The Experimental Study of Moving Targets Radio Shadows using GPS Signals

Chr. Kabakchiev
Sofia University
Sofia, Bulgaria
e-mail: ckabakchievr@fmi.uni-sofia.bg

I. Garvanov
ULSIT
Sofia, Bulgaria
e-mail: i.garvanov@unibit.bg

V. Behar
IICT-BAS
Sofia, Bulgaria
e-mail: behar@bas.bg

D. Kabakchieva
UNWE
Sofia, Bulgaria
e-mail: dkabakchieva@unwe.bg

Abstract—**This paper focuses on scientific issues related to new application of GPS in radar networks that use the effect of Forward Scattering (FS) of electromagnetic waves to detect and estimate targets on their GPS radio shadows. The aim of the paper is to describe the experimental study of GPS radio shadows of different objects irradiated by GPS signals and to develop a possible algorithm for signal processing of the radio shadows of objects. Registration of FS-GPS radio shadows from moving targets is performed using a small commercial GPS antenna and the stationary receiver. Topology of the experiment meets the requirements for the appearance of the FS effect. The results presented in this article show that from FS-GPS radio shadows of different objects can be extracted information about the parameters of the object including size, speed and direction of movement, distance to the receiver. The information extracted from FS-GPS radio shadows of objects can be used in different applications including radio barriers, security, classification and identification of moving and stationary objects.**

Keywords—FS effect; GPS; detection and estimation

I. INTRODUCTION

The main idea is that radio shadows contain valuable information about the objects that can be used to improve the performance of systems with secondary application of wireless technologies. These are FS passive bistatic positioning systems based on radio communication or radio navigation systems, in particular the GPS system. It is normal situation when in conditions of radio shadow of the object these passive radio systems lose the object. When the object is close to the line between the transmitter and the receiver, the receiver loses the reradiated signal from the object (radio shadow). Forward Scatter GPS (FS-GPS) radio shadows formed by different moving objects are investigated in this article. The occurrence of FS radio shadow is the essential physical phenomenon, which can be used to extract some useful information about the objects that generate it.

Forward Scattering Radar operates in the narrow area of the forward scattering effect where the bistatic angle is close to 180^0, and the target moves near the transmitter-receiver baseline (Fig. 1) [1]. In forward scatter radar (FSR), the forward scattering effect can be modeled using the Babinet's principle. The Babinet principle says "A plane absorbing screen of limited dimensions may be replaced by a complementary infinite plane screen with an aperture shaped exactly like the original screen (the complementary screen has openings where the original screen is closed and vice versa. The incident field diffracted at the aperture gives rise to the field coinciding with the shadow field of the original absorbing screen, (except for the sign)".

Due to the forward scattering effect, the Radar Cross Section (RCS) of targets extremely increases (by 2-3 orders) and mainly depends on the target's physical cross section and is independent of the target's surface shape and the absorbing coating on the surface. The use of GPS signals in a passive radar system is very popular as an alternative to traditional radar systems. The idea to apply a GPS L1 receiver to FSR for air target detection is discussed in [2]. Some experimental results of a GPS L1 receiver concerning the detection of air targets are shown and discussed in [3]. A possible algorithm for air target detection in a GPS L5-based FSR system is described in [4], and the detection probability characteristics are calculated in [5] in case of low-flying and poorly maneuverable air targets in the urban interference environment. GPS L1 FSR system for detection of FSR shadows of stationary ground objects is studied in [6][7]. Target detection is indicated if the signal integrated from some satellites exceeds a predetermined threshold.

In this paper, a passive FSR system where GPS satellites are exploited as non-cooperative transmitters is studied. The aim of this study is to verify the possibility to detect FS shadow of moving ground targets when GPS satellites are located at small elevation angles. The experimental scenario includes moving targets and stationary-based FS-GPS system that registers FS shadow of ground moving targets. The experimental results obtained can be used for the design of software applications to a GPS receiver that could measure traffic movement, target velocity and target classification.

The paper is structured as follows. In Section I, the principle of passive Forward Scattering Radar together with its application to FS GPS system is described. In Section II, the description of the experiment with FS GPS system in urban conditions is done. Section III describes the basic stages of signal processing for detection and parameter estimation of moving targets using their FS radio shadows. In Section IV, the experimental results obtained in result the experiment are discussed.

II. FSR EXPERIMENT DESCRIPTION

The experimental scenario includes targets that are moving into two directions and a stationary-based FS-GPS system that registers FS shadow formed by the moving targets (Figure 1). The GPS receiver is positioned at one side of the road.

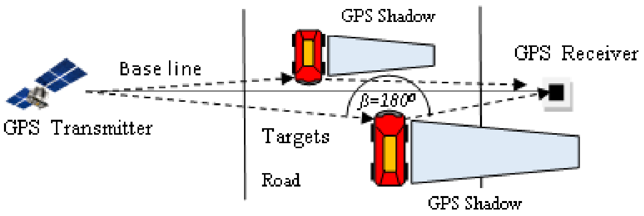

Figure 1. GPS-GSR topology

The purpose of the experiments is to verify that with a small and omnidirectional commercial GPS antenna it is possible to register differences in FS-GPS shadows of moving targets depending on their size and velocity, and also to verify whether the differences in the FS-GPS shadows allows classifying the objects (Figure 2).

Figure 2. Experimental equipment

The paper considers one experimental scenario that includes a stationary-based FS-GPS system that records FS shadows formed by cars moving on the road (Figure 2). During the experiment, the conditions for the occurrence of the FS-GPS effect have been guaranteed. In the experiment, the GPS receiver is positioned from the one side of the road and records the signal from GPS satellites. The signals are recorded from such visible satellites that are located at low elevation angles and when a baseline between satellite and receiver is perpendicular to the road, in order to meet the requirement for the occurrence of the FS effect. During the experiment, the satellite signals are recorded when cars move on the road. The objects passing on the road have different dimensions (cars, vans, buses, trucks, pedestrian etc.). The purpose of these experiments is to check whether the type of the registrated FS shadows depends not only on the dimensions of the object, but on the speed of the moving targets as well. The dependence of FS-GPS radio shadows on the size and speed of the marine targets registered by the coastal FSR is firstly shown in [1].

III. SIGNAL PROCESSING

The general block-scheme of a possible algorithm for FS_GPS shadow detection is shown in Figure 3. According to this block-scheme, several visible GPS satellites are acquired and tracked over the complete duration of recorded signals.

Here, we consider the case when the acquisition and tracking algorithms of a GPS receiver are implemented in MATLAB. According to the block-scheme shown in Figure 3, the squared values of the In-phase component at the output of the Code&Carrier tracking block are then filtered by means of the Moving Average Filter with the jumping window. This filter divides the input signal into non-overlapping intervals (jumping windows) of size *N* milliseconds and calculates the average of samples (integrates) in each interval. This filter not only improves the Signal-to-Noise Ratio (SNR) at the detector input but reduces the number of signal samples as well. Target detection is indicated if the filtered signal exceeds a predetermined threshold *H*. The Constant False Alarm Rate (CFAR) processor firstly detect single samples and then counts them using a binary nonparametric procedure for detection of sample packages of unknown length, with the decision rule “M/N–L”, in order to estimate their unknown length. The estimated sample package length is proportional to the linear dimension of the target. Next, using the CFAR processor, we use the same approach for estimation of the other target characteristics in the frequency domain. In that way we obtain two important parameters of moving targets – energy and frequency. The obtained target signature can be used for estimation of various target parameters in the time and frequency domains.

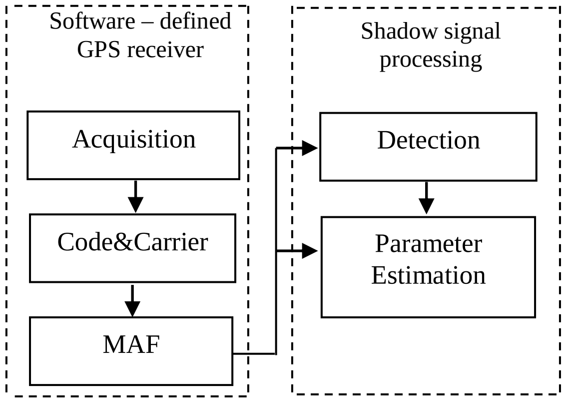

Figure 3. The general block-sheme of signal processing in a FS GPS system

The CFAR processing is a very important procedure, which is very often used especially in real systems, because it allows maintaining the required false alarm rate at the detector output using the adaptive threshold. Next, the extracted target signatures can be used to estimate different target parameters for their classifications.

IV. EXPERIMENTAL RESULTS

The GPS receiver is positioned at the one side of the road, at the height of 1 m from the ground (Figure 2 and Figure 4). The street has four lanes each with the width of 3m, two in one direction. A high building is located on the west of the receiver,

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so the GPS receiver receives signals only from the GPS satellites on the east.

Figure 4. Experiment scenario

During the experiment, several cars move at velocity of about 20 - 30 km/h relative to the GPS receiver. The constellation of the visible satellites is shown in Figure 5. It can be seen that during this experiment only four satellites are visible (7, 10, 13 and 28), one of which with the number 13 creates the best conditions for the occurrence of the FS effect.

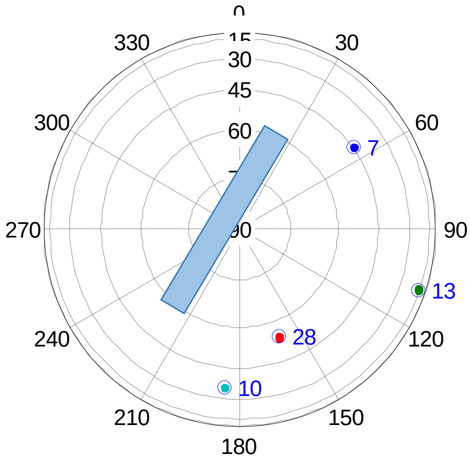

Figure 5. Satellite constellation

This satellite is located most low on the horizon, the bistatic angle between the satellite and receiver is close to 180 degrees, and the car crosses the baseline "satellite - receiver" at the angle of about 90 degrees. The signals from this satellite can be used for detection of the FS-GPS shadow created by targets. The squared in-phase components at the output of the Carrier&Code tracking block are recorded for four satellites (7, 10, 13 and 28) and further filtered by means of the MAF with the moving window of size 200ms. The FS-GPS radio shadows obtained from satellites 7, 10, 13 and 28 are shown in Figure 6. Satellites 7 and 10 are located also low on the horizon, but in their case the car crosses the baseline “satellite-receiver” at an angle different from 90º. These satellites do not meet the requirements for the occurrence of the FS effect. For that reason the signals received from these satellites cannot be used for detection of the FS shadows created by cars. The satellite 28 is located high above the horizon, which worsens the conditions of the occurrence of the FS effect and the FS shadow is small. It is so because the direction of propagation of the signals from the satellite is not orthogonal with respect to the cross section of the vehicle.

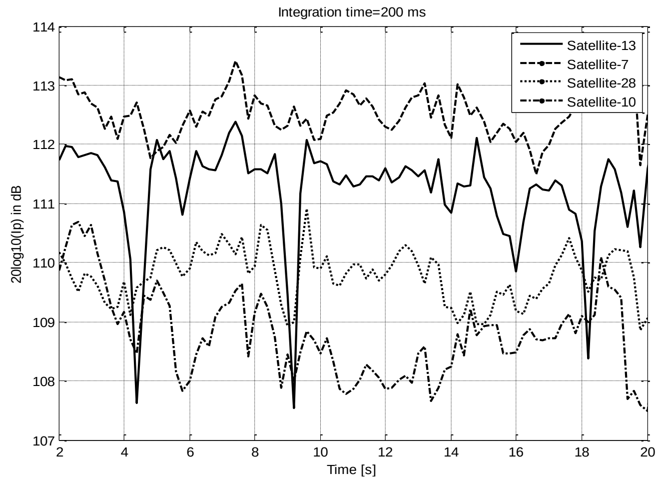

Figure 6. Filtered signals from satellites 7, 10, 13 and 28

The filtered signal from satellite 13 is shown in Fig. 7.

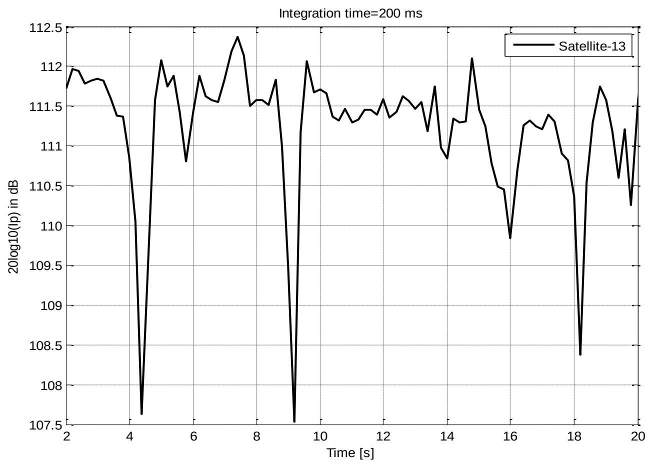

Figure 7. Filtered signal from satellite 7

This figure shows that cars passing near to the receiver have the deepest FS radio shadow (about 8-10 dB). Moreover, the size, the depth and the form of the shadow could serve as information for the development of GPS software applications - for determination of the car velocity and for traffic control. Using the multi-level threshold procedure, it is possible to determine the distance to the vehicle. The shape of the shadow (the first peak) can be used to determine the direction of travel of the vehicle. So, in this way the selection and classification of vehicles can be realized. The parameters of the FS_GPS radio shadow (width and depth) can be used for classification of the type of vehicle. The FS-GPS radio shadowsare shown in Figure 8 - for five cars and the van and in Figure 9 – for the car and the bus. Figures 8 and 9 show that the FS-GPS shadow parameters can be used to classify different moving targets. For example, the longer the vehicle, the deeper his radio shadow. The radio shadow width is proportional to the length of the vehicle and his speed of movement. The FS-GPS shadows shown in Figures 8 and 9 are formed by the vehicles moving at almost the same speed of 20-30 km/h.

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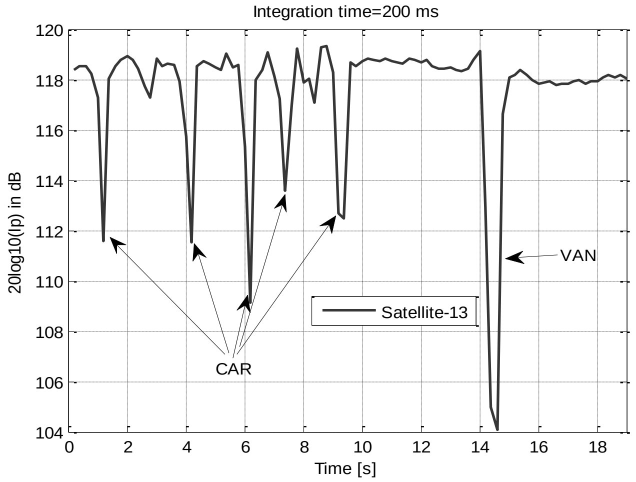

Figure 8. Filtered signals from satellite 13 (five cars and van)

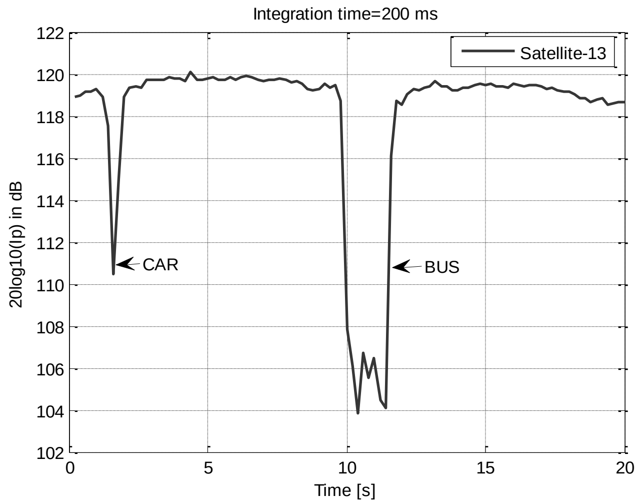

Figure 9. Filtered signals from satellite 13 (car and bus)

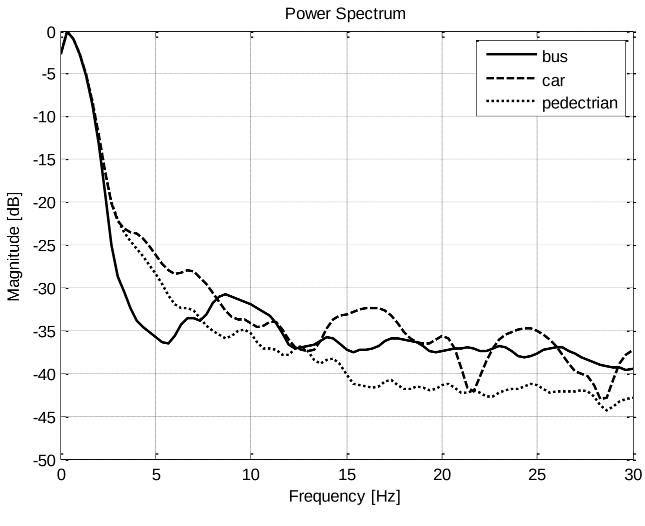

Figure 10. Power spectrum (bus, car and pedestrian)

In this study, it is observed that the FS-GPS shadow depth is proportional to the distance from the object to the receiver. The smaller this distance, the greater the FS-GPS shadow depth. The greater this distance, the smaller the FS-GPS shadow depth. As mentioned above, the road where the study is realized has four lanes, two in one direction. Figures 8 and 9also show that the FS-GPS shadow depth in each successive lane of the road is differed by about 2 dB. The length of the car is 4 m, of the van - 6 m, of the bus -12m. Applying the Fast Fourier Transform (FFT) or the Welch method (PWELCH) to the filtered signals from different targets, we obtained the corresponding power spectra (Figure 10). Figure 10 shows that the power spectrum reduces to the level of -40 dB at the frequency of 15 Hz – for the human and at the frequency of 20-30 Hz –for the car and the bus.

V. CONCLUSIONS

It is shown that it is possible to detect different objects on their FS-GPS shadows using a small commercial GPS antenna and the software-defined GPS receiver. Topology of the experiment meets the requirements for the occurrence of the FS effect. This means that the satellite and the GPS receiver are located on the same line, which crosses the object. Experiments show that the FS-GPS shadow can provide information about the object including size, speed, direction of movement, and the distance to the receiver. This information can be extracted from the width, shape and length of the FS-GPS shadows. The occurrence of FS shadow is essential physical phenomenon, which can be used to extract some useful information about the objects that create it. The information obtained can be used in various applications including radar, radio barriers, security, classification and identification of moving and stationary objects.

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