MOVING TARGET DETECTION BY ACOUSTIC FORWARD SCATTERING RADAR SYSTEM

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Abstract. *The paper explores the possibility of detection of moving target on the base of their sound shadow (sound blocking) when the target cross the baseline in the Acoustic Forward Scatter Radar System (AFSRS). Experimental sound shadows have been obtained from moving cars. The algorithm under investigation can be applied to create a network of sound barriers.*

KEYWORDS: TARGET DETECTION, FORWARD SCATTERING SYSTEM, SOUND SHADOW

1. Introduction

The paper is based on the theory of distribution of sound waves in the airspace and their interaction with moving targets. 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. In our study, sound receiver and transmitter form bistatic system because are placed in different location, where the bistatic angle between the directions "receiver-target" and "transmitter-target" should be around 180^0. This bistatic system is called Forward scattering radar (FSR) system [1]. 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. The Forward Scattering (FS) effect has been studied by many scientists and it is the basis for the creation of different radio barrier systems. In [2], the authors used GSM signals to detect targets. In [3–8], GPS signals have been applied to detect moving targets using the principles of FSR. In [9], 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 [10] 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 [11]. Such studies have been conducted by the team of this article but with GPS signals, which demonstrated the great potential in this field [3–8]. 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 car shadow detection is studied by using the acoustic forward scattering effect.

The proposed algorithm can be used for in automated tracking and traffic management systems in the future smart cities [12, 13]. This algorithm is inexpensive and usable in real-time systems. The resulting audio shadows have specific characteristics and parameters that can be evaluated and used to classify moving objects. This algorithm can also be used to create border or object security systems. Both artificial and natural sources of sound signals as well as background sounds with constant parameters can be used as the sound source.

2. Acoustic Forward Scatter Radar System

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.

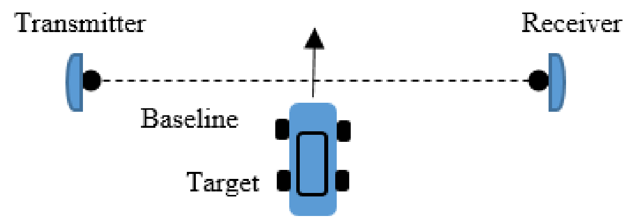

Fig. 1: *Illustration of acoustic forward scattering configuration.*

The FSR is based on the Babinet principle, which says that the shadow radiation in the optical case is completely determined by the size and geometry of the shadow contour [1, 2]. Thus scattering on the target with the rectangular cross-section is equivalent to the radiation by a rectangular aperture antenna. This principle is a theorem concerning diffraction, stating that the diffraction pattern from an opaque body is identical to that from a hole of the same size and shape except for the overall forward beam intensity. Diffraction of wave can be divided into two classes: Fresnel diffraction (when the target is close to the transmitter or the receiver) and Fraunhofer diffraction (when the target is far from the transmitter and the receiver) (Fig. 2).

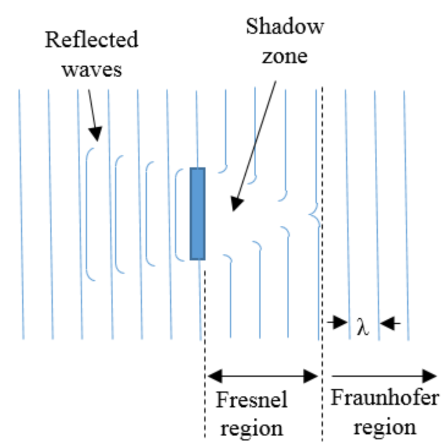

Fig. 2: *Sound diffraction.*

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.

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). Our first goal is to confirm the possibility of signal blocking caused by moving target 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 target 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 car crossing the radio barrier.

3. Signal processing

The paper presents a possible variant of signal processing in passive Acoustic Forward Scatter Radar System [11]. The general block-scheme of a possible algorithm for AFSR shadow detection includes: signal decimation and filtration, signal envelope evaluation and signal detection (Fig. 3).

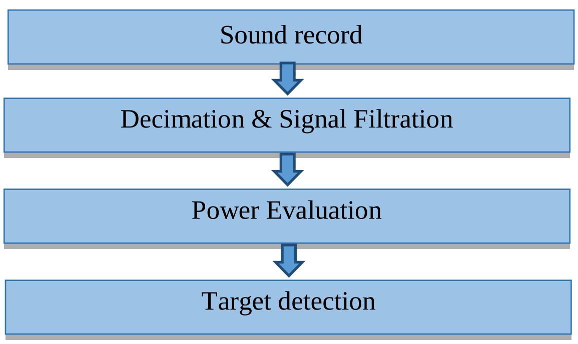

Fig. 3: *Blok-scheme of signal processing.*

The obtained target signature can be used for estimation of various target parameters in the time and frequency domains. 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 target detection by CFAR detector. The CFAR detector is a very important procedure and very often used especially in real systems, because it results in producing of precise target images separated from the existing interference. It is performed by removing clutter from the receive signals using the adaptive CFAR threshold.

4. Experimental results

During the experiments, the sound generator and the microphone are positioned on the two opposite sides of a street. The experiments include moving cars that cross the virtual baseline between the transmitter and the receiver. The acoustic system transmit signal with frequency 5 KHz (Fig. 6). The sound signal registrate at the sound frequency of 5 KHz when car crossing the baseline between the transmitter and the receiver is shown in Fig. 5.

Fig. 4: *Sound recording system.*

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. 6, where the sound shadows due to the passage of car is clearly visible.

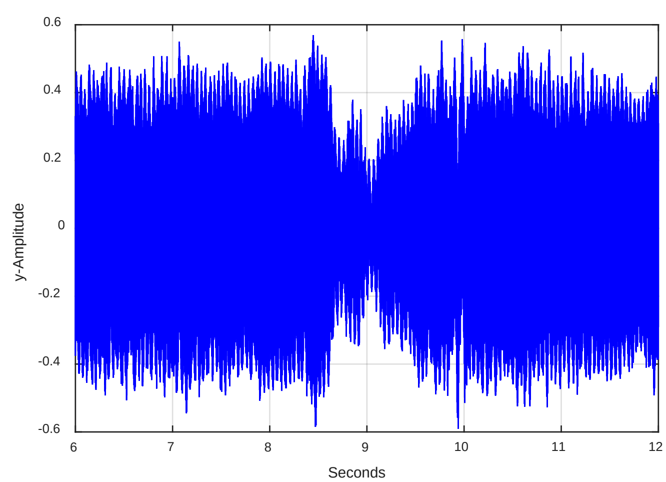

Fig. 5: *Sound record (5 KHz).*

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. 7, 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.

Through filtering the sound signal with a filter, whose frequency response is shown in Fig. 8, only the sound signal at frequency of 5 KHz is omitted. The filtered sound signal is shown in Fig. 9. The filtered signal envelope is shown in Fig. 10. From this figure can be seen that the sound shadow due to one passing car is well-shaped. A signal envelope inversion is applied before signal detection. The inverted signal envelope is shown in Fig.11.

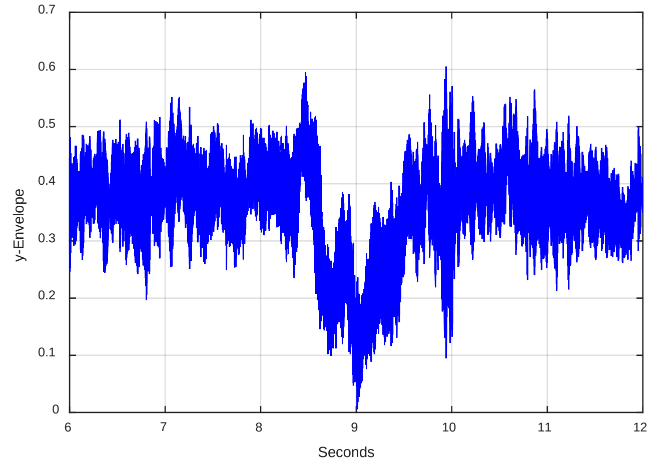

Fig. 6: *Envelope of sound signal (5 KHz).*

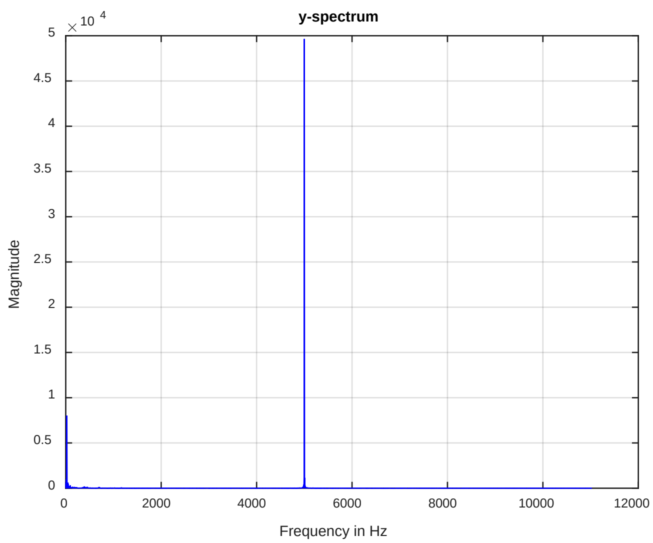

Fig. 7: *Spectrum of the recorded sound signal.*

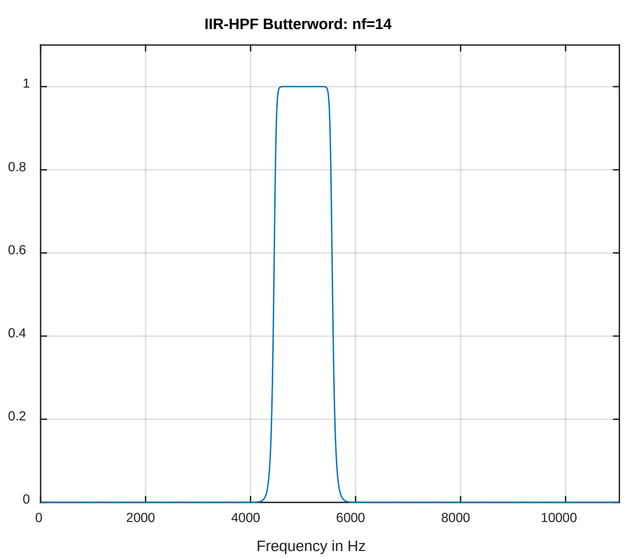

Fig. 8: *Frequency response of the bandpass filter.*

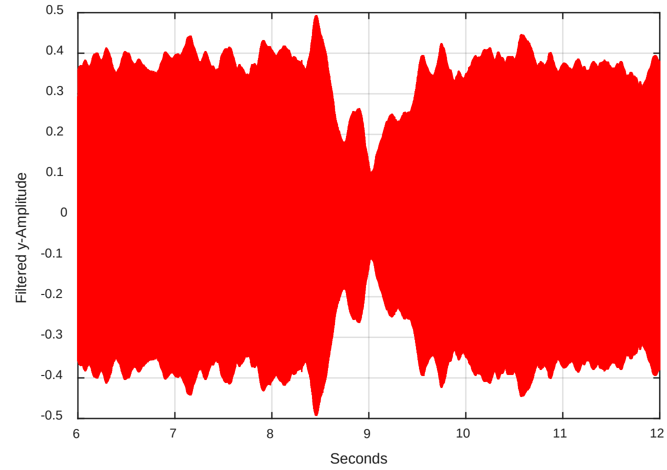

Fig. 9: *Filtered sound signal (5 KHz).*

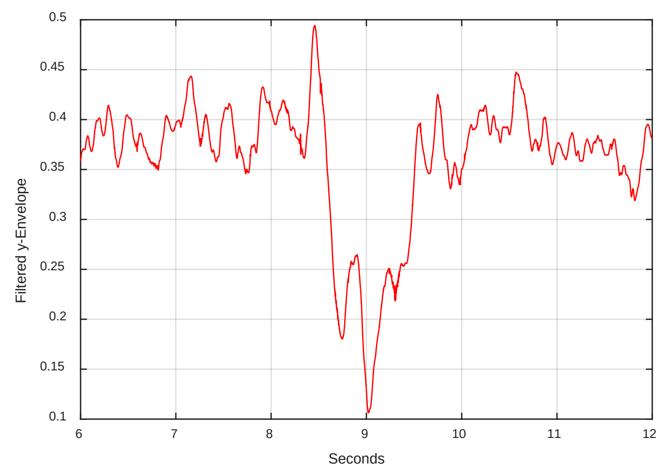

Fig. 10: *Filtered signal envelope.*

From figure 11 can be seen that the sound shadow due to one passing car is well-shaped. The CFAR detector is used to detect the sound shadow and the output of the detector is shown in Fig. 12.

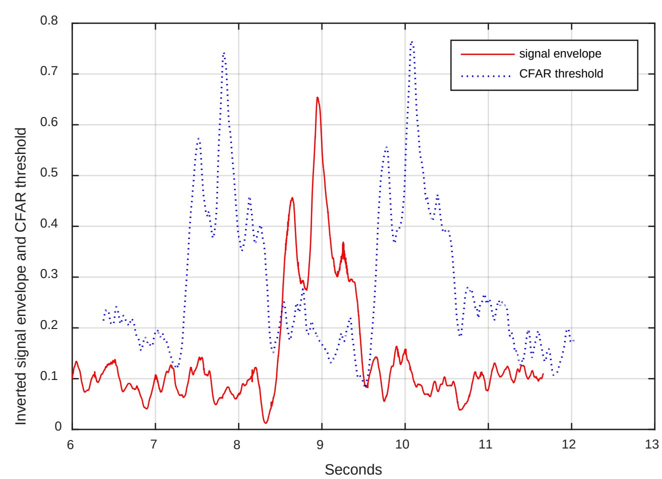

Fig. 11: *Inverted signal envelope.*

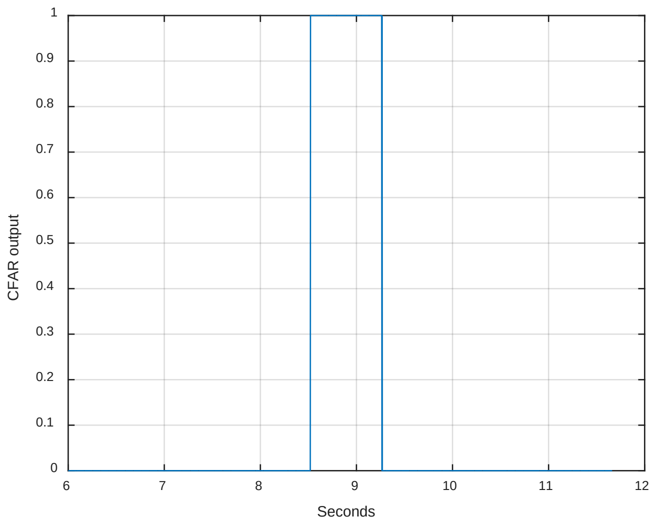

Fig. 12: *CFAR output.*

The example shows that sound signals can be used to create motion detection systems. Audio shadow parameters can be used to classify objects. A source of sound signals can be both artificial and natural sources of sound.

Conclusions:

An algorithm for detecting of moving cars crossing the baseline in the Acoustic Forward Scatter Radar System is proposed in the article.

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.

The paper provides the opportunity to explore and use information of the audio shadows from sources of sound or noise (like radio shadows) to develop new applications as monitoring and management of urban road traffic.

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