*International Journal of Advances in Computer Science & Its Applications*
*Volume 6 : Issue 1 [ISSN 2250-3765]*
*Publication Date : 18 April, 2016*

# A Novel Criterion for Vehicle Classification using Inductive Vehicle Signatures

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***Abstract*— Inductive Loop Detectors (ILD) are the most commonly used sensors in traffic management systems. Using the acquired inductive signatures, most proposed systems classify the vehicles using a criterion based on the estimation of the vehicle length, which requires to have a good a-priori estimate of its speed. Contrary to such standard proposals, in this paper we present a method for vehicle classification based on the criterion of the Fourier Transform (FT), which shows several interesting properties: firstly, robustness against variations in vehicle speed or constant acceleration, and secondly, only one inductive signature is required. Our method will be evaluated using real inductive signatures captured with a hardware prototype also developed by us.**

**Keywords—*vehicle classification, inductive loop detectors, Fourier transform, sensors, signal processing, data acquisition, data classification, decision making, hardware prototype.***

## I. Introduction

Since its introduction in the 1960s, *Inductive Loop Detectors* (ILDs) are the most common sensors used in traffic management systems. ILDs have been widely used for tasks such as vehicle classification [1], [2], vehicle re-identification [3], and speed estimation [4].

There exist different implementations of ILDs. In the US4680717A patent [5], a multiplex system for vehicular traffic detection with a single oscillator is presented. Recently, a detector of multiple vehicles requiring multichannel acquisition of analog signals has been developed in [6], which made it overly complex. Furthermore, due to the function not being fully multiplexed and to the use of the same frequencies in near loops, such development causes significant interferences between channels. In [7], we have proposed a multiplex system for a *Simple Detection of Inductive Vehicle Signatures* (SiDIVS). Our proposal implies a fully multiplexed system that avoids the interference between loops thanks to a very simple and almost fully automatic digital measurement process. Therefore, it does not require neither the use of complex and expensive analog processing circuits nor of analog signal acquisition methods.

Most traffic classification systems need accurate and reliable speed estimation with the shortest possible time delay to determine control strategies. Traffic speed estimation using dual loop detectors can be accurate for most cases [8], but it requires an adequate maintenance of both loops. Moreover, most loop stations in traffic operation are still single-loop. Although several algorithms have been developed for single-loop speed estimation, how to obtain an enough accuracy is still an open question [9], [10]. Therefore, the design of a strategy for vehicle classification to be robust against speed variations using only one loop is the main motivation of this work.

Thus, we will propose a method based on analyzing the inductive signatures in the frequency-domain instead of working in the time-domain. Considering now the coefficients in the frequency domain, the first peak is determined and, subsequently, compared with a threshold value obtained from a training step. In order to test our method, we will use inductive signatures captured with our prototype (SiDIVS) at a certain place in Galician: the AC-523 road (Ledoño-Meirama, Spain). The results show that our method, referred to as Fourier transform-based method in the following, provides greater accuracy than a traditional vehicle length-based strategy.

This paper is organized as follows. Section II shows the practical implementation of the SiDIVS prototype. Section III presents our classification method. Simulation results obtained using the real signatures captured with SiDIVS are presented in Section I V. Finally, Section V is devoted to the conclusions.

## II. SiVIDS Prototype

The SiDIVS prototype includes hardware and software elements needed for both signature measurement and registration. In this paper we will describe only some of the most interesting aspects, and we suggest to see more details in [7]. The implementation has eight channels, allowing the registration of signatures of up to four lanes with dual loops in each lane or of up to eight lanes with simple loops in each lane. This covers most of the existing types of roads and makes the system easy to be built thanks to the availability of a large number of standard circuits with eight channels, like multiplexers, decoders, buffers, etc.

The oscillation circuit employed in the proposed implementation is the well-known Colpitts oscillator, since it is the simplest resonant LC oscillator. The pulses from the oscillation loop that has been selected as input are carried to a counter input, so that when a fixed number of pulses, denoted as $m$, is reached, the measured clock signal periods, denoted as $N$, are captured from a timer working at the frequency of the reference clock signal, $f_r$. The use of eight oscillators instead of a single one allows us to avoid the introduction of an analog multiplexer into the oscillation loop, which would be an additional error source. The output signal of the multiplexer is carried to a shaping circuit, which converts the sinusoidal signal at its input into a digital pulse. That digital pulse is the

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input at the counter in the micro controller, which manages the entire system.

Due to the large amount of data captured by the system, a *Compact Flash* (CF) memory is employed for the recording of the signatures that will be subsequently analyzed by a computer using signal processing algorithms. This off-line work will allow us to perform the vehicle classification for monitoring and control applications of vehicular traffic.

For the implementation of our system we have chosen the AT89C51RE2 microcontroller since it incorporates the comparison and capture units needed in our application and it can be easily interconnected to a CF memory bus.

Fig. 1 shows a picture of the implemented hardware prototype. The left side of the board includes the eight oscillation circuits with multiplexing and a 16-pin connector for the connection of the eight inductive coils. The right side contains the micro controller and a *Real-Time Clock* (RTC) circuit with a lithium battery providing the date and time. The CF memory card used for the storage of the captured signatures can be seen at the bottom. One of the main advantages of the proposed system is that it can be implemented at a very low cost, thanks to its simplicity.

The oscillation period of the coils is continuously measured to determine the reference value of each coil at rest, i.e., without the presence of a vehicle. With the objective of adapting to the variations in the environmental conditions indicated by the coils, an adaptive algorithm is employed to correct the reference value accordingly to such external factors. When the measured period of a coil is less than its reference value, which means that a vehicle is over the coil, the corresponding entry is made in the internal memory, storing the inductive signature of the vehicle.

## III. Classification Methods

This section will describe our proposed method to classify vehicles as opposed to standard strategies that have been used for this purpose.

### A. *Length-based Method*

Since two inductive signatures are obtained from each passing vehicle, the traditional method to classify vehicles consists of estimating their length. Let $t_i^i$ and $t_f^i$ be the initial and the final time instants of a vehicle in the loop $i$ ($i=1, 2$), respectively, and $d$ the distance between the initial point of both loops. The vehicle speed is then computed as follows

$$\hat{s} = \frac{d}{t_i^2 - t_i^1}. \quad (1)$$

The length estimate of a vehicle, denoted as $\hat{L}$, can be obtained by using the following expression

$$\hat{L} = \hat{s}\,\frac{(t_f^1 - t_i^1) + (t_f^2 - t_i^2)}{2} - l, \quad (2)$$

Fig. 1. Photo of the hardware prototype.

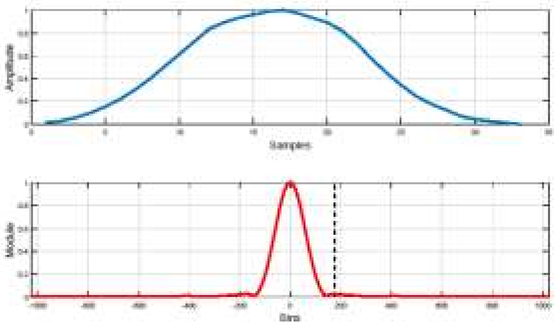
where $l$ is the loop length (that it is assumed to be the same for both loops).

Since we are interested in classifying the vehicles accordingly to three types i.e., cars, vans and trucks, we will have to determine two decision values or thresholds, denoted as $\varepsilon_1$ and $\varepsilon_2$. Instead of using pre-fixed lengths, such thresholds will be obtained from a training step by minimizing the classification errors between similar vehicles i.e., cars-vans and vans-trucks. Therefore, using this length-based criterion, the estimated length $\hat{L}$ is computed from each acquired signature and, subsequently, compared with the test thresholds as described in the following rule,

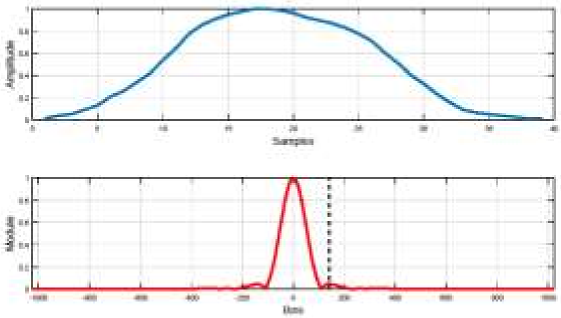
$$\begin{aligned} &\hat{L} \le \varepsilon_1 \rightarrow Car, \\ &\varepsilon_1 < \hat{L} \le \varepsilon_2 \rightarrow Van, \\ &\hat{L} > \varepsilon_2 \rightarrow Truck. \end{aligned} \quad (3)$$

### B. *Proposed Fourier Transform-based Method*

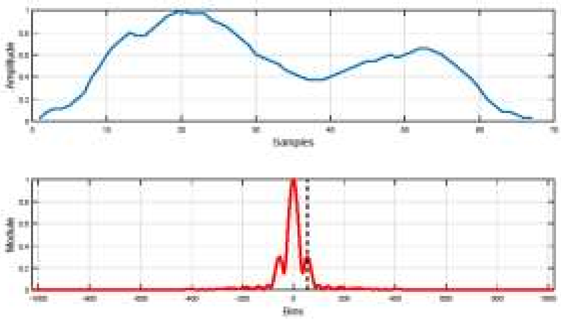
Fig. 2 shows three real signatures captured with SiDIVS: one corresponding to a car, another one to a van, and the last one to a truck. For each example, the louder part corresponds to the acquired signature, which has been normalized with respect to its maximum value. The bottom part is the FT, computed by means of the Fast Fourier Transform (FFT) algorithm, which has been also normalized respect to the coefficient at the frequency bin $f=0$. The maximum frequency bin after $f=0$ is marked with a dark line in the corresponding figures. Note that the signatures of cars and vans are very similar, although for vans we can observe a peak at the frequency bin $f = 170$ greater than that appeared in the case of cars. Moreover, as it can be concluded from observing the FT of the truck example, its first peak or local maximum is higher compared to those obtained for both car and van examples.




(a) Car signature.




(b) Van signature.




(c) Truck signature.

Fig. 2. Examples of inductive signatures.

Taking into account the FT of each type of vehicle before explained, the proposed **FT-based criterion** computes the FT of the acquired signature. Then, it finds the first peak as follows,

$$\hat{c} = \frac{\max\left(\left|Y(f>0)\right|\right)}{\left|Y(f=0)\right|}, \tag{4}$$

where *Y(f)* represents the Fourier transform coefficient corresponding to the frequency bin $f$. With this estimated value, denoted by $\hat{c}$, the vehicle type will be determined using the following rule,

$$\begin{aligned} &\hat{c} \le \varepsilon_1 \rightarrow Car, \\ &\varepsilon_1 < \hat{c} \le \varepsilon_2 \rightarrow Van, \\ &\hat{c} > \varepsilon_2 \rightarrow Truck. \end{aligned} \tag{5}$$

# IV. Experimental Results

We have captured more than nine hundred inductive signatures in one real scenario, the AC-523 road (Ledoño-Meirama, Spain), as was mentioned before. At the same place where the inductive signatures have been captured, we have placed a video camera for the recording of the passing vehicles, so we could associate each vehicle to its corresponding inductive signature. Using the signatures and the video, all the signatures have been classified into the three different types considered in this work, i.e. cars, vans and trucks, by means of a manual procedure.

As it can be seen in Fig. 3, there are two inductive loop sensors in each side of the road and, as a result, we can obtain two signatures from each passing vehicle. These sensors are squares with a side length of $w = l = 200$ cm and a distance between their centers of 5 m. These inductive signatures will be very similar, although there can be small differences due to the fact that they are taken in different loops and time instants and, in general, for different positions and accelerations of the vehicle.

For the training step, we have used a total of *909* signatures registered in the loops 1 and 3 of the AC-523 road, with a total number of *680* cars, *61* vans, and *168* trucks. As explained before, the optimum thresholds obtained from the test are the following,

- Length-based method: $\varepsilon_1 = 560$ cm, and $\varepsilon_2 = 650$ cm.
- FT-based method: $\varepsilon_1 = 0.06$, and $\varepsilon_2 = 0.11$.

Table I shows the error percentage for each type of vehicle classification obtained from our scenario, i.e. the AC-523 road, with the training step (using the loops 1 and 3 for considering all passing vehicles), and also considering the loops 2 and 4. Thus, we can register all the vehicles passing on the road. We can see that the smallest errors are obtained when our FT criterion is applied, with the enormous advantage of using only one loop per lane. Moreover, most classification errors are produced for vans, since car and van signatures are very similar, as it can be seen in Fig. 2. However, note that the FT criterion proposed in this paper leads to fewer errors in such case than the corresponding length-based criterion.

# V. Conclusions

This paper presents a simple method to classify vehicles accordingly to three vehicle types: cars, vans and trucks. The inductive signatures are transformed to the frequency domain using the well-known Fourier transform. Experimental results performed with our prototype, also briefly described in the paper, show that the proposed method based on a spectral feature extraction provides a more reduced total classification error under real scenarios than standard strategies, but also with a very low computational cost.

## Acknowledgment

The authors thank Xunta de Galicia and Ministerio de Economía y Competitividad of Spain for its financial support under grants number R2014/037 and TEC2013-47141-C4-1- R,

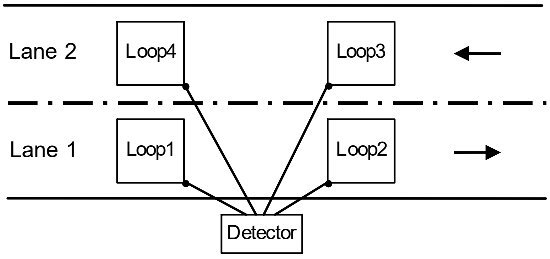



Fig. 3. Interconnections from the inductive loop to the detector.

TABLE I
CLASSIFICATION ERROR (%) IN AC-523

| Criteria | Cars | Vans | Trucks | Total |
|---|---|---|---|---|
| Length, training step | 2.06 | 55.74 | 4.17 | 6.05 |
| FT, loops 1 and 3, training step | 1.62 | 31.15 | 4.76 | 4.18 |
| FT, loops 2 and 4 | 2.06 | 32.79 | 8.33 | 5.28 |

respectively. The authors also thank Dimaco S.C.G. (A Coruña) by the assignment of infrastructures needed for the experimental tests in real scenarios.

## References

[1] J. Gajda, R. Sroka, M. Stencel, A. Wajda, and T. Zeglen, "A vehicle classification based on inductive loop detectors," in *Instrumentation and Measurement Technology Conference, 2001. IMTC 2001. Proceedings of the 18th IEEE*, vol. 1, May 2001, pp. 460–464.

[2] S.-T. Jeng, L. Chu, and S. Hernández, "Wavelet–k nearest neighbor vehicle classification approach with inductive loop signatures," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2380, pp. 72–80, 2013.

[3] M. Ndoye, V. Totten, B. Carter, D. Bullock, and J. Krogmeier, "Vehicle detector signature processing and vehicle reidentification for travel time estimation," in *Transportation Research Board 87th Annual Meeting*, May 2008.

[4] Y. Wang and N. L. Nihan, "Freeway traffic speed estimation with single-loop outputs," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1727, pp. 120–126, 2000.

[5] M. Martin, "Microprocessor controlled loop detector system," Jul. 14 1987, uS Patent 4,680,717. [Online]. Available: http://www.google.co.in/patents/US4680717

[6] S. Ali, B. George, L. Vanajakshi, and J. Venkatraman, "A multiple inductive loop vehicle detection system for heterogeneous and lane-less traffic," *Instrumentation and Measurement, IEEE Transactions on*, vol. 61, no. 5, pp. 1353–1360, May 2012.

[7] J. J. Lamas-Seco, P. M. Castro, F. J. Vazquez-Araujo, and A. Dapena, "Sistema multiplex para la deteccion sencilla de huellas inductivas de vehiculos," in *XXIX Simposium Nacional de la Union Cientifica Internacional de Radio (URSI)*, September 2014.

[8] B. Coifman, "Using dual-loop speed traps to identify detector errors," *Transportation Research Record: Journal of the Transportation Re- searchBoard*, , no. 47–58, 1999.

[9] Z. Jia, C. C., C. B., and P. Varaiya, "The pems algorithms for accurate, real-time estimates of g-factors and speeds from single-loop detectors," in *ITSC 2001. 2001 IEEE Intelligent Transportation Systems.*, vol. 1, August 2001, p. 536–541.

[10] X.-Y. Lu, P. Varaiya, R. Horowitz, Z. Guo, and J. Palen, "Estimating traffic speed with single inductive loop event data," in *Urban and Traffic Data Systems 2012*, vol. 1, August 2012, p. 157–166.

[11] L. A. Klein, M. K. Mills, and D. R. Gibson, "Use of vehicle signature analysis and lexicographic optimization for vehicle re-identification on freeways," *Traffic Detector Handbook: Third Edition—Volume I. Federal Highway Administration*, U.S. Department of Transportation. FHWA- HRT-06-108. 2006.

[12] C. M. Day, T. M. Brennan, M. L. Harding, H. Premachandra, and A. Jacobs, "Three dimensional mapping of inductive loop detector sensitivity using field measurement," vol. 2128, pp. 35–47, 2008.

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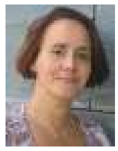

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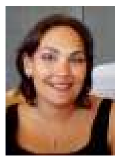

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