

VEHICLE CLASSIFICATION BASED ON THEIR GPS SIGNAL SHADOWS

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Abstract: The goal of this paper is to study algorithm for detection and classification of moving objects based on parameter estimates from their GPS signal shadow. The suggested algorithm uses satellite GPS signals to create radio barriers and to detect moving terrestrial targets. It can be examined as an algorithm for secondary application of the wireless technologies (SAWT). This technology is extremely modern and up-to-date and can find application in Industry 4.0 with regard to the reduction of the electromagnetic radiations. The GPS signals included shadow from several moving vehicles, processed in MATLAB environment in order to obtain the estimations of their parameters. In IBM SPSS Statistics, Scheffe test is used for classifying the moving objects. The results reveal that proposed signal processing of the GPS signal shadow combined with this statistical approach can be successfully applied in practice for object classification.

Keywords: SIGNAL PROCESSING, ESTIMATION, CLASSIFICATION

1. Introduction

Intelligent Transportation Systems aim to reduce traffic jam occurrences and travel times [1]. They are providing vehicle-related statistical data, which are among the key components for future smart cities. In order to achieve such information about the current traffic flow, the sensor measurement is needed. At the moment, there is no existing solution for traffic flow detection and vehicle classification that is able to guarantee high classification accuracy, low deployment and maintenance costs, low power consumption and a weather-independent operation. The paper proposes a solution to the task of road traffic data collection with GPS Forward Scatter (FS) system and vehicle classification.

The advantage of this type of data collection system is that it does not pollute the radio distribution with additional radio signals as well as the presence of GPS signals anywhere around us allows to be used worldwide [2-3].

GPS FS system, where the GPS satellites are used as transmitters, are increasingly becoming popular as an alternative to traditional radar systems [4-9]. The GPS Forward Scatter Radar (GPS FSR) is a specific case of FSR, where the GPS satellites are exploited as "transmitters of opportunity". In [6-9], 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 the GPS FSR system is described in [8], and the detection probability characteristics are analytically calculated in [9]. The next few articles [10-12] are devoted to experimental measurements made by using GPS L1-based FSR system and the Software-Defined GPS receiver, developed by the Aerospace Department at the University of Colorado [13], allowing to observe the geometric shadows (signal blocking) of ground objects of different sizes, mobile and stationary. In [7] is offered a data mining classification of cars based on GPS shadows in FSR system. In [14] is proposed algorithm for signal processing of GPS signal shadows combined with Machine Learning, which can be successfully applied in practice for clustering moving objects in general, and in particular – for clustering vehicles in the context of road traffic.

The current paper uses algorithms for signal processing of real GPS signals and parameter estimation of moving objects. Algorithms for signal processing are implemented in MATLAB environment [18, 20]. In IBM SPSS Statistics, Scheffe test is applied for classifying the moving vehicles [17, 19]. It can be assumed that possibility to apply signal processing methods and statistical analyses will approve object classification.

The paper includes the following sections: Introduction, Signal and data processing, Experimental results, Conclusions, and References.

2. Signal and Data Processing

The block-scheme of a proposed algorithm for vehicle classification based on their GPS signal shadow is shown in Fig 1.

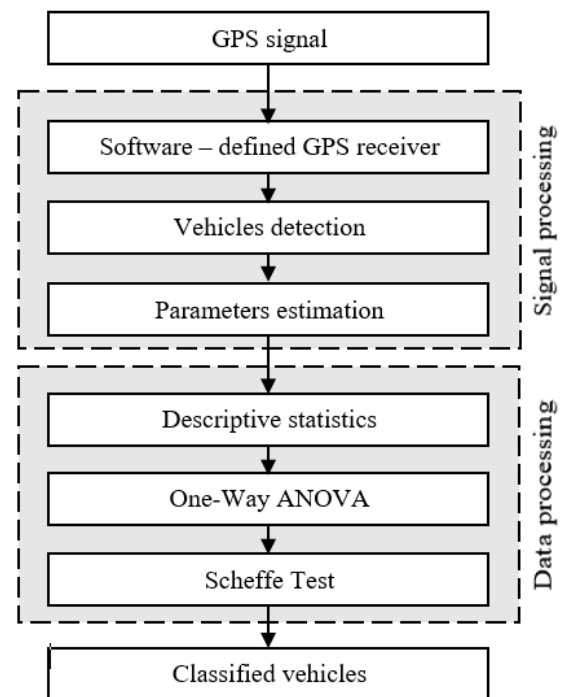


Fig. 1 Signal and data processing

According to Fig. 1, in the software-defined GPS receiver, the phase quadrature component of the signal at the output of the Code & Carrier block (I_p) is obtained as a result of execution of a set of program files for acquisition and tracking, presented in [10-12]. The signal I_p is further transformed as follows:

$$y = [(x - \max(x))]^2, \text{ where } x = \text{abs}(I_p) \quad (1)$$

The SNR of the signal y is further improved by filtering using the Moving Average Filter [15, 16]. According to the CFAR detection approach based on the criterion of Neyman – Pearson, the following algorithm can be used for testing a simple hypothesis H_1 (target is present) against a simple alternative H_0 (target is absent):

$$H_1 : \text{if } \max\{y_f(n)\} \geq T_{fa} \cdot \sum_{l=1}^L y_f'(l) \quad (2)$$

$$H_0 : \text{otherwise}$$

Target detection is indicated if the integrated signal exceeds a predetermined threshold [10].

The registered GPS signal shadows are characterized by the following parameters (Figure 2):

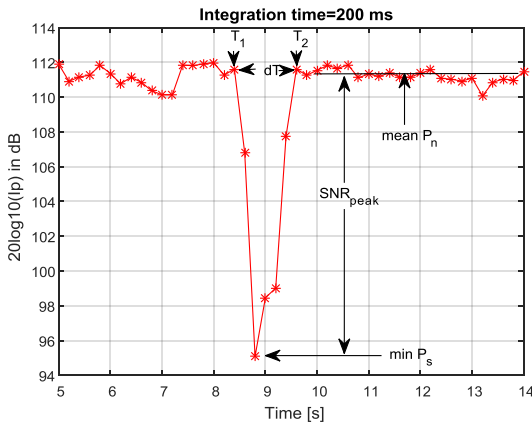


Fig. 2 GPS shadow parameters

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

$$dT = T_2 - T_1 \tag{3}$$

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

Peak Signal-to-Noise Ratio (SNR), estimated as the difference between the average noise power in dB and minimal value of the radio shadow in dB, found in the interval $[T_1, T_2]$:

$$SNR = mean(P_n) - min(P_s) \tag{4}$$

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

Mean Power of the Target Shadow (P_{aver}) in dB is estimated as:

$$P_{aver} = 10log_{10}(mean(P_{s,i})), i = 1 \div N \tag{5}$$

Mean Energy of the Target Shadow (E_{aver}) is calculated as a result of the average power and the length of the shadow in the time samples:

$$E_{aver} = P_{ave} N \tag{6}$$

The classification procedure starts with descriptive statistics consideration such as number of cases, mean, standard deviation, standard error of the mean, minimum, maximum, and 95% confidence interval for the mean, summarized the distinguished characteristics of the sample. Then One-Way ANOVA technique is applied for a quantitative dependent variable by a single factor (independent) variable in order to test the hypothesis that several means are equal. When One-Way ANOVA and F-tests outline that there are statistically significant differences between categories, post hoc tests are conducted to identify exactly which means differ.

Scheffe test for post hoc multiple comparisons is the most flexible test that reveals significantly different group means as well as homogeneous subsets of means that are not different from each other at an alpha level of 0.05 that is why it is preferred in statistical analysis [17, 19].

3. Experimental Results

The experimental scenario includes three cars, which are small, middle and large ones (Kia Rio, VW Touran, and Opel Vivaro). The cars are simultaneously moving in one direction at a velocity of 20 km per hour. They are moving at 5 ÷ 10 m from each other. During the experiment the stationary-based GPS receiver (a GPS recording system developed by the Colorado University) records the GPS signal, which include shadows from moving cars (Figure 3). The distance from the GPS receiver up to the cars is between 2 ÷ 4 m. In order to record shadows from vehicles should be selected only such satellites that are low located over the horizon. In the experimental scenario, this condition for the occurrence of the forward scatter GPS effect was fulfilled. The purpose of these experiments is to make records of GPS signal shadows from moving objects, 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 will be used for car classification by Scheffe test.



Fig. 3 Experiment topology

In this experimental study, the software GPS L1-based recording system (GNSS_SDR) is used to record and store GPS signals from different vehicles. The number of signal records for Kia Rio is 105, for VW Touran is 96, and for Opel Vivaro is 73. To detect radio shadows of moving targets the averaging algorithm is used with an interval of integration 200 ms. After estimation of the parameters of the GPS signal shadows from three types of cars, statistical data processing is performed to classify the moving objects. The mathematical expectation and the standard deviation of all measured parameters have been calculated for each experimental car (Table 1).

Table 1: Mathematical expectation and standard deviation of shadow parameters for three types of cars

Descriptive Statistics						
Targets	Length/Height (mm)	Estim.	dT	SNR	P _{aver}	E _{aver}
Kia Rio	4045/1455	Mean	1.21	8.84	2.77	14.85
		STD	0.34	5.17	2.51	16.14
VW Touran	4406/1685	Mean	1.34	10.26	3.80	16.90
		STD	0.28	4.62	2.02	9.12
Opel Vivaro	4998/1971	Mean	1.54	12.68	5.40	29.23
		STD	0.41	4.00	2.42	17.24

The application of One-Way ANOVA makes it possible to assess how variations of the independent variable “car type” affect the variations in the means of the dependent variables dT , SNR , P_{aver} , and E_{aver} (see Table 2).

Table 2: One-Way ANOVA

ANOVA						
		Sum of Squares	df	Mean Square	F	p
<i>dT</i>	Between Groups	4.81	2	2.41	21.08	0.000
	Within Groups	30.93	271	0.11		
	Total	35.75	273			
<i>SNR</i>	Between Groups	638.19	2	319.09	14.52	0.000
	Within Groups	5955.61	271	21.98		
	Total	6593.79	273			
<i>P_{aver}</i>	Between Groups	298.34	2	149.17	27.53	0.000
	Within Groups	1468.17	271	5.42		
	Total	1766.51	273			
<i>E_{aver}</i>	Between Groups	9822.91	2	4911.46	23.60	0.000
	Within Groups	56403.56	271	208.13		
	Total	66226.47	273			

The results show that “car type” as a “factor variable” causes significant mean differences in all dependent variables at $p < 0.001$ and $df=2,271$: $F=21.08$ at $p=0.000$ for *dT*; $F=14.52$ at $p=0.000$ for *SNR*; $F=27.53$ at $p=0.000$ for *P_{aver}*, and $F=23.60$ at $p=0.000$ for *E_{aver}*. F-value reveals that the strongest factor impact is found at *P_{aver}*, *E_{aver}* and *dT*, and less at *SNR*. Post Hoc Multiple Comparison Tests outline statistically significant mean differences, as exhibited in Table 3.

Table 3: Post Hoc Multiple Comparisons

Scheffe Tests					
	(I) Car Type	(J) Car Type	Mean Difference (I-J)	Std. Error	Sig.
<i>dT</i>	VW Touran	Kia Rio	0.14*	0.05	0.017
		Opel Vivaro	-0.20*	0.05	0.001
	Kia Rio	VW Touran	-0.14*	0.05	0.017
		Opel Vivaro	-0.33*	0.05	0.000
	Opel Vivaro	VW Touran	0.20*	0.05	0.001
		Kia Rio	0.33*	0.05	0.000
<i>SNR</i>	VW Touran	Kia Rio	1.43	0.66	0.099
		Opel Vivaro	-2.42*	0.73	0.005
	Kia Rio	VW Touran	-1.43	0.66	0.099
		Opel Vivaro	-3.85*	0.71	0.000
	Opel Vivaro	VW Touran	2.42*	0.73	0.005
		Kia Rio	3.85*	0.71	0.000
<i>P_{aver}</i>	VW Touran	Kia Rio	1.04*	0.33	0.007
		Opel Vivaro	-1.59*	0.36	0.000
	Kia Rio	VW Touran	-1.04*	0.33	0.007
		Opel Vivaro	-2.63*	0.35	0.000
	Opel Vivaro	VW Touran	1.59*	0.36	0.000
		Kia Rio	2.63*	0.35	0.000
<i>E_{aver}</i>	VW Touran	Kia Rio	2.04	2.04	0.605

	Kia Rio	Opel Vivaro	-12.33*	2.24	0.000
		VW Touran	-2.04	2.04	0.605
	Opel Vivaro	VW Touran	-14.37*	2.20	0.000
		Kia Rio	14.37*	2.20	0.000

*The mean difference is significant at the 0.05 level.

According to the Scheffe tests, there is a significant mean difference at $p < 0.05$ between each couple of compared means, except for Kia Rio and VW Touran, with regard to *SNR* and *E_{aver}* (Table 3). These findings suggest that there are significant differences among analyzed moving targets. Means for groups in homogeneous subsets are displayed in Table 4-7. The harmonic mean of the group sizes is used, because the group sizes are unequal. Harmonic mean sample size is 89.18.

Table 4: Homogeneous Subsets for *dT*

Scheffe: <i>dT</i>				
Car type	N	Subset for alpha = 0.05		
		1	2	3
Kia Rio	105	1.21		
VW Touran	96		1.34	
Opel Vivaro	73			1.54

Table 5: Homogeneous Subsets for *P_{aver}*

Scheffe: <i>P_{aver}</i>				
Car type	N	Subset for alpha = 0.05		
		1	2	3
Kia Rio	105	2.77		
VW Touran	96		3.80	
Opel Vivaro	73			5.40

Table 6: Homogeneous Subsets for *SNR*

Scheffe: <i>SNR</i>			
Car type	N	Subset for alpha = 0.05	
		1	2
Kia Rio	105	8.84	
VW Touran	96	10.26	
Opel Vivaro	73		12.68

Table 7: Homogeneous Subsets for *E_{aver}*

Scheffe: <i>E_{aver}</i>			
Car type	N	Subset for alpha = 0.05	
		1	2
Kia Rio	105	14.85	
VW Touran	96	16.80	
Opel Vivaro	73		29.23

Based on homogeneous subsets statistics it can be concluded that the classification algorithm differs: the three cars into three clusters with regard to *dT* and *P_{aver}*, but grouped them into two clusters in terms of *SNR* and *E_{aver}* due to similar characteristics of the small- and the middle-sized cars in our experiment.

5. Conclusions

In this paper, measuring and classification of moving objects based on their GPS signal shadow are obtained. The parameter estimations of GPS signal shadow from moving cars are processed in MATLAB environment. In IBM SPSS Statistics, Scheffe test is used for classifying the moving objects. The results reveal that signal processing of GPS signal shadow and statistical technique can be successfully applied in practice for classification purposes.

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