Experimental Study of Moving Man Detection by Acoustic Forward Scattering Radar System

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ABSTRACT

The article explores the possibility of detection of people on the base of their sound shadow (sound blocking) when people cross the baseline in the Acoustic Forward Scatter Radar System (AFSRS). Experimental sound shadows have been obtained from moving people crossing AFSRS at different sound frequencies and different distances of people to the receiver. The sound shadow parameters of moving people, i.e. length of target shadow and peak Signal-to-Noise Ratio have been evaluated. The algorithm under investigation can be applied to create a network of sound barriers.

KEYWORDS

Forward scattering, moving target, shadow effect, target detection

1 INTRODUCTION

The paper is based on the theory of distribution of sound waves in the airspace and their interaction with moving targets. In our study, receiver and transmitter form the bistatic system. When the target moves close to the virtual line between the receiver and the transmitter it creates the diffraction of the transmitted signal. In this configuration, the receiver signal is received as a result of the phenomenon of diffraction of sound signals. Depending on the distance of the object to the receiver, there are three diffractive zones, zone of geometrical shadow (deep shadow), Fresnel zone and Fraunhofer zone. In the zone of deep shadow, when the object crosses the virtual line "transmitter-receiver" at very close distances from the transmitter, the object blocks the transmitted signal and the received signal power sharply reduces due to the blocking of signal. In Fraunhofer zone, however, when the object crosses the virtual line "transmitter receiver" at very large distances from both, the transmitter and the receiver, the so-called Forward Scattering (FS) effect appears and the received signal power is strongly increases due to the FS effect [1–3]. This effect has been studied by many scientists and it is the basis for the creation of different radio barrier systems. In [4], the authors used GSM signals to detect targets. In [5–11], GPS signals have been applied to detect moving targets using the principles of FSR. In [12], the authors proposed the usage of WiFi to detect moving targets by FS principles. Most of proposed technologies are used the principles of FS configuration or split receiver and transmitter and an object passing between them. In [13] are given the normal mode model for a waveguide to analyze the phenomena of forward scattering created by a target crossing the virtual line "transmitter-receiver", and its physical significance. The experimental results demonstrated the capability of forward scattering detection for slow moving objects.

The diffraction of the sound signals is a well-studied phenomenon and it is similar to the diffraction of the electromagnetic signals. Despite the difference in the nature of the radio and acoustic signals, the shadow effect is present in both types of signals [14]. The sound shadow from an obstacle on the road to the sound signal is usually used in the practice for making sound barriers on roads to protect people from the noise of moving cars.

The idea of this article is to use the sound shadow to detect moving objects crossing the virtual line between the sound transmitter and the sound receiver.

Such studies have been conducted by the team of this article but with GPS signals, which demonstrated the great potential in this field [5–11]. The purpose of this article is to apply the accumulated knowledge and skills from the field of radio signals in the field of sound signals and as a result to develop algorithms for detecting mobile targets using the sound shadows created by the targets. In this article, one possible algorithm for moving people shadow detection is studied by using the acoustic forward scattering effect. The parameters of sound shadows created by moving people, i.e. the shadow length and the peak SNR, are also evaluated.

2 FORWARD SCATTERING SYSTEM AND SOUND SIGNAL PROCESSING

Forward scattering system is a special case of bistatic configuration where the bistatic angle is close to 180 degrees. The bistatic angle is the angle between transmitter, target and receiver, as shown in Fig.1.

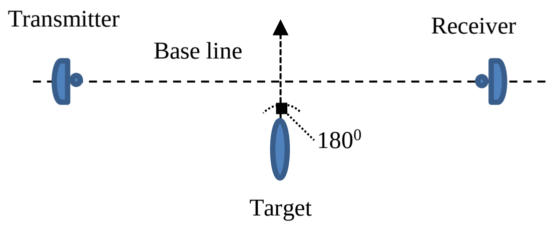


Figure 1: Illustration for forward scattering configuration.

Sound waves are affected by the different targets that they come into contact with. For example, denser materials are better at absorbing sounds than thinner ones. Although materials can absorb sounds, they can also reflect and diffract them. Diffraction of a sound is when the wave gets to an object and propagates around it. The phenomenon of diffraction is the basis of the signal propagation in the in forward scattering system (Fig. 2).

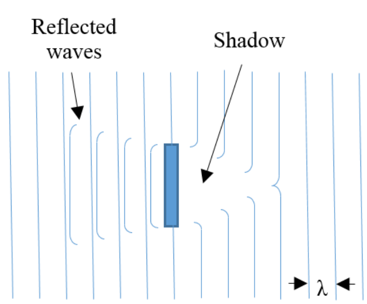


Figure 2: Sound diffraction.

Our first goal is to confirm the possibility of signal blocking caused by moving people crossing the baseline in the Acoustic Forward Scatter Radar System (AFSRS).
Naturally, to ensure the registration of sound shadows the values of the sound signal in the sound shadow zone must be distinct from the noise of the receiver by a few decibels. That's why we chose to make the recordings of sound signals on a variety of distances, when people are very close to the receiver and are in the sound shadow area. For the simplicity of the experiment, we chose the moving object to be man crossing the radio barrier.
For example, the limit distance of the sound shadow can be approximately evaluated as $2D^2/\lambda$ where D is the width of the human and λ is the sound wavelength. If the human width is 0.6 m then the limit distance of the sound shadow due to the human is 2.2 m for the sound frequency of 1 KHz, 6.5 m - for the sound frequency of 3 KHz and 11 m - for the frequency of 5 KHz.
The experimental records have been made at distances from the transmitter to the human which are less than the limit distances of the sound shadow for the chosen sound frequency.

3 SIGNAL PROCESSING

The signal processing in the Acoustic Forward Scatter Radar System includes: signal decimation and filtration, signal envelope evaluation, signal detection and signal parameter estimation (Fig. 3).

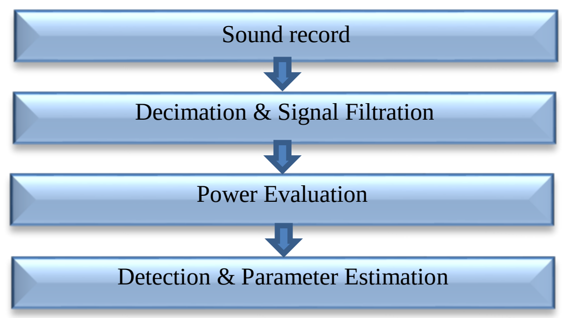


Figure 3: Blok-scheme of signal processing.

In this experiment, the sound receiver samples the received signals at the sampling rate of 40 KHz. Therefore, the received signal is firstly decimated and next filtered by the bandpass filter in order to remove undesired signals. The next step is evaluation of the signal envelope. For the convenience of detection, the signal envelope is inverted and further is used for signal detection and shadow parameter estimation.

4 DETECTION AND ESTIMATION OF PERSONNEL ACOUSTIC SHADOW

Our first goal is to confirm the possibility of signal blocking caused by moving people crossing the baseline in the Acoustic Forward Scatter Radar System. Our second goal is to confirm the likeness of the shadows in the Forward Scatter Radar system obtained regardless of the type of targets and regardless of the type and nature of the waves falling on the object, e/m or sound waves.
Naturally, to ensure the registration of sound shadows the values of the sound signal in the sound shadow zone must be distinct from the noise of the receiver by a few decibels. That's why we chose to make the recordings of sound signals on a variety of distances, when people are very close to the receiver and are in the sound shadow area. The audio recordings are pre-processed with the selected standard algorithm (Fig. 3), then the detection of shadows created by the moving people is performed by an operator (Fig. 4), by analyzing the changing of the envelope of the received signal. Because the detection is done in the shadow area, therefore we register the envelope "holes" (envelope blocking).
The registered sound shadows (for example, in Fig. 4) are characterized by the following parameters. Length of Target Shadow and Peak Signal-to Noise Ratio, and other. In our study only these sound shadow parameters are estimated.

4.1 Length of target shadow estimation

The length of a target shadow, obtained by the FS sound system can be approximately related to the physical size of the object and his speed. The length of the target shadow (dT) in seconds is estimated as:

$$dT = T_2 - T_1 \quad (1)$$

where T_1 and T_2 are the beginning and the end of the target shadow in the time domain.

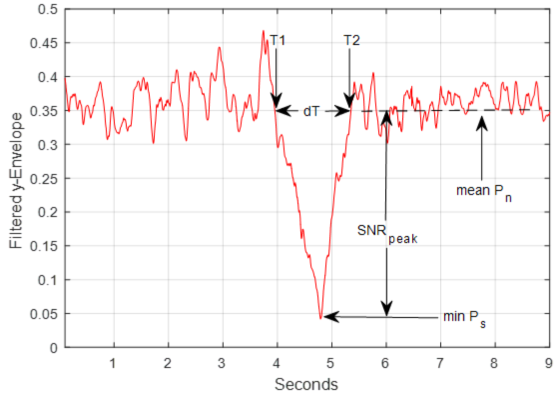


Figure 4: Shadow Parameters.

4.2 Peak Signal-to-Noise Ratio

The peak signal-to-noise ratio (SNR_{peak}) is estimated as the difference between the average noise power and minimal value of the radio shadow, found in the interval [T_1, T_2].

$$SNR_{peak} = mean(P_n) - \min(P_s) \quad (2)$$

where P_n is the noise power and P_s is the power of the target shadow.

4 EXPERIMENTAL RESULTS

During the experiments, three men pass consistently in time in front of the microphone at distances of 1.5 m., 3 m. and 4 m, respectively. When choosing the distances between receivers and moving people crossing the 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.

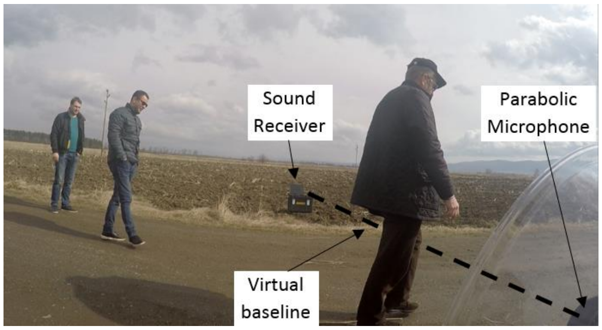


Figure 5: Sound recording system.

For that reason, the sound generator is positioned at six meters from the microphone. This means that during the experiments all men cross the baselines "transmitter-receiver" of acoustic system (Fig. 5).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. 6).

Figure 6: Wildtronics parabolic microphone.

The statistical data are collected at the sound frequencies of 1 KHz, 3 KHz and 5 KHz. The sound signal registrate at the sound frequency of 5 KHz when three people crossing the baseline between the transmitter and the receiver is shown in Fig.7. In this figure, it can be seen the areas with reduced signal power (signal blocking) of the received acoustic signal as a result of this crossing. The sound signal envelope is shown in Fig. 8, where the sound shadows due to the passage of people are clearly visible.

During the experiment, both the useful sound signal and other sounds and disturbances are recorded. The spectrum of the recorded signal is shown in Fig. 9, where it is seen that the recorded signal contains a predominant signal at frequency of 5 KHz, but the lower and higher frequencies are interfering.

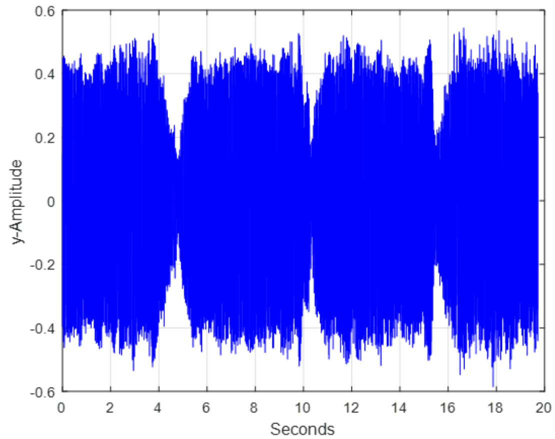


Figure 7: Sound record (5 KHz).

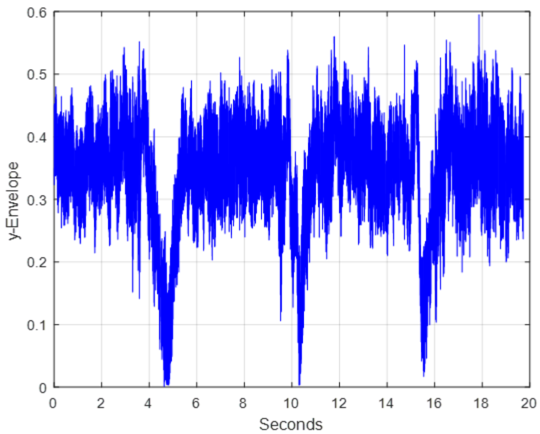


Figure 8: Envelope of sound signal (5 KHz).

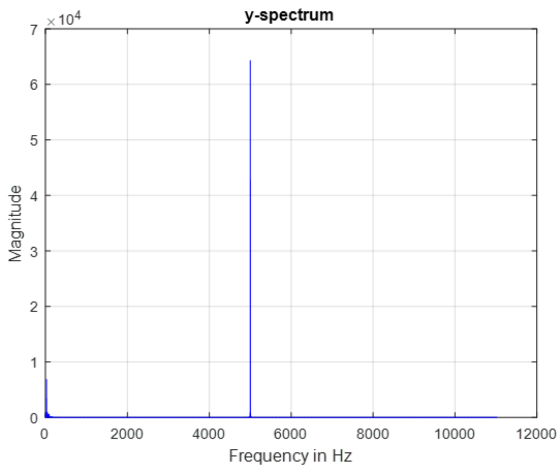


Figure 9: Spectrum of the recorded sound signal.

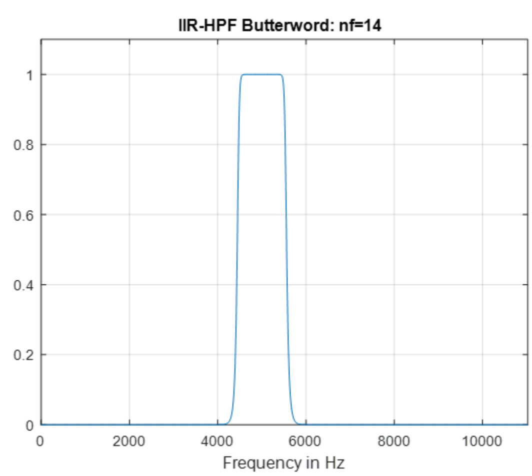


Figure 10: Frequency response of the bandpass filter.

Through filtering the sound signal with a filter, whose frequency response is shown in Fig. 10, only the sound signal at frequency of 5 KHz is omitted. The filtered sound signal is shown in Fig. 11. The filtered signal envelope is shown in Fig. 12. From Fig.11 can be seen that the sound shadows due to three passing men are distinct and well-shaped, with the similar form but different parameters.

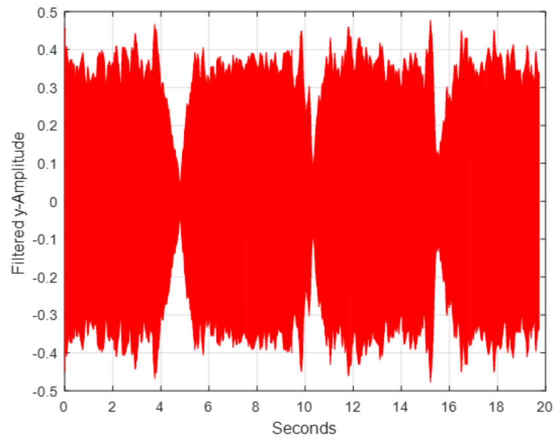


Figure 11: Filtered sound signal (5 KHz).

A signal envelope inversion is applied before signal detection. The inverted signal envelope is shown in Fig.13. From this figure can be seen that three sound shadows resulting from the crossing of three men the baseline between the receiver and the sound source can be detected.

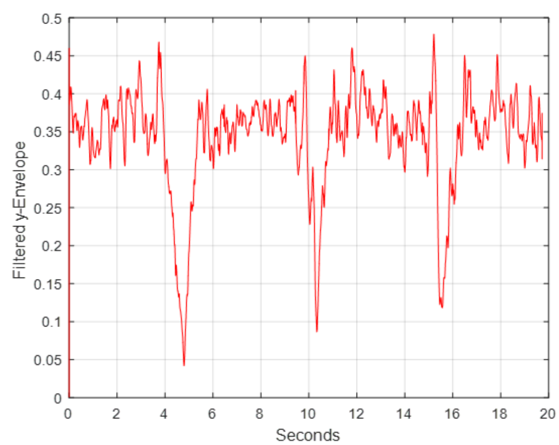
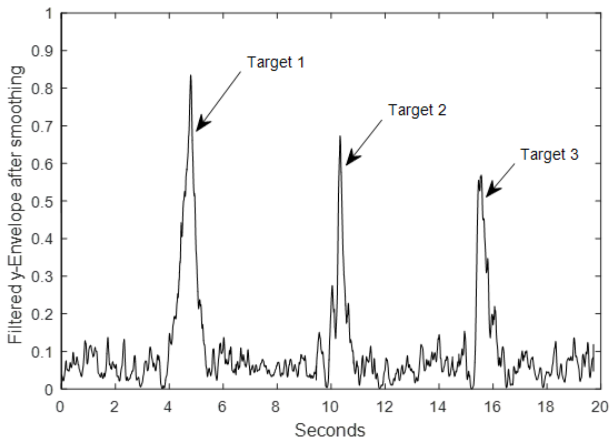


Figure 12: Filtered signal envelope.

Figure 13: Inverted signal envelope.



After the preliminary analysis of data, the filtered data has been statistically processed in order to calculate the statistical parameters of shadow parameters. The mathematical expectation of measured parameters has been calculated for each experiment (Table. 1).

Table 1: Mean parameters

Freq.	Target 1		Target 2		Target 3	
	dT	*SNR*	*dT*	*SNR*	*dT*	*SNR*
1KHz	1.49	0.36	1.67	0.32	1.49	0.29
3KHz	1.05	0.62	1.09	0.48	0.95	0.41
5KHz	0.87	0.81	0.89	0.61	0.84	0.49

One of the objectives of this statistical processing is the determination the influence of the sound frequency on the Forward Scatter effect of a moving man in the shadow area.
The other goal is to roughly estimate the sensitivity of the measurement method that we have chosen to obtain a shadow (Acoustic Forward Scatter Effect) by a moving man, depending on the increase in distance, for the needs of practice. In this case, we assume that the linear dimensions of three men participating in the experiment are similar.
The average values of the measured parameters (*dT* and *SNR*) for Target 1 at three different sound signal frequencies (1, 3 and 5 KHz) are shown in Fig. 14.
From Fig. 14 can be seen that the frequency of the sound signal influences on the Forward Scatter effect of a moving human in the shadow zone and therefore the sound frequency influences on shadow parameters. For a 1 KHz signal, the shadow is wider and shallower (lower SNR), and at 5 KHz the shadow is narrower and deeper (higher SNR). Mean values of the measured shadow parameters (*dT* and SNR) for the three targets (1, 2 and 3) at sound frequency of 5 KHz are shown in Fig. 15.

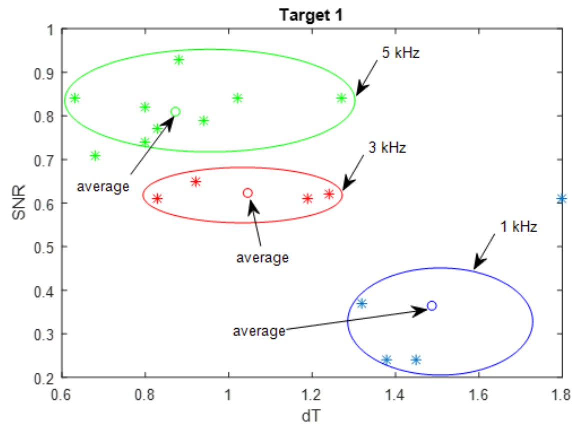


Figure 14: *SNRpeak*(*dT*)

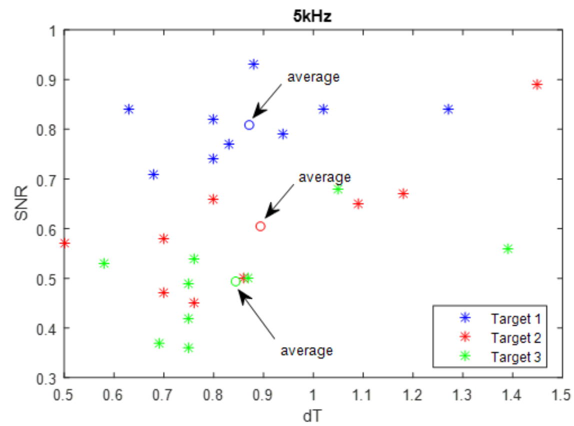


Figure 15: *SNRpeak*(*dT*)

From Figs. 14-15 and Table 1 can be seen that the selected method of shadow measurement using the Acoustic Forward Scatter Effect of a moving man is sensitive to increasing the distance between the man and the microphone. When this distance increases, the depth of sound shadow becomes smaller (lower SNR). The width of the sound shadows is approximately the same. It is not sensitive to changing the distance between the man and the microphone.

6 CONCLUSIONS

An algorithm for detecting and evaluating the parameters of moving people crossing the baseline in the Acoustic Forward Scatter Radar System is proposed in the article.
The experimental records have been made at distances from the transmitter to the human which are less than the limit distances of the sound shadow for the chosen sound frequency.
The limitation in our study was the power of the transmitted audio signal generated by the computer. That's why we limited ourselves to studying the deep shadow zone only (AFSRS).
From the results obtained, it can be seen that the low-frequency sound signal can be used to register the shadow of slowly moving objects - humans, in the near zone in the AFSRS.

Experimentally, it has been confirmed that the sound shadow in the ABFSRS depends on: sound signal frequency; Sound shadow depth (SNR) reduces when the distance between the target and the microphone increases.

The use of powerful, self-powered sound sources such as AFSRS will allow us in the future to explore the FS effect in the sound range, which appears when objects cross the virtual line between the receiver and the transmitter at very large distances from the transmitter and from the receiver.

ACKNOWLEDGMENTS

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