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Seismic Sensors Communication

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Abstract:

*The presented paper deals with the possibilities, characteristics and useable properties of seismic-acoustic communication in the group of nodes, supplementing the information coverage of existing **U**nattended **G**round **S**ensors – UGS, including the selection of a suitable working frequency band for seismic communication. The conclusion of the paper generalizes the results of seismic-acoustic communication as verified in practice, and describes the advantages and disadvantages of communication channels defined in this way. In addition, the paper includes illustrative photographs of the practical design and graphic results of real measurements.*

Keywords:

Seismic detection, unattended ground sensor, seismic communication, remote sensing

1. Introduction

The field-end UGS that are currently used and described in the literature usually communicate with Intelligent Gateway through two-way secure communication. If, however, a higher coverage of the area of interest is required, the number of UGS must be increased accordingly, which is associated with the risk of being detected by enemy EW-SIGINT systems because of denser RF operation. An increase in the coverage of area of interest whilst simultaneously maintaining a reasonable number of UGS installations is possible provided that the existing UGS are supplemented with a group of supporting passive sensors – nodes that communicate with UGS via signals of seismic surface waves. This principle can be applied since each UGS is, as standard, equipped with a geophone; therefore, it is also able to receive data signals from supporting nodes without problems.

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The main advantage of nodes conceived in this way using seismic communication is the opportunity to have them installed completely underground without the giveaway sign of a visible antenna, thus reducing the risk of their potential detection by the enemy

2. Features of UGS in Use

At the present time, there are several types of passive reconnaissance systems to which various UGS can be connected. Apart from the seismic, magnetic, passive infrared and acoustic sensors used as a standard, hydro-acoustic, chemical, optical and other sensors can also be connected to some systems, thereby significantly extending the capacities of the current reconnaissance systems. Besides their basic function – to detect the presence of the object in question – a number of UGS are able to identify the type of object and to effectively suppress false detections of objects caused, for example, by movements of animals, weather effects, etc. The detection and classification data analysed from individual sensors located within an area are usually transferred via a duplex, data-protected radio channel to the parent unit – gateway. The gateway unit is currently understood as a highly sophisticated device which enables the transfer of data to almost all available platforms, such as Iridium, GSM Cell phones, FleetSat, Orbcomm, HF-1000, PRC-137F, ViaSat TDL, Globalstar, EPLRS UHF radio and others. As a standard feature, one gateway facilitates the operation of multiples of selected types of UGS. The gateway is frequently designed as a part of the Future Combat System – FCS network.

After the installation of UGS, it follows that it is useful to check the basic detection range and quality of the radio connection to the parent gateway. In practice, there are often conflicting requirements as regards the location of the installation. A railway embankment can be an example, where it is more suitable to locate the UGS on one side of the embankment with regard to the maximum detection range of the magnetic sensor, but in relation to radio connection, the UGS location on the other side of the embankment proves more advantageous. Generally, UGS are installed in the concealed field locations and the situation can occur where a snow storm covers the radiation parts of the antenna and the radio communication range is reduced. Particularly adverse climatic conditions are the cause of serious problems, which can also occur in situations where UGS are operated within small self-organizing radio networks.

A possible solution for short transmission routes is utilization of seismic communication between individual UGS. The configuration for a general reconnaissance system as discussed is given in Fig.1 [1-5].

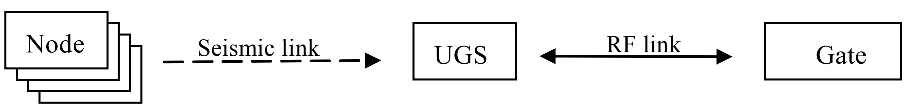

Fig. 1 Possible configuration of a passive reconnaissance means

3. Node-UGS Seismic Communication

The UGS is able to communicate with the parent gateway. To reduce the volume of radio communication or the number of UGS installed, we will supplement the standard UGS with other elementary sensors – **nodes**, which will communicate with their parent UGS. As the UGS is normally equipped with a geophone, there is the possibility for node communication via seismic surface waves, which the UGS is able to measure, process and analyze without any problem. For an illustration of the signals, Fig. 2 gives a spectrogram of signals from seismic surface waves which contains records of a passing car, the movement of a person and the flight of a propeller-driven aircraft at low level.

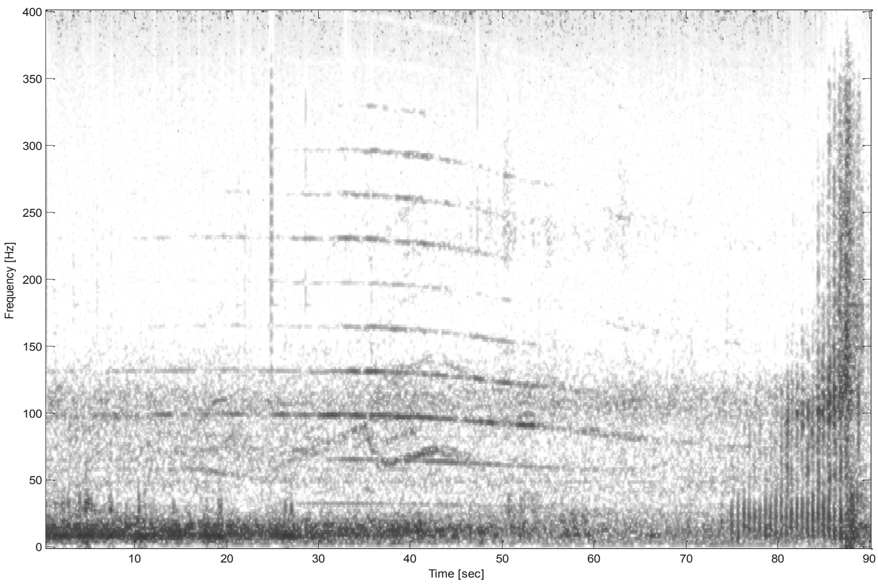

Fig. 2 Record of seismic signal for various sources

Fig. 2 shows that most ground targets – persons, tracked or wheeled vehicles – can be detected in a frequency band of 15 Hz to 100 Hz. Aircraft and helicopters flying at low levels display a large number of harmonic components, up to values of several hundreds of hertz, but their basic frequency is found within the band of interest from 15 Hz to 100 Hz, where there is also a noticeably distinct shift due to the Doppler effect. The lower frequency band of signals processed is normally limited to 10 Hz to 15 Hz, not only due to the reduced sensitivity of the geophone below its resonance frequency which, for the requirements of the UGS, moves at values of from 6 Hz to 15 Hz, but mainly due to suppression of the natural seismic background disturbance. The seismic background disturbance may have a natural character (short micro-seismic effects, remote earthquakes, vibration of forest growth, wind blasts, rain, etc.) or it may be caused by human activity (factory operation, noise of service pipelines, traffic on remote roads, etc.).

To generate communication signals of interest through seismic surface waves, artificially generated by individual nodes, it is possible to use a small electric motor with a material body fixed eccentrically. For practical purposes, numerous vibration motors are available and they are most often divided by their mechanical design into cylindrical and coin ones.

To check the possibility of data transfer via signals of seismic surface waves, a gauging fixture was constructed with three types of vibration motors inside. The catalogue data for these motors are shown in Table 1.

Tab. 1. Specified characteristics of vibration motors used

Model	Size [mm]	Speed [rev/min]	Operating voltage [V]	Operating current [mA]	Type	Weight [g]
Z4NC1A159	4.7 × 6.2	10000	1.3	120	Cylindrical	1.2
Z6CH1A008	20.8 × 8	7500	1.3	150	Cylindrical	2.8
RVN10004D	10 × 4	8000	3.0	80	Coin	1.5

Vibration motors operating at different speeds were chosen deliberately so that they could be distinguished at the frequency level. The claimed frequency values were 166 Hz, 133 Hz and 125 Hz, i.e. the specified values exceed the 100 Hz value which is of concern.

All the above types of vibration motors were fixed mechanically in a plastic insert. The plastic insert may be fixed inside a standard geophone housing, PE-3/C type, in the both vertical and horizontal planes. All the vibration motors in the plastic insert were fixed with identical orientation of vibration direction. The supply to the vibration motors was made by primary cells with voltage stabilizers of 1.5 V and 3 V. The appearance of the insert design with the fixing of motors prior to encasement is given in Fig. 3.

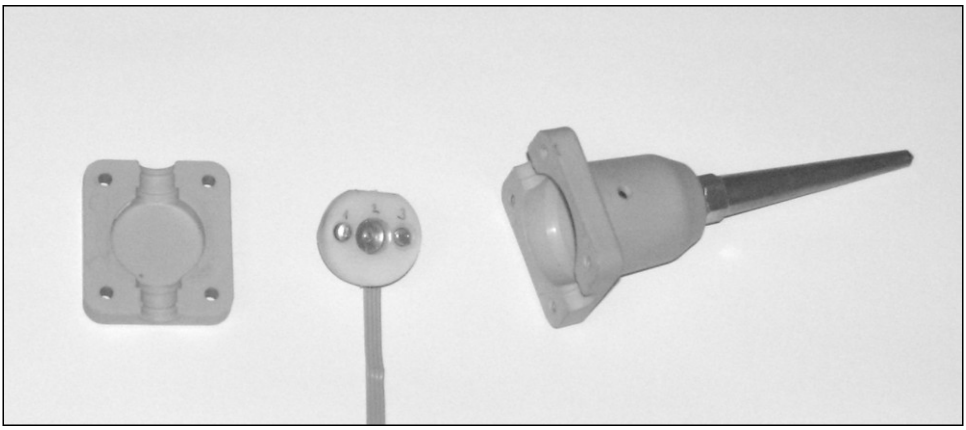

Fig.3 Photograph of mounting of three different types of vibration motors in the PE-3/C housing

The operation was tested under true winter conditions. At the time of the measurement, the air temperature was minus 11 °C, and the surface was covered with a layer of frozen snow, 25 cm deep. Although the soil was partially frozen, it was possible to install both the geophone and the housing with vibration motors without problem. The vibration motors were located both vertically and horizontally. A record for distances (10, 20 and 30 metres) was recorded between the geophone and the housing with vibration motors and for both vibration direction orientations. The record of signals of seismic surface waves was performed using a standard geophone SM-6 with a natural frequency value of 4.5 Hz connected with an amplifier with a constant voltage gain of 82 dB in the frequency band from 3 Hz to 1 kHz. The signals were recorded onto a digital recorder Tascam DR-1 with a sampling frequency of 44 kHz. A photograph of the measurement point is given in Fig. 4.

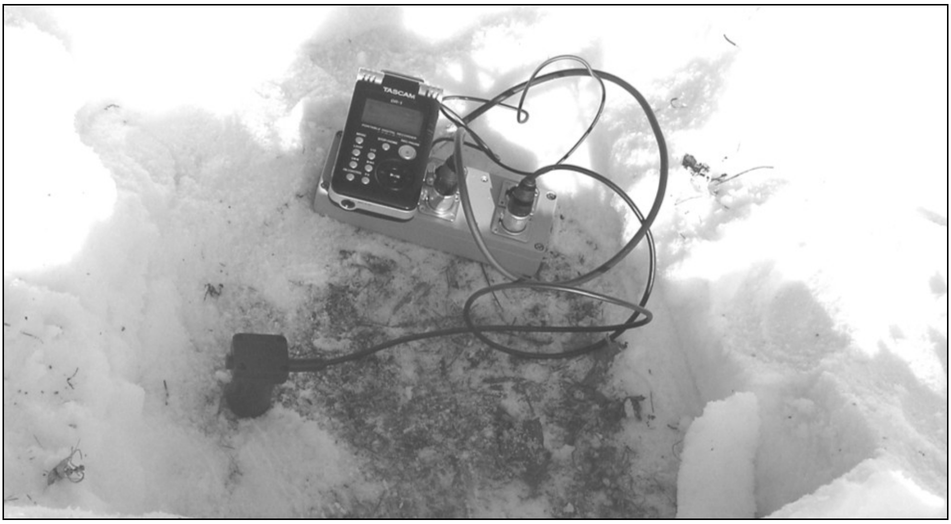

Fig. 4 Photograph of measurement point (SM-6 geophone, amplifier, DR-1 recorder)

Fig. 5 gives a spectrogram of the record of signals of seismic surface waves for the vertical vibration direction orientation. The individual vibration motors were switched on at intervals at the individual distances. It can be deduced from the spectrogram that the mean frequency values are 155 Hz, 165 Hz and 180 Hz for the individual vibration motors, values which correspond approximately to those specified by their manufacturers. On the other hand, it appeared that the vibration speed value for cylindrical test motors was not constant over time, even when a stabilized source of supply voltage was used. The problem of constant speed did not occur in the flat type of vibration motor, which is of a brushless design with electronic speed control. It may also be deduced from the spectrogram that the signal of seismic surface waves was detectable up to a distance of approximately 20 metres, beyond which its effectivity fades.

Fig. 6 gives a spectrogram of records of seismic surface wave signals for the horizontal vibration direction orientation. In this case, it may be stated that the signal of seismic surface waves is detectable only up to a distance of 10 to 12 metres, which is in compliance with the theory and characteristics of Rayleigh surface waves whose maximum mechanical energy is oriented in the vertical plane.

Fig. 7 gives a spectrogram of records of seismic surface wave signals for the vertical vibration direction orientation and for a combination of vibration motors activated simultaneously. This record was made and tested, in particular, to determine whether a combination of several vibration motors with different speed values operating simultaneously could be used for data transfer between the node and UGS. The answer is affirmative, on condition that the frequency bands are at a distance of at least 10 to 15 Hz from one another, but at the expense of utilising a greater number of vibration motors, which, however, will probably not be practicable. Not maintaining the due frequency spacing can be seen in the record in Fig. 4 at the time of the 25th and the 28th second, when two frequencies merge and are mutually non-distinguishable [6-8].

For the practical application of data transfer via the seismic channel, it is substantially more advantageous to use one vibration motor with electronic speed control and feedback stabilization added. This solution can be performed with an integrated micro-controller, using a multi-state discrete modulation, type Frequency Shift Keying – FSK. This demand, however, introduces the requirement for effective digital processing of seismic surface wave signals on the part of the UGS and the use of either several band-pass filters working in parallel or, for preference, FFT with a sufficiently high frequency resolution. In this case, it is possible to select 4 to 6 independent frequency bands. It must be stated that the weight of the vibration bodies of the motors used was only 0.5 g to 0.8 g. Due to this low weight, the leading edge of signals in the spectrograms is relatively steep; however, for a practical range under operating conditions, it will be necessary to increase the vibration energy appropriately so that the seismic surface wave signals are generated more efficiently. The measurement has demonstrated that the vertical location of vibration motors gives better results within the efficiency range, which is in compliance with the assumption.

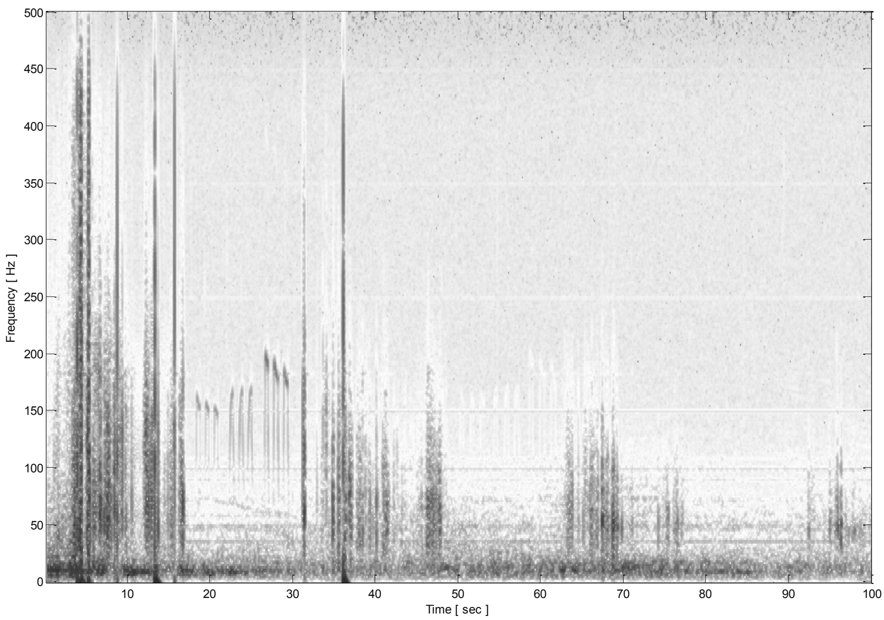

Fig. 5 Spectrogram of seismic surface wave signals, vertical orientation

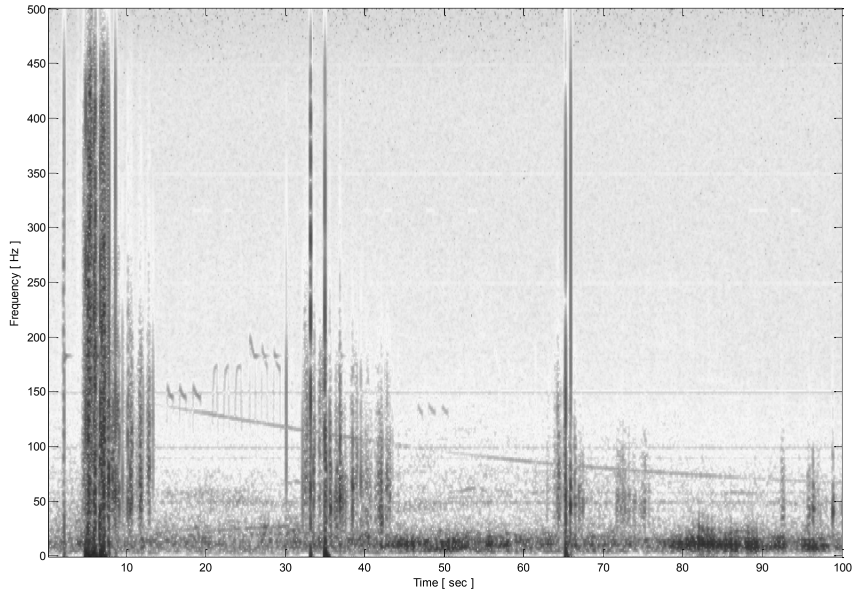

Fig. 6 Spectrogram of seismic surface wave signals, horizontal orientation

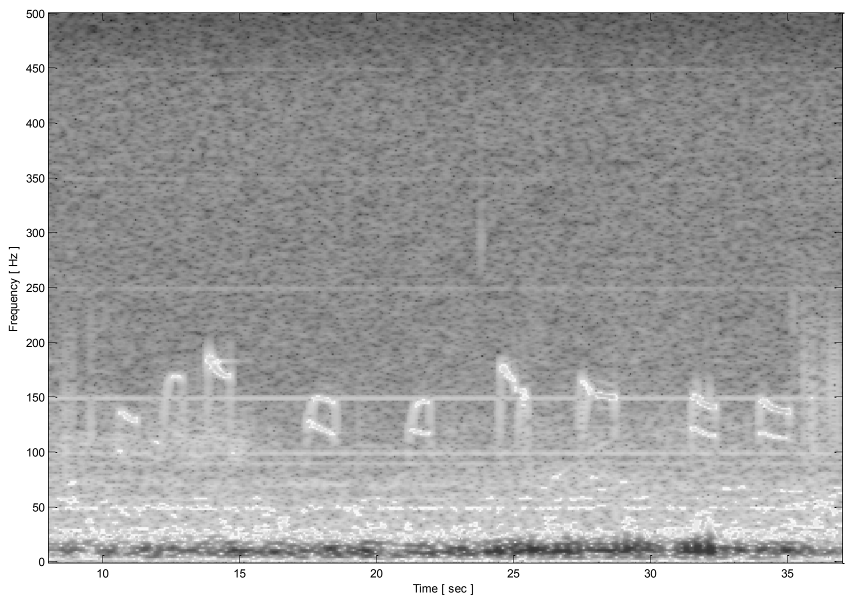

Fig. 7 Spectrogram of seismic surface wave signals, horizontal orientation, and combination of vibration motors switched on

The seismic communication channel cannot be detected or disturbed using common electronic combat means. In the acoustic range, the vibration motor run was not audible at the place of installation.

The measurement and analysis of seismic surface wave signals induced by the vibration of small vibration motors was performed independently in both summer and winter conditions to eliminate the effect of changes in the characteristics of seismic surface wave propagation for various types of subsoil, and the temperature and moisture of the soil. In relation to the range, both measurement results are, however, comparable, so it is possible to regard seismic communication in the node-UGS direction as an alternative meriting future attention.

4. Conclusion

In this contribution, the basic principle is dealt with for data transfer between the node and UGS for short distances. This principle guarantees data transfer under the conditions of substantial snow cover, non-existence of direct radio visibility and the possibility of full disguise of the individual parts of the system. Technically, seismic communication is easily realizable on the transmitting side by supplementing the node with a suitable vibration motor, on the receiving side it is only necessary to modify software for the processing of signals from the geophone and other hardware modifications are less necessary. In practice, a range of 12 metres has been achieved for a vibration weight of 0.8 g. This range can be increased by using a vibration element of a greater weight.

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