobserved Moving Military Machineries

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Abstract- The main purpose of this paper is to develop a seismic location station that can detect unobserved, moving military objects, and heavy military machineries behind a forest or a mountain at a distance of 1-2 kilometers from the determined location. Seismic location station includes specific 3D seismic detectors based on the very sensible piezoelectric sensors. The proposed piezoelectric detectors are based on the PVDF+$BaTiO_3$+PZT polymer hybrid composite fabricated based on nano sized $BaTiO_3$ (or SiO_2) and micro sized PZT (plumbum zirconate titanate) piezoelectric material. A polyvinylidene fluoride (PVDF) was taken as polymer filler. This study presents the results of the development of seismic wave cells based on 3D seismic detectors. Additionally, a plan is developed and offered for a solution to detect unobserved moving military trucks.

Keywords- Seismic waves, seismic location station, piezoelectric detector, moving military machineries, seismic wave's cell.

1. Introduction

When land forces carry out operations in mountainous or forested regions, they have difficulties detecting unobserved, moving, heavy machineries (tanks or other armored trucks trucks) (Hashimov, 2015; Hashimov, & Bayramov, 2015). As a result, the probability of unexpected attacks increases. Therefore, under conditions of mountainous terrain, it is very important to reveal distant, moving, heavy trucks. Seismic systems can be used to detect the seismic vibration from light and heavy vehicles, trains, and tanks (Anderson et al., 2001; Edwards 2004). Moreover, such seismic systems can be used to detect the acoustic-seismic and hydro acoustic-seismic vibrations from targets such as helicopters, aircrafts, and ships.

Seismic systems have the best ability to detect terrestrial objects among all passive detection systems (Zvejinski, 2005). They have not practically any limitation to detect type of object besides some kind of soil (marshland, drift sand). The high information capacity of seismic signals allows to recognize objects over a vast space (Tubaishat and Madria, 2003; Marchacshinov, 2009 & 2010; Panfilov, 2010).

Many scientific articles are devoted to the detection problem of moving objects by seismic and acoustic methods (Anderson, 2001; Edwards & Robinson, 2004; Zvejinski, 2005; Marchacshinov, 2009 & 2010; Panfilov, 2010; Xin Jin et al., 2012; Alex Pakhomov & Tim Goldburt, 2006; Daniel, 1976; Jinhui Lan et al., 2004).

One article (Xin Jin et al., 2012) is devoted to an automatic acoustic set scanning moving "human activity" on the ground. This paper presents a wavelet-based method for target detection and classification by using unattended ground sensors systems. The proposed method has been validated by the data sets of seismic and passive infrared sensors for target detection and classification, as well as for payload and movement type identification of the targets.

Pakhomov and Goldburt (2006) presented the analyzed acoustic spectrums, obtained from unconventional

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targets: 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.

Daniel (1976) presented an approach for locating military ground targets with a triangular array of geophones. The target-location system was used in field studies to determine directional angles to military targets, including a 2.5-ton truck, an off-road, and combat engineering vehicle on a tank chassis. The results of the analysis indicate that the location of targets using seismic energy is possible within accuracies of 5^o and ranges exceeding 450 m. (Daniel H., 1976).

Jinhui Lan et al. (2004) presented a novel method of target classification by means of a micro accelerometer. The seismic signals from moving vehicle targets are detected by a micro accelerometer, and targets are automatically recognized by the advanced signal processing method.

We know the general physical idea of moving target detection and propagation acoustic waves. Moving targets exert a time changing force at the earth's surface. The soil starts vibrating and then the seismic sensor converts such vibrations into electrical signals. For moving targets in the air or in the water (helicopters and aircraft, ships, or submarines), there are more complicated physical processes. Moving targets produce acoustic waves in their corresponding medium. After propagation, these waves exert a force on the earth's surface. Then, the soil vibrates and the seismic sensor converts such vibrations into an electrical signal.

This paper is devoted to the development of a seismic location station that can detect unobserved, moving military objects. A seismic location station is developed based on 3D seismic triangular detectors and can detect heavy (P > 2 ton), moving, unobserved (behind a forested area or mountain) combat vehicles at a distance of 1- 2 kilometres. These 3D sets can detect the space location, speed, and trajectory moving target with space and angular accuracies of several meters and < 3^o, respectively. The seismic detector we have proposed to use was a high sensitivity, piezoelectric detector using PVDF+$BaTiO_3$+PZT polymer hybrid piezoelectric composites based on the nano sized $BaTiO_3$, SiO_2 and micro sized PZT (plumbum zirconate titanate) piezoelectric transducer. Polyvinylidene fluoride (PVDF) was used as a polymer filler (Kerimov et al. 2011; Kurbanov et al., 2013).

2. Seismic Waves Cell

The seismic location station is a passive set and radio electronic equipment cannot detect it. Using software in real time, the receiving signals from the seismic detectors were processed, and the following tasks were solved (Marchacshinov, 2009 & 2010):

- Detection of moving, ground objects;
- Filtration of false signals (noise) and classification of detected moving objects (tank or combat vehicle);
- Determination of coordinates and trajectories of targets on the move.

The disturbance of aircraft or helicopters by rain or wind can be seismic noise. Seismic wave detection becomes worse in friable soil and for deep snow cover. However, for mountainous regions like Azerbaijan, these factors are not considerable.

The developed piezoelectric detector is one of the main parts of the seismic location station (Fig. 1).

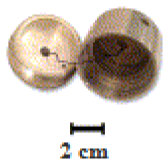

Fig. 1. Piezoelectric detector.

This piezoelectric detector can receive very weak seismic waves and converts them to electrical signals. Then, the signals are amplified, filtered by a special electrical circuit, and transmitted to a processing block. A piezoelectric detector was fabricated using polymer (polyvinylidene fluoride) PVDF+$BaTiO_3$+PZT hybrid piezoelectric composites on the basis of nano sized $BaTiO_3$ (or SiO_2) and micro sized PZT piezomaterials (Kerimov et al., 2011; Kurbanov 2013). This piezoelectric detector has very high acoustoelectric characteristics (Fig.2).

There is a frequency dependence of the amplitude of the output signal of the piezoelectric detector per unit of acoustic wave pressure (acoustic electric sensitivity), as seen in Fig.2. There is a sufficiently high and stable acoustic electric sensitivity of piezoelectric detectors in the frequency range of surface seismic waves (0.005-0.2 кHz). In the range of low frequency (1÷10) Hz, subsurface seismic vibrations are weak as a result of climate factors.

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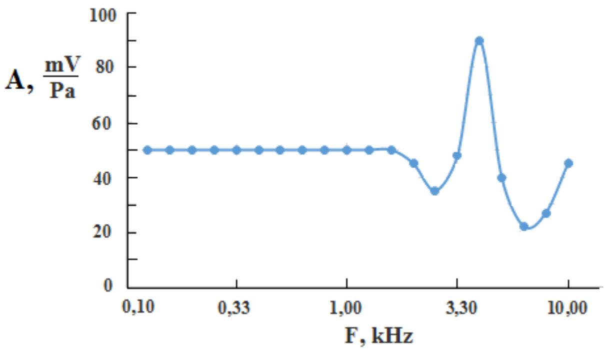

Fig. 2. Acoustoelectric characteristics of the piezoelectric detector.

Fig. 3 shows the developed construction of a single-coordinate piezoelectric detector PD.

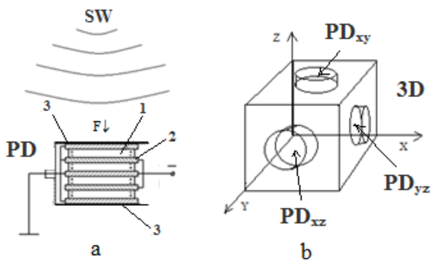

Fig. 3. Design of a single-dimensional PD (a) and 3D-dimensional (b) piezoelectric detectors: 1–piezoelectric plates; 2–foil layers, 3– insulating layers; PD_{XY}, PD_{XZ} and PD_{YZ} are piezoelements allocated on the *XY*, *XZ*, and *YZ* planes, correspondingly; SW- seismic wave.

Seismic waves impact the surface of the PD, pressures on piezoelectric plates, and, as result, an electric signal is generated. To precisely analyze the space location of the seismic wave source, three single-coordinate PD are collected in integrated construction, which is the 3D detector. Here, three single-coordinate piezoelectric detectors PD_{xy}, PD_{xz}, and PD_{yz} are located on three orthogonally related planes XY, XZ, and YZ (sides of the cube) (Fig. 3b).

Then, three 3D detectors are collected in one cell-receiver construction SWC (Seismic Waves Cell) (Fig. 4), information recorded by three 3D detectors is sufficient to determine the location of object.

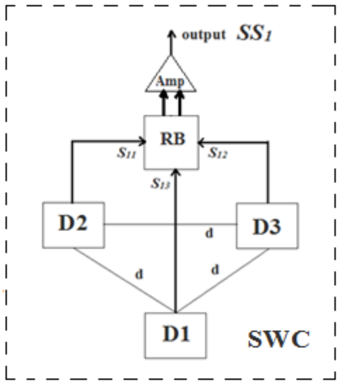

Fig. 4. The chart of the Seismic Waves Cell (SWC). D1, D2, D3 – 3D seismic detectors; RB - receiving box; Amp – amplifier; d – distance between detectors (base of SWC).

Mounted in the subsurface soil layer at a depth of 20-50 cm, the sensitive elements of 3D detectors convert seismic vibrations into electric signals, which are transferred to the input of the registration block RB. The distance between the 3D detectors in cell (a base) is d = 7 m. The output signals from the 3D detector can be expressed as $S = f(X,Y,Z)$. Output signals from the three 3D detectors in one cell can be expressed as:

$$S_1 = f(X_1, Y_1, Z_1)$$
$$S_2 = f(X_2, Y_2, Z_2)$$
$$S_3 = f(X_3, Y_3, Z_3)$$

These signals input into a registration block RB, are amplified and form output signals SS_i:

$$SS_i = F(S_{i1}, S_{i2}, S_{i3})$$

To locate a target, the following scheme was employed: the location of target is determined by the directional angles to a target from two spatially separated triangular cells (Fig. 5). The point of intersection of the two lines defined by the directional angles is the estimated location of the target. Triangulation determines the two coordinates required for the location. The directional angles are determined from the data received at the reference array.

In the current case, we have *n* mounted SWC which reveals a high coordinate accuracy of the target location.

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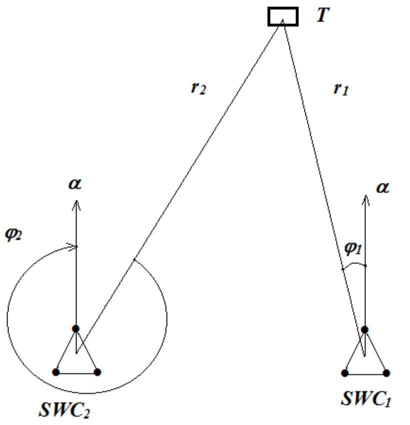

Fig. 5. The determination of the target location by triangulation: r_1 and r_2 are distances to target T; α is a reference direction; φ_1 and φ_2 are directional angles.

3. Seismic Location Station

$SS_1, SS_2, \ldots SS_n$ signals from n SWC cells of the seismic location station input to analyzing block AB (Fig. 6). In addition, block AB analysis *ASS* signals from the acoustic system AS in anticoincidence regime that eliminates false signals from aircraft or helicopters (fig. 7). Depending on a given task, climate and environmental conditions, a number of SWC (n), the width of the seismic location station (a base) can be (50-100)m.

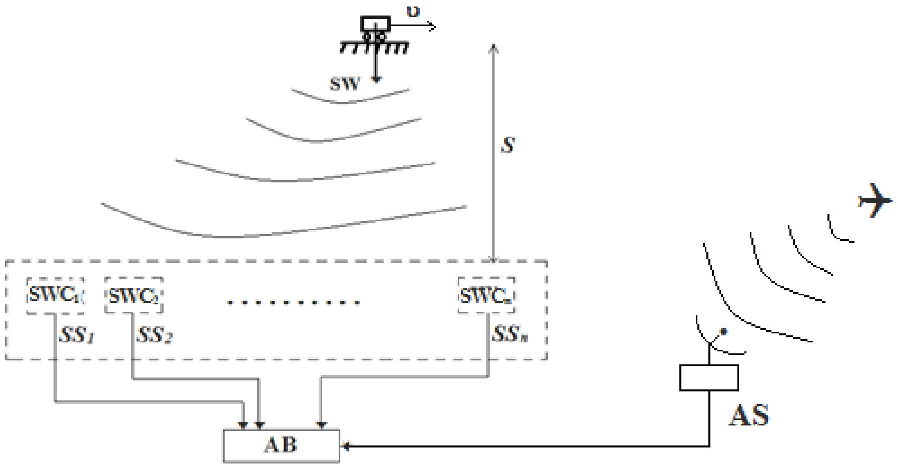

Fig. 6. Seismic location station SLS. SWC$_i$ - seismic waves cells; SS_i – output signals from SW$_i$; SW – seismic waves from moving truck; υ - velocity of truck; S – distance to moving truck-target; AB - analyzing block; AS-acoustic system.

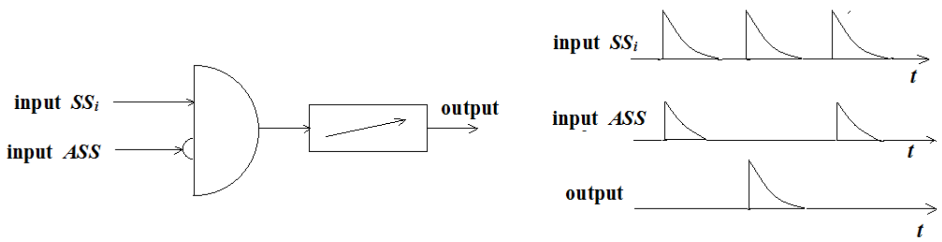

Fig. 7. Anticoincidence circuit.

The geometric configuration of the seismic location station SLS was developed to the greatest extent possible to increase its sensitivity to exactly locate remote moving objects, define the path trajectory, and speed of movement.

To classify discovered moving objects, SS_i signals in the AB block are compared with calibrating signals obtained from the database. These calibrating signals are obtained for various kind of moving, heavy military trucks (tanks, combat vehicles) at various meteorology conditions (hot or cold weather, rain, snow) for various soils, and for various distances (300 - 2000 m). The speed of seismic wave spread υ depends on the properties of the soil and weather conditions and ranges from 90 to 250 m/sec. Considering the mountainous highlands, we have

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υ=220 m/sec. Therefore, to increase the measurement accuracy of coordinates, speed, trajectory, and type of target the next chain of solutions was employed very sensitivity piezoelectric sensors (Fig. 8)

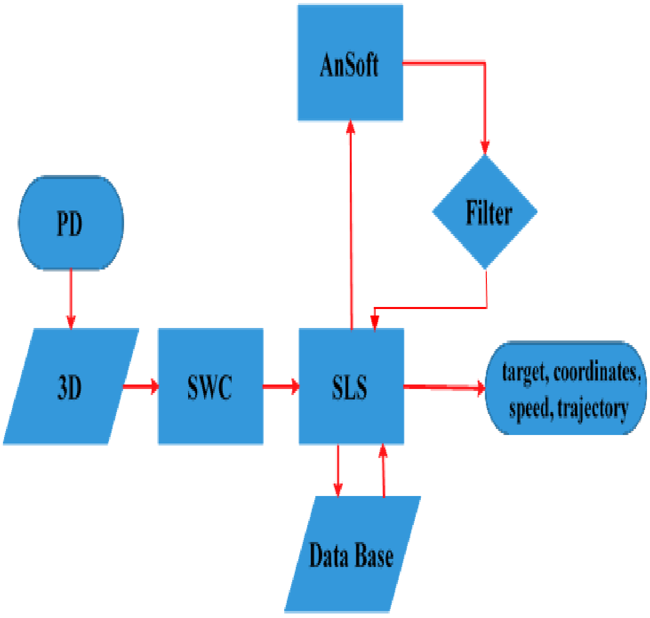

Fig. 8. Solution plan to detect unobserved moving military trucks.

SWC – special geometric configuration of seismic location station
SLS – special analyzing software
AnSoft – filtration false signals
Filter – database of seismic signals of moving heavy trucks
Data Base. This solution set provides the efficiency of the seismic station.
PD and three-coordinated forms
3D – triangular configuration of seismic detectors

4. Conclusion

This paper presents the results of the development of a seismic location station with special geometry. The development of seismic wave cells based on the 3D seismic detectors is presented. A solution plan to detect unobserved, moving military trucks is offered.

It can detect coordinates, speed, trajectory, and type of unobserved, moving, heavy military trucks at a distance of 1-2 kilometers from the station. The seismic station has been developed based on 3D seismic detectors. Seismic detectors are high sensible piezoelectric transducers including polymer hybrid piezoelectric PVDF+$BaTiO_3$+PZT composites based on nano sized $BaTiO_3$, SiO_2 and micro sized PZT piezomaterials. Polyvinylidene fluoride is used as a polymer filler.

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