Comparative analysis of object shadows obtained by GPS and sound signals

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Abstract— The paper explores the shadows created by moving humans in two types of Forward Scatter (FS) systems, which use GPS signals and sound signals. The comparative analysis of results is based on the correlation analysis and focused on establishing of relationships between different types of shadows. The results show whether it is possible to use sound barriers for detection of moving objects.

Keywords—Signal processing; target shadow detection; Forward Scatter radar;

I. INTRODUCTION

The article is based on the theory of distribution of electromagnetic and sound waves in the airspace and their interaction with moving objects. In our study, receivers and transmitters are located at different positions in the space and form the bistatic system. When the object moves close to the virtual line between the receiver and the transmitter it creates the Forward Scatter (FS) effect, which is the basis of these studies [1-3]. In this article, the two considered FS systems transmit and receive signals, which are different in structure, and the physics of their distribution in the air space is different.

GPS signals are electromagnetic waves, and sound waves are mechanical waves. Both types of signals differ in the speed of their distribution and frequency of repetition, but the wavelength in both types of signals is chosen comparable. Our hypothesis is that the strength of the received signals, i.e. shadows created by moving humans crossing bistatic FS GPS or FS sound barriers, are similar in the area of diffraction.

This is possible only in case of selecting the same experimental conditions in the area of diffraction. In both cases, we have satisfied the conditions of occurrence of the FS effect in the area of diffraction. It means that the conditions of the experiment are consistent with the frequency of the received signals, the object's size and also the distance to the object from the receiver and the transmitter. In this article, the correlation analysis of the received signals is used to assess the closeness of the nature of the signals from the shadows, obtained from FS GPS and sound systems, and as well as the distance "receiver - moving person" at the moment of crossing the FS GPS or sound barrier

II. DIFRACTION AND PRINCIPLES OF FSR

Diffraction of wave can be divided into 3 regions (Fig. 1): 1) region of deep shadow (shadow zone), region of Fresnel diffraction (when the target is close to the transmitter or the receiver) and region of Fraunhofer diffraction (when the target is far from the transmitter and the receiver) [4, 5].

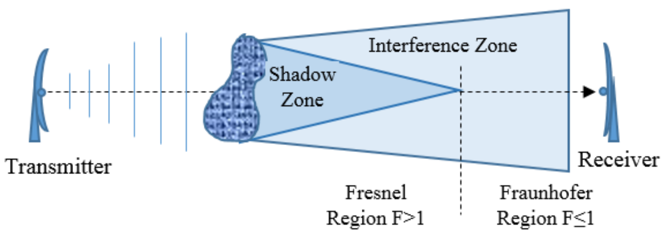

Fig. 1. Regions of diffraction

In Fresnel diffraction, the size of the target is comparable with the Fresnel zones, which takes place when the target is relatively close to the receiver or the transmitter. Here, the diffraction pattern varies from high intensities to low intensities as the targets cross different Fresnel zones. These variations will depend on the coverage percentage of one or more Fresnel zones. The parameter used to determine whether the target is in the Fresnel or Fraunhofer zone is defined as:

$$F = \frac{a^2}{D_r \lambda} \quad (1)$$

If $F << 1$, then the Fraunhofer diffraction is considered. On the contrary, when $F \geq 1$, the Fresnel diffraction dominates. In (1), a is the greatest dimension of the target, D_r is the distance to the receiver or the transmitter and λ is the wavelength of the signal. (Fig.1).

$$\lambda = \frac{v}{f} \qquad (2)$$

In (2), v is the velocity of electromagnetic waves (3.10^8m/s) or sound waves (333 m/s in the air space), f is the frequency of electromagnetic waves (1575.42 GHz – for L1 GPS signal) or sound waves (1, 3, 5 KHz).

III. Experimental Description

In this experimental study, the GPS L1-based recording system consists of two types of GPS receivers. The first GPS receiver (Antaris AEK-4R) is used to determine the location of the satellites over the horizon, while the other software GPS recording system (GNSS_SDR) is used to record and store GPS signals from different targets (Fig. 2).

Fig. 2. GPS experimental equipment

The GPS receiver GNSS_SDR is proposed and developed in the Aerospace Department of the Colorado University, USA [5]. This recording system receives and records the raw GPS data flow using the small commercial GPS antenna and the USB-based device. The recorded GPS signals are saved as binary files in the computer memory. The acoustic system consists of the sound transmitter that operates at a certain frequency and the sound recording system with the Wildtronics parabolic microphone (Fig. 3).

GPS signals and sound signals have been recorded during the experiments with the same scenario. The GPS receiver and the parabolic microphone are located at one and the same position and directed in one and the same direction. When choosing the distances between receivers and moving people crossing the FS GPS and FS sound barriers, we have chosen such distances, which satisfy the conditions for the occurrence of the deep shadow in the area of diffraction. It means that the conditions of the experiment are consistent in both cases with the frequency of the received signals, the size of the target and distances "receiver - object" and "object-transmitter" in the case of the sound barrier. For that reason, the sound generator is positioned at six meters from the microphone. During the experiments, three men pass consistently in time in front of the GPS receiver and the microphone at distances of 1.5 m., 3 m. and 4 m, respectively.

Fig. 3. Sound recording system

This means that during the experiments all men cross the baselines "transmitter-receiver" of both systems, GPS and acoustic (Fig. 4).

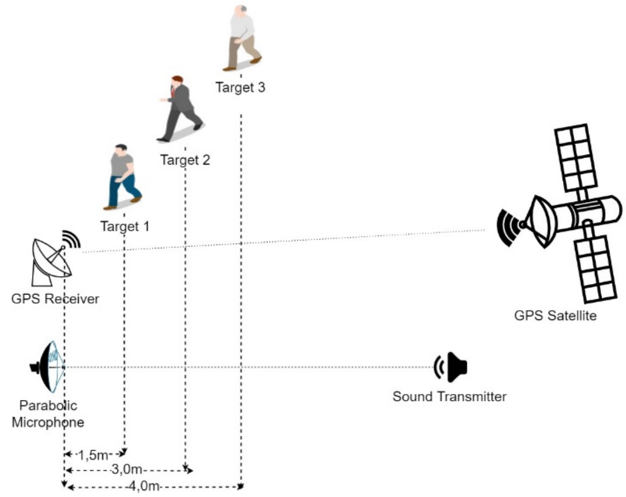

Fig. 4. Experiment topology

IV. Experimental Results

The experimental results are obtained in the zone of deep shadow. The wavelength of the carrier signal emitted by GPS satellites is $\lambda = 0.19$ m – for the L1 C/A signal.

A. GPS shadow

During the experiments, GPS satellites are located as shown in Fig. 5.

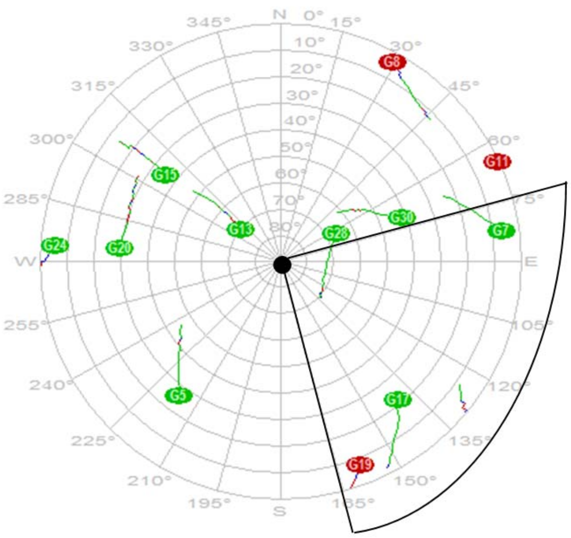

Fig. 5. Satellites position

As shown in Fig. 5, the most appropriate satellites for observation of deep shadows are with numbers 7 and 19. The results, obtained after the processing of GPS signals from these satellites, are shown in Fig 6. As can be easy seen, the three men have created three radio shadows with similar shapes and parameters. These shadows can be used to detect moving humans.

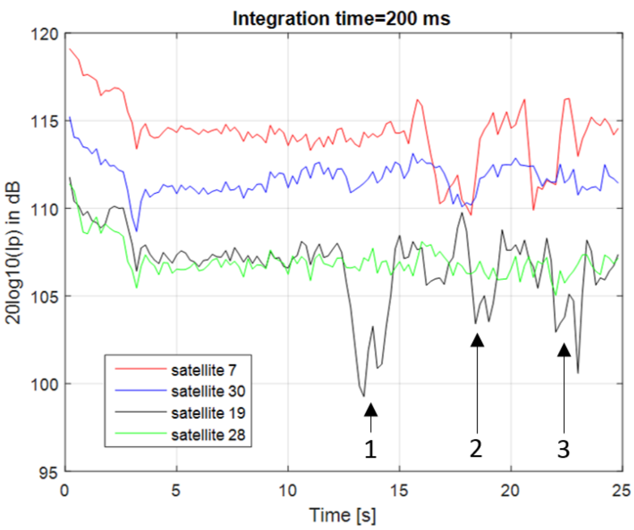

Fig. 6. GPS shadow from 3 mouving man

B. Sound shadow

By using the same topology of the experiment, but by recording the sound signal generated at frequency of 1 KHz and by applying the appropriate signal processing we obtained the results shown in Fig. 7.

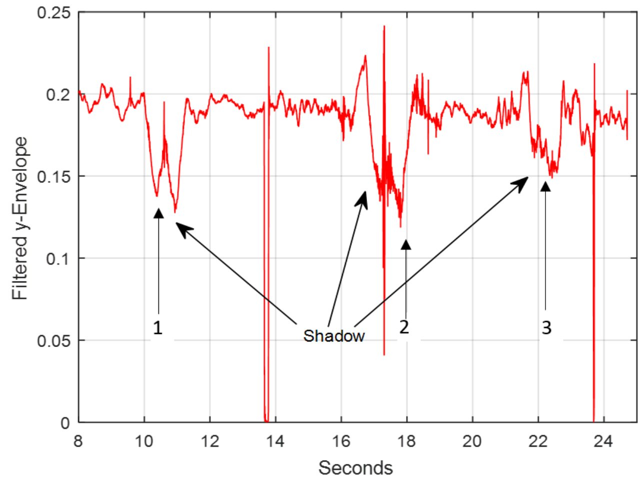

Fig. 7. Sound shadow from 3 mouving man (f = 1 KHz)

Like the experiment with GPS signals, the three men crossing the baseline "transmitter- receiver" also have created the sound shadows in the acoustic system.

As can be seen from Fig. 6 and Fig. 7, the signals from the shadows of one and the same targets moving at one and the same distances, obtained in result of recording by two different FS GPS and FS sound systems, are very similar.

C. Experimental results desription

The recordings of sound and GPS signals that contain shadows from moving people are made as it is described in section 2. The number of GPS records is 5, and each record contains shadows formed by 2 satellites. The number of sound recordings obtained at 1 KHz is 10, at 3 KHz is 8, and at 5 KHz is 7.

D. Comperativ analysis of object shadows obtained by GPS and sound signals

In this article the correlation analysis of the received signals containing the shadows is used to assess the closeness of the nature of shadows, obtained by FS GPS and sound systems, in MATLAB. The calculated correlation coefficients are used to show the similarity between different types of signals from the shadows regardless of the nature of their transmission and the distance to the object, which crosses the FS GPS or sound barrier.

The correlation coefficients between shadows of people moving in GPS and sound range are shown in Table. 1. The correlation coefficients for sound are obtained at three frequencies (1 KHz, 3 KHz and 5 KHz). The correlation coefficients are calculated between shadows 1 & 2, 2 & 3, 1 & 3, as shown in Fig. 6 and 7. All correlation coefficients in Table 1 are obtained after averaging of all correlation coefficients obtained for all possible combinations.

In Table 1, the results are obtained only by averaging separately the obtained correlation coefficients in the sound and GPS ranges. For 1 KHz, 10 averagings are performed, for 3 KHz, 8 averagings are performed, and for 5 KHz, 7 averagings are performed. For GPS signals, 10 averagings are performed. From Table. 1 follows that the obtained correlation coefficients have very close values.

TABLE I. SOUND AND GPS CORRELATION COEFFICIENT BETWEEN TARGET SHADOWS

Signals	Frequency	Correlation coefficient between target shadows		
		1 & 2	2 & 3	1 & 3
Sound	1 KHz	0.75	0.66	0.76
	3 KHz	0.62	0.63	0.56
	5 KHz	0.79	0.81	0.67
GPS	1575.42GHz	0.69	0.56	0.65

From Table. 1 it can be seen that there is correlation (similarity) between the shadows in the sound and the GPS ranges. High values of correlation coefficients indicate that there is a high degree of closeness between the three shadow types. This is because they are formed from physical objects of the same type (human) of similar size (height, weight). Differences in values of correlation coefficients indicate that shadows are sensitive to differences in people's parameters.

To confirm our hypothesis that the phenomenon of diffraction does not depend on the physical nature of the shadow, the mutual correlation coefficients between acoustic and GPS signals in the shadow area are calculated. In this article, we calculate the correlation coefficients between sound signals for each of the tested ranges (1 KHz, 3 KHz and 5 KHz) and GPS signals in the shadow area (Fig. 1).

These correlation coefficients calculated between GPS and sound shadows with numbers 1 & 1, 2 & 2, 3 & 3 are given in Table 2. The correlation coefficients in Table 2 are obtained after pre-treatment. The average value is obtained according to the following scheme. For 1KHz, 3KHz and 5KHz sound ranges, we have calculated the correlation coefficients after averaging of 100, 80 and 70 calculated correlation coefficients between sound and GPS records.

TABLE II. CORRELATION COEFFICIENT BETWEEN SOUND AND GPS TARGET SHADOWS

Sound Frequency	Correlation coefficient between sound and GPS shadows		
	1 & 1	2 & 2	3 & 3
1 KHz	0.71	0.59	0.53
3 KHz	0.63	0.59	0.57
5 KHz	0.61	0.51	0.54

The values in Table. 2 show that there is a correlation (similarity) between shadows in the sound and GPS ranges. The correlation coefficients have the lower values than those shown in Table. 1. This is due to the difference in the physical nature of the signal. In one case, the shadows are formed by GPS signals and, in the other case, by sound signals. Nevertheless, it can be argued that there is a great deal of proximity between shadows formed by GPS signals and sound signals. This shows that the diffraction phenomenon does not depend on the physical nature of the signal forming the shadow from the object.

V. CONCLUSIONS

In this article, the correlation coefficients are calculated between the sound and the GPS shadows obtained in the deep shadow area. The results of GPS and sound signals show that the phenomenon of diffraction does not depend on the physical nature of the signal (GPS signals or sound signals). This means that in case of sound signals the shadows of the objects resulting from the diffraction phenomenon can be used to detect the objects as it was demonstrated in case of GPS signals [4, 5].

ACKNOWLEDGEMENTS

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