Experimental Parameter Estimation of Vehicles GPS Shadows by Forward Scattering Systems

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Abstract: *In this paper, we conduct an experimental study with the aim to obtain a large number of estimates of various parameters characterizing the GPS shadows created by three types of moving vehicles. The experimental cars have a similar size and therefore, the obtained estimates have similar values. From the results, it can be seen that the cars can be differentiated by means of their shadow parameters.*

1. Introduction

In last years, passive radar systems where GPS satellites are used as transmitters are becoming increasingly popular as an alternative to traditional radar systems. The GPS Forward Scatter Radar (GPS FSR) is a specific case of FSR, where GPS satellites are exploited as 'transmitters of opportunity'. In [1-6] the authors consider the possibility to detect different targets in bistatic and forward scatter radar, which exploit GPS satellites as transmitters. A possible algorithm for target detection using GPS L5-based FSR system is described in [7], and the detection probability characteristics are analytically calculated in [8]. The next few articles [5-9] are devoted to experimental measurements made by using GPS L1-based FSR system and the Software-Defined GPS receiver, developed by the Aerospace Department in the University of Colorado [10], allowing to observe the geometric shadows (signal blocking) of ground objects of different sizes, mobile and stationary.

Our hypothesis was that at such a very weak signal on the surface of the earth from GPS L1 satellite, in order to register the radio shadow of some object, its size must be large, and the distance from the receiver to the object must be small. The purpose of these experiments was to clarify the real possibilities of the proposed GPS L1-based FSR system for recording radio shadows created by different objects - depending on the object's size, distance from the receiver to objects, speed of objects, and satellite constellation at the time of recording. The obtained recordings are not available for processing in the field conditions because the

processing of radio shadows of objects requires the additional time in the laboratory, which further impedes research. In conducted experiments, our GPS L1-based FSR system consists of the USB-based recording system with a small commercial GPS antenna, which records the raw GPS data flow and stores it as binary files in our computer, and the Software-Defined GPS receiver to process the recorded data in MATLAB [10, 11].
The purpose of this article is to explore different types of GPS shadows created by different vehicles of different sizes and types. This knowledge is necessary to extract the characteristic parameters of the radio shadows, which can be used for the further Data Mining vehicles classification.

2. Signal Processing

The general block-scheme for target radio shadow processing using a Software-Defined GPS receiver [10] is shown in Fig.1.

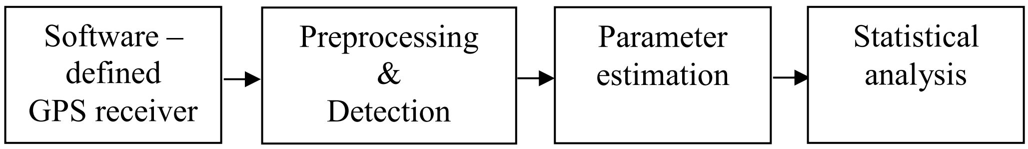

Figure 1. Block-scheme of signal processing

The Software-Defined GPS receiver contains the Acquisition block to identify satellites, and the Code & Carrier Tracking block to form the navigation message. Next, the obtained navigation message is integrated every two hundred milliseconds in order to form the radio shadow of the object. Next the integrated navigation message is inverted and then used for further detection of the object on his radio shadow. During the experiments, the choice of satellites, at which is observed the deepest shadow from the object, is made by the operator, not automatically. The pre-processing and detection block includes invention and integration of navigation message and finally CFAR detection [12, 13]. CFAR processor performs automatic detection of the target radio shadow, after which the selected parameters of the target radio shadow are estimated manually by an operator.

3. GPS Shadow Parameters Estimation in the Time Domain

The registered GPS radio shadows (for example, in Fig. 2) are characterized by the following parameters:

3.1. Length of target shadow estimation

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

$$dT = T_2 - T_1 \tag{1}$$

where T_1 and T_2 are the beginning and the end of the target shadow in the time domain, which are estimated manually by the operator when processing the experimental records of the target shadow in Matlab (Fig. 2). The length of the target shadow as the number of time samples (N) is estimated as:

$$N = dT/Ts \tag{2}$$

In (2), Ts is the sampling rate of the signal. In our case $Ts = 200ms$ and it coincides with the integration time of the navigation message in the Preprocessing & Detection block.

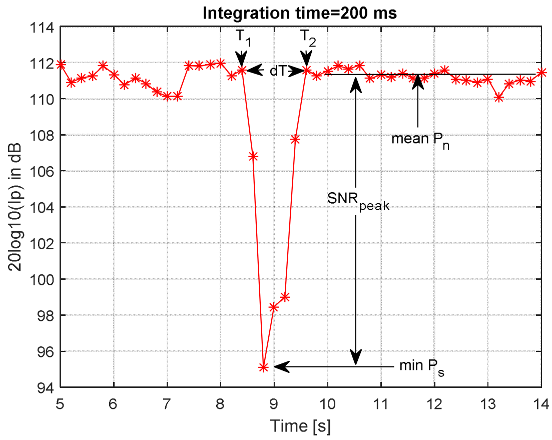

Figure 2. GPS Shadow Parameters

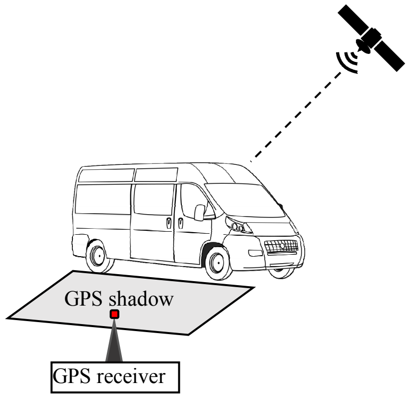

Figure 3. FS GPS Shadow

3.2. Peak Signal-to Noise Ratio

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

$$SNR_{peak}[dB] = mean(P_n) - \min(P_s) \quad (3)$$

In (3), P_n is the noise power in dB and P_s is the power of the target shadow in dB

3.3 Mean Power of the Target Shadow

The mean power of the target shadow (P_{ave}) in dB is estimated as:

$$P_{ave}[dB] = 10\log_{10}\left(mean\left(P_{s,i}\right)\right), \quad i = 1 \div N \quad (4)$$

3.4 Mean Energy of the Target Shadow

The mean energy of the shadow (E_{ave}) is calculated as the product of the average power and the length of the shadow in the time samples:

$$E_{ave} = P_{ave} N \quad (5)$$

3. Experiment description

The experimental scenario includes three cars, which are small, middle and large, (Kia-Rio, WV-Touran, Opel-Vivaro). The cars are moving simultaneously into one directions at velocity of 20 km per hour. The cars are moving at 5 ÷ 10 m from each other. The distance from the GPS receiver up to the cars is between 2 m and 4 m. During the experiment the stationary-based GPS FSR system records the radio shadows formed by cars moving on the road (Fig. 3). During the experiment near the village Dolni Bogrov-Sofia, over 100 records of the radio shadows, created by cars have been made for two days (6-7 March, 2017) (Fig.4).

Figure 4. GPS receiver position 42°41'21.64", 23°30'32.21"

Figure 5. Experiment topology

As shown in Fig. 4, the GPS receiver (GPS recording system developed by the Colorado University) is positioned on the one side of the road and records the signal from GPS satellites. The signals are recorded from all visible satellites. The purpose of these experiments is to make records of radio shadows from moving targets, at one and the same distances from the receiver, which move at the same speed for shadow parameter estimation in the time domain. These parameter estimates can be used next for car classification by the Data Mining approach.

During the experiment, the GPS receiver Antaris AEK-4R is periodically used to determine the coordinates of the visible satellites (elevation and azimuth). The satellite constellation on the sky is very important for creating and registration of the GPS shadows. By analyzing the satellites coordinates, the operator selects a satellite, whose baseline between it and the GPS receiver is most close to the perpendicular to the direction of the cars movement and which is located most low on the horizon (Fig. 6). In our case, the satellites are 9 and 17.

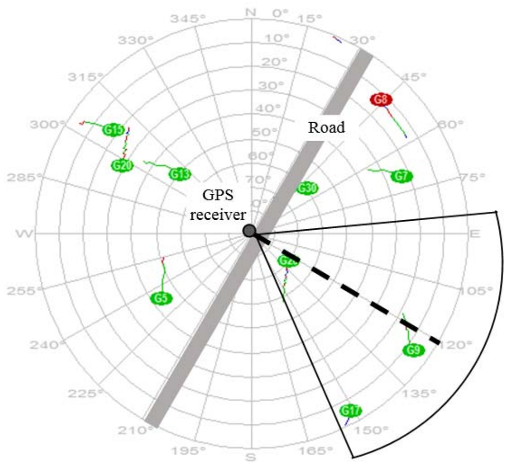

Figure 6. Satellite constellation

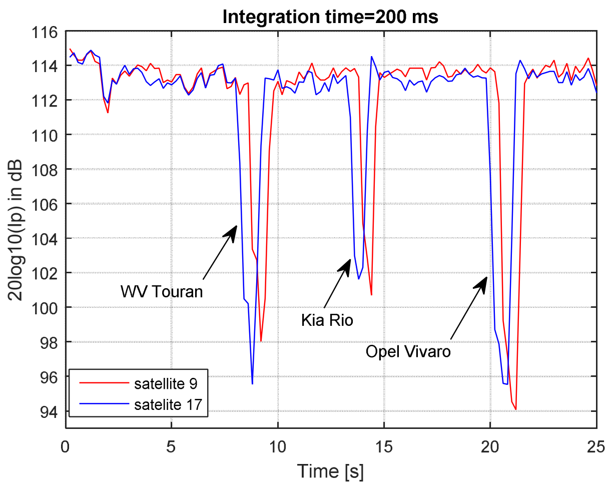

Figure 7. GPS shadows from satellites 9 and 17

3. Processing of Experimental Records of GPS Shadows

By using the soft-defined GPS receiver, the database has been accumulated, which contains the navigation messages from all visible GPS satellites. In laboratory conditions have been selected the records of suitable satellites that best meet the FSR topology. This means that all cars in the experiment intersect approximately perpendicularly to the line between such a GPS satellite and the GPS receiver.

The records from these satellites have been processed by the operator using the program Matlab and as a result have been calculated the estimates of the shadow parameters mentioned above in the article, for each type of the experimental cars. The estimates of the shadow parameters of the three cars have been summarized in a table that also contains the other additional information about the coordinates of satellites, day of records, file number and more.

Before the statistical data processing, the preliminary analysis of the shadow parameters is made in order to filter out the target shadows unsuitable in shape and parameters. Such shadows and their parameters are obtained from satellites, which to a lesser extent satisfy the FSR topology. This means that the car in the experiment intersects the baseline "receiver - satellite" at an angle which is very different from 900 (the shadow becomes wide and shallow). The resulting parameters are graphically presented in Figures 8-11. For example, the average energy as a function of SNR_{peak} is plotted for the three cars in Fig.8, and the length of the shadow as a function of SNR_{peak} is plotted for the three cars in Fig. 9.

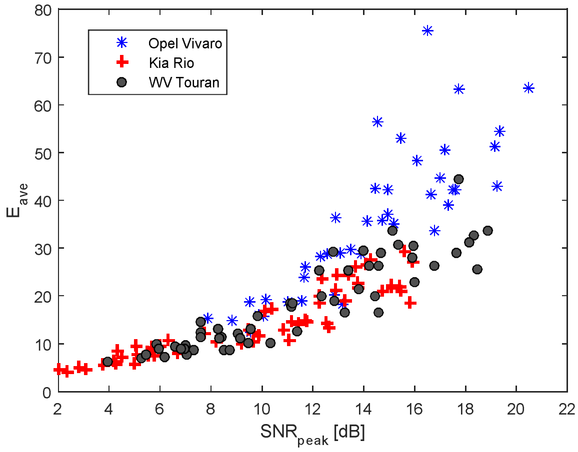

Figure 8. $SNR_{peak}(E_{ave})$

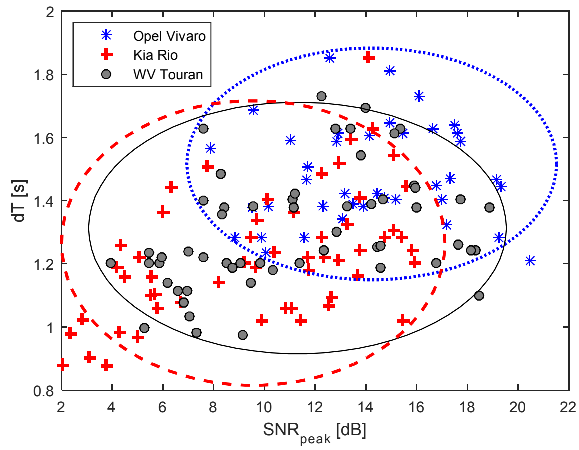

Figure 9. $SNR_{peak}(dT)$

The distributions of the length of the shadow of the three tested cars as a function of the average shadow energy and the average shadow power are shown in Fig.10 and Fig.11.

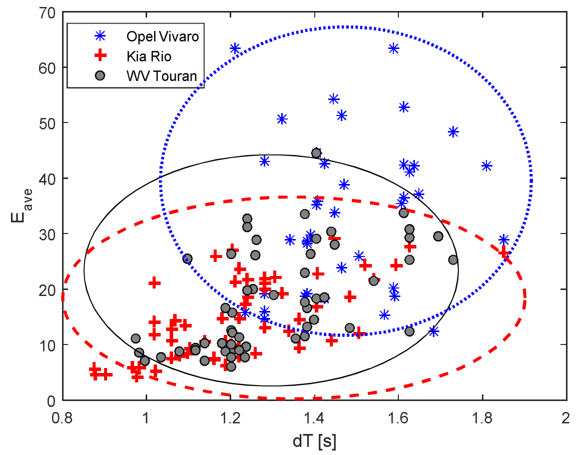

Figure 10. $dT(E_{ave})$

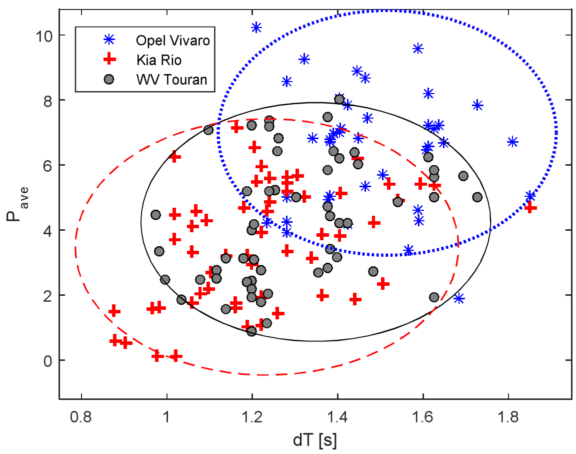

Figure 11. $dT(P_{ave})$

After the preliminary analysis of data, the filtered data has been statistically processed in order to calculate the statistical parameters of all shadow parameters. The mathematical expectation and the standard deviation of all measured parameters have been calculated for each experimental car (Table. 1). The goal of this statistical processing is to check the possibility of using the resulting parameters for classification of cars by means of a statistical approach.

Targets		Length/ Height (mm)	Estim.	*dT*	*N*	*SNR peak* [dB]	*Pave*	*Eave*
	Kia Rio	4045/ 1455	Mean	1.22	5.8	9.77	3.58	14.55
			STD	0.2	1.05	4.21	1.84	7.13
			Mean/STD	***6.1***	***5.52***	***2.32***	***1.95***	***2.04***
	WV Touran	4406/ 1685	Mean	1.3	6.04	11.22	4.25	18.07
			STD	0.18	1.08	4.15	1.9	9.32
			Mean/STD	***7.22***	***5.59***	***2.7***	***2.24***	***1.94***
	Opel Vivaro	4998/ 1971	Mean	1.56	7.37	14.21	6.48	35.34
			STD	0.4	2.01	3.2	1.81	15.4
			Mean/STD	***3.9***	***3.67***	***4.44***	***3.58***	***2.29***

Tabl. 1 Mathematical expectation and standard deviation of shadow parameters for three types of cars

From the results in Table 1 follows that the obtained estimates of the mathematical expectation and standard deviation of all measured parameters increase with increasing the linear dimensions of cars. To compare data for the purpose of classification is done statistical data normalization as mathematical expectations (Mean) of all parameters is divided on their STD (bold and italics). Normalized statistical parameters show that cars can hardly be distinguished if the classification criteria is based on the values of Mean/ STD.

However, the difference between GPS shadows of the small and big cars allows differentiating them. On the other hand, it appears that the sensitivity of the method allows you to see the differences in the cars of a similar class, between small and medium cars and between medium and large cars. This shows the capability of the approach used to assess the parameters of GPS shadows purposes. For classification should, however, be used other more sensitive method other than statistical, for example, the Data Mining Approach. These findings are confirmed by the visual presentation of shadow parameters in Figs. 8-11. It can be seen that the areas of the distribution of the shadow parameters of the three cars overlap with each other, but the overlap between the distribution areas of the shadow parameters of the smallest and largest cars is less.

4. Conclusions

The purpose of the article was to examine the sensitivity of the method to distinguish cars similar in size and type by using their GPS shadows. A large number of experimental recordings of GPS shadows of 3 types of cars (small, medium and large) had made during two-days experiments. The recordings were made with the commercial and non-professional equipment. The topology of the experiments is the same as that used in the FSR systems.

The statistical processing of the resulting estimates of GPS shadow parameters shows that the selected cars create the GPS radio shadows with different parameters. From the results, it is evident that the statistical approach is possible to apply for the classification of cars from their radio shadows. The quality of the classification depends on the size and shape of vehicles. The proposed approach and results can be used in various systems for security and surveillance facilities.

Acknowledgment

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