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Comparative Analysis of Two GPS Forward Scattering Systems For Cars Parameter Estimation

C. Kabakchiev[1], I. Garvanov[2], V. Behar[3], A. Kabakchiev[4], D. Kabakchieva[5], H. Rohling[6], K. Kulpa[7], A. Yarovoy[8]

1Sofia University, Bulgaria, e-mail: ckabakchiev@fmi.uni-sofia.bg

2University of Library Studies and Information Technologies, Bulgaria, e-mail: i.garvanov@unibit.bg

3Institute of Information and Communication Technologies, Bulgaria, e-mail: behar@bas.bg

4Air Traffic Service Authority – "BULATSA", Sofia, Bulgaria, email: av.kab@abv.bg

5University of National and World Economy, Bulgaria, e-mail: dkabakchieva@unwe.bg

6Technical University of Hamburg-Harburg, Germany, e-mail: rohlingr@tu-harburg.de

7Technical University, Warsaw, Poland, e-mail: kulpa@ise.pw.edu.pl

8Technical University, Delft, Netherland, e-mail: a.yarovoy@irctr.tudelft.nl

Abstract: *In this paper, by comparing the GPS shadow parameters of the same cars obtained from the same satellites and recorded by the two different systems under the same conditions, the Stereo dual GNSS front end (NSL's) and the GPS recording system of the Colorado University, we assess indirectly the capabilities of the new system for FSR applications.*

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 [1-5] 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 [6], and the detection probability characteristics are analytically calculated in [7]. The next few articles [5-12] 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 [13], allowing to observe the geometric shadows (signal blocking) of ground objects of different sizes, mobile and stationary.

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 [13]. At the moment, only the new European GPS signal recording system, i.e. the Stereo dual GNSS front-end (NSL's) is offered at the market, which has been developed on the principles of software-defined radio technologies and has the capacity to digitize, acquire and track satellite signals from the full complement of

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GNSS systems, including GPS, Galileo, GLONASS, Compass, QZSS, EGNOS, GAGAN, MSAS and WAAS [14]. Our goal in the article is to explore the capabilities of the new European GPS signal recording system for FSR applications. This is done by comparing the radio shadow parameters obtained from the same cars and the same GPS satellites, whose signals have been recorded by the two different recording systems under the same conditions of the experiment. The comparison is made with the GPS signal recording system used by us for FSR applications and developed by Colorado University.

The proposed technology could be used to monitor and protect an area. By using the barrier principle, it is possible to detect and classify moving objects in the protected area. The coordinates of the receiver in this zone are known and permanent and the change of satellite coordinates over time is also known. At some point in time it is known which satellites form with the receiver the barrier for detecting and evaluating the parameters of the objects in the guarded zone. This technology would can be also used in the traffic management in a smart city.

2. Signal Processing

The processing of the received GPS signals is done with the Software-Defined GPS receiver, which contains the Acquisition block to identify satellites and the Code & Carrier Tracking block to form the navigation message. 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 hundreds milliseconds in order to form the radio shadow of the object [11].

To obtain the results described in this article, the programs for GPS signal processing (SoftGNSS) have been optimized and accelerated by using the Matlab capabilities to parallel data processing to maximize the load on modern multi-core computers. An algorithm for semi-automatic processing of records of GPS signals of different duration and also for visualization of the obtained results has been developed, resulting into generating of a large amount of graphics necessary for data pre-processing.

In the processing, the obtained navigation message is integrated every two hundred milliseconds in order to form the radio shadow of the moving object.

The algorithm proposed in [10] is used for estimation of the received GPS shadow parameters (duration, depth, energy and power). The obtained GPS shadow parameters can then be used to classify moving objects (people, cars, buses, airplanes), for example, through the Data Mining approach [11].

3. GPS Shadow Parameters Estimation in the Time Domain

The parameters of GPS shadows, used in this paper, are the same as in the article [10]. The registered GPS radio shadows (for example, in Fig. 1) 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. 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.

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].

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

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:

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

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:

$$E_{ave} = P_{ave}N \tag{4}$$

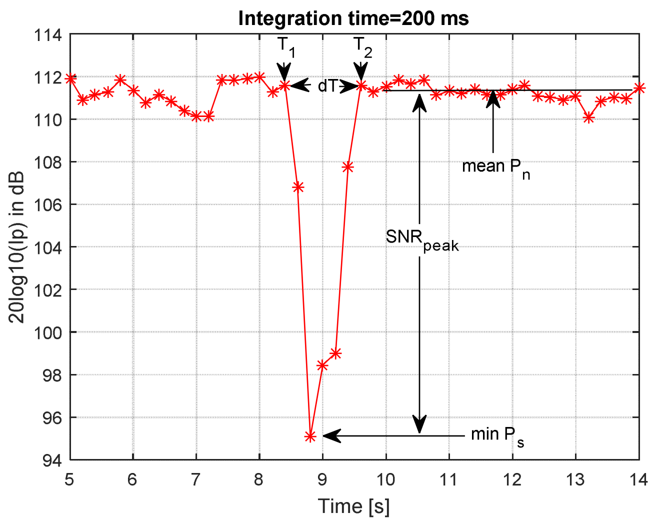

Figure 1. GPS Shadow Parameters

3. Experiment description

A task in conducting these FSR experiments with cars was to assess the capabilities of the new, contemporary European recording system Stereo dual GNSS front-end. Our hypothesis was to indirectly assess the capabilities of the new system by comparing the shadow parameters obtained from the same cars irradiated by the same GPS signals recorded by the two different systems under the same conditions, the new recording system and the GPS recording system developed by Colorado University.

The new GPS signal recording system Stereo dual GNSS front-end (NSL's) described in [13] has been developed on the principles of software-defined radio technologies and has the

capability to digitize, acquire and track satellite signals from the full complement of GNSS systems, including GPS, Galileo, GLONASS, Compass, QZSS, EGNOS, GAGAN, MSAS and WAAS.
STEREO is a fully flexible dual-chain GNSS Radio Frequency Front End (RF FE) that is being used for prototype development, signal and system testing, research, and teaching. Stereo contains two FEs, one covering the Upper L-Band and the other covering the full RNSS spectrum allowing the following signals to be tracked and acquired: GPS L1/L2/L2C/L5; Galileo L1/E5a/E5b/E6/AltBOC; GLONASS G1/G2/G3; Compass B1/B2/B3; QZSS LEX.
The new GPS signal recording system is shown in Fig. 4. During the experiments, a professional GPS antenna with better technical characteristics than the commercial ones was used.
As shown in Fig. 3, the two GPS receivers (the GPS signal recording system developed by the Colorado University and the new GPS signal recording system Stereo dual GNSS front-end) are positioned on the one side of the road and record the signal from GPS satellites.
The experimental scenario includes two cars, which are small and large, (Kia-Rio and Opel-Vivaro). The cars are moving simultaneously into one directions at velocity of 20 km per hour. The cars are moving at 3 ÷ 4 m from each other. The distance from the GPS receivers up to the cars is between 2m and 4m. During the experiment the stationary-based GPS FSR systems record the radio shadows formed by cars moving on the road (Fig. 2). During the experiment, over 100 records of the GPS shadows, created by cars have been made.

Figure 2. GPS receiver position 42°41'21.64", 23°30'32.21"


Figure 3. Experiment topology

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.
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 closest to the perpendicular to the direction of the cars movement and which is located lowest on the horizon (Fig. 5). In our case, the satellites are 9 and 17.

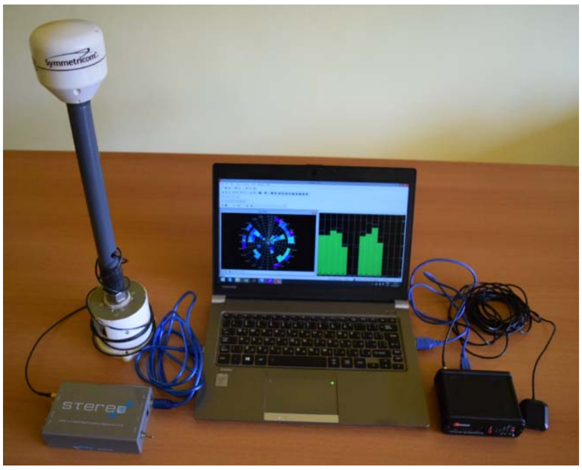

Figure 4. Satellite constellation

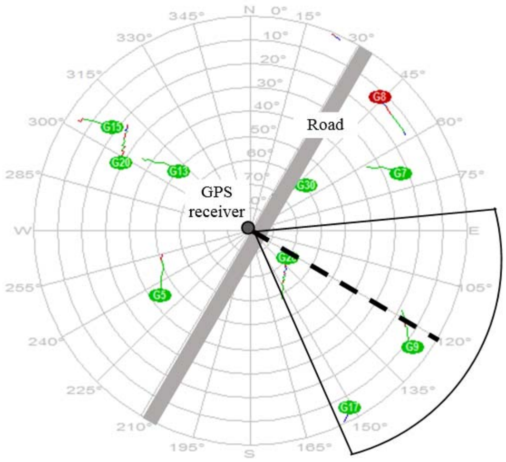

Figure 5. Satellite constellation

3. Processing of Experimental Records of GPS Shadows

The records from satellites 9 and 17 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 two 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 90^0 (the shadow becomes wide and shallow).

Targets		GPS receiver	Estim.	dT	N	SNR peak [dB]	Pave	Eave
	**Kia Rio**	GPS Receiver 1	**Mean**	1.22	5.8	9.77	3.58	14.55
			STD	0.2	1.05	4.21	1.84	7.13
		GPS Receiver 2	**Mean**	1.27	5.95	9.22	3.1	14.03
			STD	0.27	1.39	4.98	2.08	7.48
	**Opel Vivaro**	GPS Receiver 1	**Mean**	1.56	7.37	14.21	6.48	35.34
			STD	0.4	2.01	3.2	1.81	15.4
		GPS Receiver 2	**Mean**	1.6718	7.95	14.3	6.14	37.5
			STD	0.21	1,09	4.7	2.27	20.78

Table. 1

After the preliminary analysis of data by semi-automatic processing of the recorded GPS signals, the operator selects the starting and ending points of the car shadows on the basis of visualization of the GPS signals from the cars. Then the estimates of the parameters (duration, depth, energy and power) of the resulting GPS shadows are automatically calculated based on the algorithm proposed in the article [11]. The thus obtained parameters of the GPS shadows of the two cars are represented in the form an Excel-table for the subsequent generalized statistical processing [11, 12]. The preliminary rough assessment of the GPS shadow parameters of the car recorded by the two different GPS signal recording systems (GPS receiver 1 - is the GPS signal recording system developed by the Colorado University and GPS receiver - 2 is the GPS signal recording system Stereo dual GNSS front-end) can be done by comparing their statistical parameters (Mean and STD). The mathematical expectation (Mean) and the standard deviation (STD) of all measured parameters have been calculated for each experimental car (Table. 1). Mathematical expectation and standard deviation of GPS shadow parameters for two types of cars for two types of GPS recording systems, are very similar.

4. Conclusions

The preliminary rough assessment of the quality of the two GPS signal recording systems, i.e the GPS signal recording system developed by the Colorado University and the GPS signal recording system Stereo dual GNSS front-end, carried out by comparing the statistical parameters of the GPS parameters of the car's shadows, shows their equivalence for FSR applications.

This gives us the possibility in the future to perform the similar FSR research for different objects (moving and stationary), with other GPS signals (for example, with GPS L5) as well as signals from other Galileo and Glonass navigation systems. This in turn will increase the capabilities of applying the algorithms being developed and solving a larger range of useful tasks. This technology would can be also used in the traffic management in a smart city.

Acknowledgment

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