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Geo-referencing naturalistic driving data using a novel method based on vehicle speed

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Abstract: Naturalistic driving is an experimentation model that allows us to recognise the driving modes observing the driver's behaviour at the wheel of a set of people in natural conditions during long periods of observation. This research methodology aims at increasing the representativeness of the data collected in opposition to data stemming from highly controlled laboratory experiments. However, naturalistic driving research designs produce large volumes of data that are difficult to handle. Thus, it is very important to work with suitable methods for representing and interpreting data, allowing us to observe the variability of the results. The aim of this study is to implement a new methodology adapted to the particularities of the naturalistic method that allows us to retrieve the positioning information through a georeferencing process of the available data. This method is the first step (preprocessing) to achieve a more clear and intuitive representation (cartographic representation) using Geographic Information Systems (GIS).

1 Introduction

For the last few years, naturalistic driving studies have become an important trend in the area of traffic safety, in order to characterise driving behaviour in realistic situations. Naturalistic driving observation is a method to objectively observe individual driver and crash-related behaviour. More specifically, naturalistic driving observation includes objectively and unobtrusively observing a group of standard drivers in their normal driving context while driving their own vehicles. Its methodology is based on the control of the whole process of driving continuously for different subjects. This method allows for observation of the driver, vehicle, road and traffic environments as well as the interaction between these factors. Some important studies of this issue can be found in [1–8].

Naturalistic driving observation can be described as a 'massive' and 'blind' method to analyse a large amount of parameters. It is so-called massive because it tries to collect and parameterise all the aspects that have influence on driving, whereas as blind because there is no specific goal. Rather, it can be used for many different goals, namely, relative to the vehicle, to the infrastructures and to the driver [1, 7, 9]. To be specific, concrete goals are the study of the driver's behaviour [10–12], the analysis and improvement of car following models [2, 13], the assessment of drivers' drowsiness and distraction [5, 14, 15], the inattention on near-crash/crash risk [1], recognising safety–critical events [3, 16], the evaluation of automotive forward collision warning and collision avoidance [17], the driver eye fixations [18], the manoeuvres and the relation between driver distraction and interaction with electronic devices [19, 20], the analysis of driver's brake operation in near-crash situation [21] and lane changes [6].

Naturalistic driving is a research method with two main advantages over the traditional methods: (a) the experimental process is unconditional given that the investigator has a minimal intervention over the test and (b) it allows to study a great number of parameters and variables that have (or can have) influence on the driver's behaviour. However, this method also has major drawbacks like requiring heavy resources in terms of samples, duration, gathering, storage, reduction, analysis and interpretation of data. One of the most complex processes is undoubtedly the reduction of data before performing analysis. Thus, once the data are collected, a filtering data process is performed, that is named triggering the data [3]. The main goal of this data reduction approach is the discrimination between normal driving situations (negative situations) and the critical events (positive situations) while driving [4].

In Europe, the PROLOGUE project stands for PROmoting real Life Observation for Gaining Understanding of road user behaviour [7, 22]. The main objective of PROLOGUE is to demonstrate the usefulness, value and feasibility of conducting naturalistic driving observation studies in a European context in order to investigate traffic safety of road users, as well as other traffic-related issues such as eco-driving and traffic flow management. In Spain, PROLOGUE was performed by INTRAS (University Research Institute on Traffic and Road Safety) through a test field performed near the city of Valencia during the months of June and July of 2010 [23]. For the performance of this trial, five drivers participated for four days and for two hours every day. In this test, a group of parameters were measured:

- Group 1: Dynamics of the car: distances, speed
- Group 2: Relation driver–vehicle: steering wheel rotation angle, pedal positions, gear
- Group 3: Comfort parameters: regulation of electric windows, use of control locking
- Group 4: Parameter of instrument panel: indicators (water temperature, oil, fuel)
- Group 5: Environmental parameters: temperatures (outside, inside), interior noise
- Group 6: Data acquisition parameters for the driver: visual behaviour (driver), additional dashboard
- Group 7: Monitoring parameters of experimental events: activation of experimental stimulus, stimulus buttons

The experience of INTRAS in this trial allows recognising two limitations about this trial. On the first hand, it was not a pure trial because the employed car (named ARGOS) was an experimental car and not the drivers' own car [23]. This simple fact can partially influence in the driver's behaviour. On the second hand, the driver is given a set of initial instructions before the test that can influence its natural driving behaviour as well.

Naturalistic driving research designs produce large volumes of data that are difficult to handle. Thus, it is very important to work with good methods for representing and interpreting data, allowing you to observe the variability of the results. One of the best ways to represent data collected in naturalistic settings is via cartographic representation. Thus, data can be integrated in a Geographic Information System (GIS) to geospatially analyse it. A complete review of the subject of GIS can be found in [24, 25]. For this purpose, it is important to work with accurate georeferencing and coordinate systems, such as Differential Global Navigation Satellite Systems (DGNSS), which give us a kinematic (moving vehicles), accurate (in the range of centimetre–decimetre), steady and reliable (signal loss) positioning. However, there are certain moments when positioning may not be recorded, be unreliable or positioning data may simply not be collected due to information saturation and/or system failures. Signal loss can often be justified when the satellite signal cannot reach the receiver as in underpasses, but there can be difficult reception conditions due to the effect of multipath or other error sources as well [26–28]. The combination of high precision Global Navigation Satellite Systems and inertial measurement is the most common technique to carry out this precise positioning since in some areas Global Positioning Systems (GPS) signals are lost or degraded [29].

A comprehensive bibliography can be found focusing both on the topic of positioning systems with GNSS [30–32] and on kinematic positioning type [33, 34]. It is recommended to read [35–37] for this type of work and applied to traffic management.

2 Methodology for recovering and preprocesing data

Although there are cartographic studies focusing on the analysis of traffic data [38–41], almost none focuses on the representation of naturalistic driving data. Moreover, previous studies that use GIS in road traffic applications have shown a number of applications as the implementation of control systems and traffic management [42, 43], urban traffic noise pollution [44] and analysis of congestion in urban environments [45]. Only Gordon *et al.* [46] considered the relation between naturalistic driving and GIS analysing specific situations of crashes and critical situations. However, a complete representation of the large data sets is needed to develop normal driving patterns. Furthermore, none of the works mentioned above proposes a methodology for recovering the lost data.

The experiment carried out by INTRAS in 2010 allowed to record a large amount of data on different studied variables (such as speed, acceleration, steering angle, etc.) with a temporal frequency of 1 cs (10^{-2} s). However, there was no positioning information, making it impossible to georeference the available information. For this purpose, it was then proposed to achieve a method for georeferencing the available data to make a positioning in every moment of the track possible.

Thus at first, a stretch of road was chosen that was common to every experimental day to compare between different days and/or subjects more easily. For this study, a section of the V-21 highway was chosen in both directions (round trip), of about 16 km long, between the city of Valencia (Spain) in its northern boundary and the exit 2 of the highway, near to the town of Puzol. For the determination of the reference points of this study, a clearly visible landmark was employed as a road gantry, an access/exit of the highway, a viaduct and/or bridge.

Once the stretch of the road was defined, the way was digitalised to obtain a line considered that served as the axis to locate the reference points. The central axis of the highway was taken as the most accurate approximation to the track followed during the different days of the experiment. A base map, an orthoimage of the Valencian region of 2008, was employed, which was owned by the ICV (Valencian Cartographic Institute), in RGB colour system with a spatial resolution of about 50 cm and defined in the ETRS89 coordinate system, zone 30. On this orthoimage, a common trajectory in both senses was digitalised (round trip) through the polyline tool of any geoprocessing software (Figs. 1*a* and *b*). For this study, the software ArcGIS Desktop from ESRI was used, which allowed to save the file in a proper format, with the shape extension (.shp).

With the road axis, the alphanumeric information was put over it. Since no positioning data were attached to this information, the image data was employed, which was obtained by recording in a video camera system, an important and frequently used device in this type of study [10, 47]. In theory, to carry out the experiment, the test car captured video images from several cameras positioned at different points of view (Fig. 2): scene, back, face and two lateral cameras (SPL-1 and SPL-2). At first, all of them, except the face and back ones, were valid for this experiment as it was possible to observe, with a better or worse point of view, the workspace of interest to this study, that is, the track of the highway.

The use of the cameras with the simultaneous use of a text menu that represented a number of basic variables, such as distance, time, speed and instant acceleration, allowed to extract information from any point on the route. However, because the frequency of data collection for some of these variables was less than the theoretical (1 cs) one, a specific

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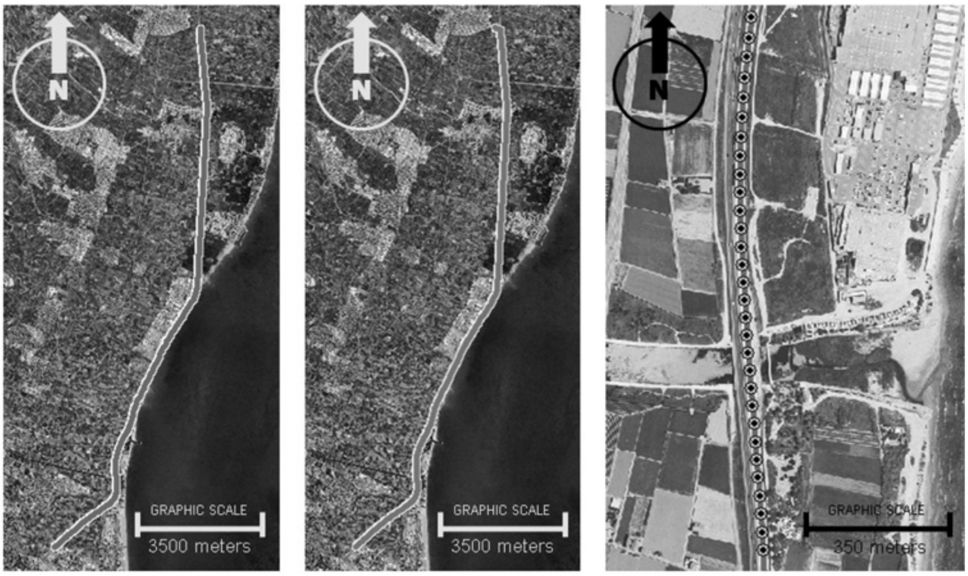
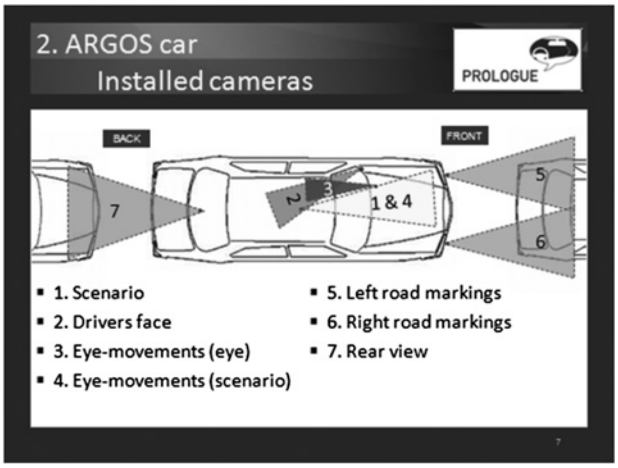


Fig. 1 *Round trip route (image 1a: direction Valencia–Puzol; image 1b: Puzol–Valencia)*
In image 1c a section of the route with georeferenced points can be observed


2. ARGOS car
Installed cameras

- 1. Scenario
- 2. Drivers face
- 3. Eye-movements (eye)
- 4. Eye-movements (scenario)
- 5. Left road markings
- 6. Right road markings
- 7. Rear view

Fig. 2 *Position of the cameras in the experimental car*

procedure was implemented admitting to simplify the amount of information. It is relied on the natural frequency of information captured from the two basic variables in this procedure: time and distance. Thus, while time is taken up with a temporal frequency of 1 cs (10^{-2} s), the distance variable is recorded every second (1 s).

The combined use of video and distance data, time and some additional variables (of support) determines, with a little margin for error, the exact point at which the vehicle passed the baseline estimate. Thus, the range of information of our study's stretch was delimitated. From the starting point, a new database was calculated based on distance increments (Δd), with a temporal frequency of 1 s. Thus, the amount of information was simplified in a ratio of 100:1, permitting to manage the information in a considerably more agile and effective way.

Hence, a set of points was obtained that was georeferenced over the route layer drawn in the ArcGis layer through the polyline coincident to the route. The location should be decided only on the basis of criteria of distance's increments from a point (i) from the previous one ($i-1$), taking as origin the initial point of reference. The number of points for each day depended directly on the everyday vehicle travel time and, consequently, on the traffic events of that day (Fig. 1*c*).

The difference between the lengths of the automatically generated route (experimental one) with respect to the digitised route (theoretical route) is the estimation error (offset). The amount of errors is due to various error sources that will be explained later. The unit of measure of this error will clearly be in metres and its sign is positive or negative, depending on whether the length derived from field data is higher (negative) or lower (positive) than the theoretical route obtained in the digitised mapping process.

$$\text{Estimation error } [m] = \text{experimental route} - \text{theoretical route} \quad (1)$$

This estimation error can be calculated in per cent with respect to the total length of the route, obtaining the '%error'

$$\%\text{error } [\%] = \frac{\text{estimation error} \times 100}{\text{theoretical route}} \quad (2)$$

The results obtained for the different days of the experiment are shown in the following table (Table 1).

All the errors obtained were lower than ±5% of the route length, half of them below ±1.5%. An average error of 1.18% was obtained and a standard deviation of 2.57%, whereas if the sign (absolute errors) was ignored, the average error is 2.29% with a standard deviation of 1.61%. Taking into account the errors obtained initially, a method had been implemented to interpolate the value of offset distance between the set of all points in an equitable manner, thereby obtaining a compensation parameter for each of the points (m/point). This parameter was obtained from the error of estimation, but also inversely depended on the number of points used or, which is the same, the travel time spent by the subject (see Table 1). With this parameter, the route points were forced (experimental route) to be spatially coincident with the theoretical route. In the

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Table 1 Results obtained in the experimentation procedure

Study stretch	Day	Day code	Points	Offset	%error	Compensation
one way (Valencia–Puzol)	29/06/2010	0838	619	−622.89	−3.93	1.01
one way (Valencia–Puzol)	02/07/2010	0813	580	−181.64	−1.15	0.31
one way (Valencia–Puzol)	19/07/2010	0818	589	−167.19	−1.05	0.28
one way (Valencia–Puzol)	2007/2010	0820	530	22.25	0.14	−0.04
one way (Valencia–Puzol)	2307/2010	0807	639	134.29	0.85	−0.21
one way (Valencia–Puzol)	08/07/2010	0806	617	154.57	0.98	−0.25
one way (Valencia–Puzol)	16/07/2010	0821	620	165.58	1.04	−0.27
one way (Valencia–Puzol)	14/07/2010	0804	552	201.36	1.27	−0.37
one way (Valencia–Puzol)	13/07/2010	0823	548	260.07	1.64	−0.48
one way (Valencia–Puzol)	22/07/2010	0829	621	303.16	1.91	−0.49
one way (Valencia–Puzol)	09/07/2010	0807	531	483.60	3.05	−0.91
one way (Valencia–Puzol)	30/06/2010	0832	598	623.06	3.93	−1.04
one way (Valencia–Puzol)	12/07/2010	0844	533	671.55	4.24	−1.26
one way (Valencia–Puzol)	06/07/2010	0839	580	682.50	4.31	−1.18
one way (Valencia–Puzol)	21/07/2010	0811	649	763.05	4.81	−1.18
return (Puzol–Valencia)	23/07/2010	0807	782	−662.21	−4.15	0.85
return (Puzol–Valencia)	21/07/2010	0811	937	−534.53	−3.35	0.57
return (Puzol–Valencia)	20/07/2010	0820	710	−219.09	−1.37	0.31
return (Puzol–Valencia)	02/07/2010	0813	646	11.08	0.07	−0.02
return (Puzol–Valencia)	22/07/2010	0829	1.068	43.27	0.27	−0.04
return (Puzol–Valencia)	01/07/2010	0805	684	48.63	0.30	−0.07
return (Puzol–Valencia)	29/06/2010	0838	652	190.63	1.20	−0.29
return (Puzol–Valencia)	26/07/2010	0809	1.393	237.05	1.49	−0.17
return (Puzol–Valencia)	19/07/2010	0818	1.316	374.22	2.35	−0.28
return (Puzol–Valencia)	15/07/2010	0809	1.001	679.26	4.26	−0.68
return (Puzol–Valencia)	06/07/2010	0839	799	684.14	4.29	−0.86
return (Puzol–Valencia)	08/07/2010	0806	991	722.12	4.53	−0.73

next figure (Fig. 3), data from relative error of the offset distance (*X*-axis) and compensation in metres for each point (*Y*-axis) was related for every trial day.

$$\text{Compensation}\left[\frac{m}{\text{point}}\right] = \frac{\text{estimation error}}{\text{points number}} \tag{3}$$

1.1 Error sources

This methodology is based on a number of not-real assumptions, but necessary in a semi-automatic process of large volumes of information. A set of inaccuracies are included because of different error sources. Among these error sources, the following ones will be highlighted:

- The delimitation of a single common route that passes through the centre of the way. This route does not take into account the variability of movement of the driver (overtaking, changes of position and lane), which leads to irretrievable loss of accuracy.
- Problems in the determination of the reference points of the study stretch due to the problems of saturation and collapse information derived from the data registration system, poor visibility of video because of the problems of image slowdown and/or inclement weather, the presence of noise etc.
- The time offset between the time of capture of the orthoimage (2008) and the moment in which the experiment was performed (2010). Thus, for this time offset there were changes in the design of the road (sections under construction, renovations of the road, etc.), representing a variation with respect to the estimated theoretical route.
- The introduction of the operator error at the time of acquisition of the reference points, motivated by subjective criteria and precision variables when determining the precise moment that such points should be taken.

3 Representation of the georeferenced data through acquired speed parameter

Once the information was georeferenced, the position information of each point was linked to its corresponding

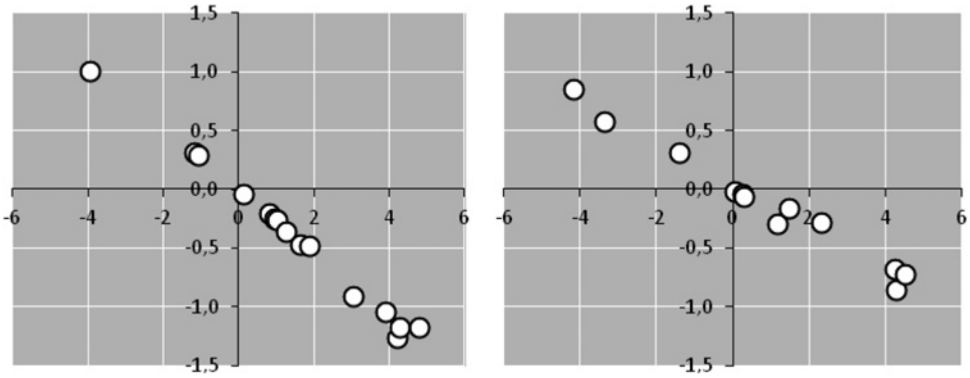

Fig. 3 *Relation between relative error (X-axis) and compensation parameters (Y-axis) for the way out (left image) and return trip (right image)*

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alphanumeric information. At present, any of the data (physical parameters) recorded by the system can be represented during the trial.

Below, there is a sample representation of one of the physical parameters: the acquired speed. In traffic research, the speed parameter is one of the most studied for its relationship with critical–safety situations and accidents. Inappropriate speeds are a source of traffic accidents, higher operating costs and more exhaust emissions, among other negative effects [48]. Many studies relate the speed limits of the track to the driver's behaviour and even to subjective perception regarding these limits [49]. The overall objective of these kinds of studies is to calculate the new speed limits in order to improve road safety and to increase the acceptance and credibility of these speed limits by drivers [48, 50, 51].

First, as an example, defining a track section of 1920 m in the round trip (VLC–Puzol) determined between 1.60 and 3.52 km from the starting point. The specific location of this study area can be observed in the yellow box in Fig. 4. This section is mainly characterised by being one of the most sinuous sections of track and presents, among other interesting aspects, a highway exit in the most northern sector (between kilometre points 3.18 and 3.36).

The graphical representation of the acquired speed parameter by each one of the drivers and on each day is represented in Fig. 5. In this figure, a plot of the evolution of the speed can be seen (*Y*-axis) in relation to the distance (*X*-axis). It can be observed that there is no uniform driving pattern for every driver and every day. However, certain similarities in the driver's behaviour can be observed as, for example, the speed pattern of the first driver (A) between days 1 and 2 and, although less clear, of the last driver (F) between the days 1 and 3, where a similar reduction of speed in the end part can be observed. Furthermore, the speed variability for each one of the drivers and days is

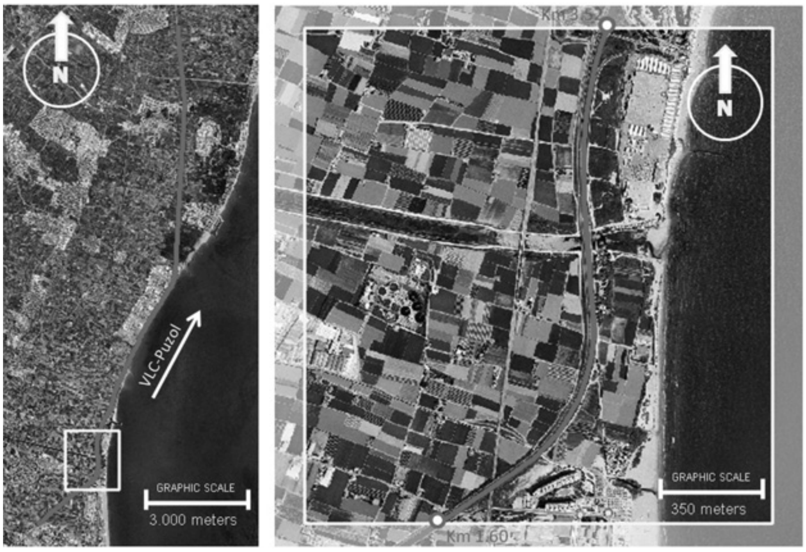

Fig. 4 *Delimitation of the study area for the speed parameter representation for each one of the drivers and days*

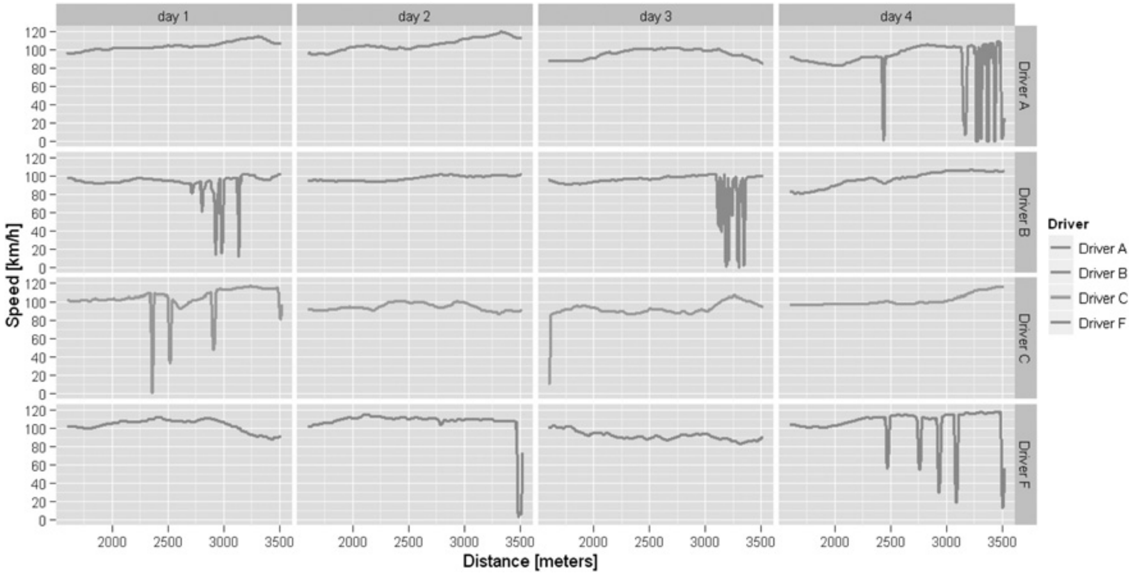

Fig. 5 *Graphical representation of the acquired speed in km/h (Y-axis) for each one of the drivers and days within the delimited section in Fig. 4 (kilometre point in X-axis)*

represented, as well as sharp contrasts were found in some cases due to a variety of reasons: reckless manoeuvres, traffic congestion, and so on.

Another way to represent these data is via cartographic representation, which offers a clearer and more intuitive representation than the traditional methods using the GIS, a tool with a great processing potential. The magnitude of the physical parameter, in this case the acquired speed, is directly represented over the orthoimage, which is of great importance for the interpretation of the variability of the represented parameter.

A new track section of 253 m in length and located in the northern part of our road trip (VLC–Puzol) was determined, between kilometre point 15.57 and the end of the route (kilometre point 15.85). In this section, the most important aspect is the highway exit from the trial vehicle. In Figs. 6*c* and 6*d*, the speed of each driver at each point is represented through the shaded area. Each black line within this shaded area represents a speed isoline separated at intervals of 10 km from each other. It can be observed that the deceleration of driver B was more gradual on day 4 (Fig. 6*c*) than on day 3 (Fig. 6*d*).

Once again, a new area of study was determined, within the first part of our route (VLC–Puzol). This area is represented in Figs. 7*a* and *b*. It corresponds to a track section of 1125 m, between kilometre points 3.12 and 4.25, very close to a residential area (Port Saplaya). Here, the speed is represented through a buffer area, wherein successive speed increments (10 km/h) are represented with different colours. In the images below, there can be noted that the speed of

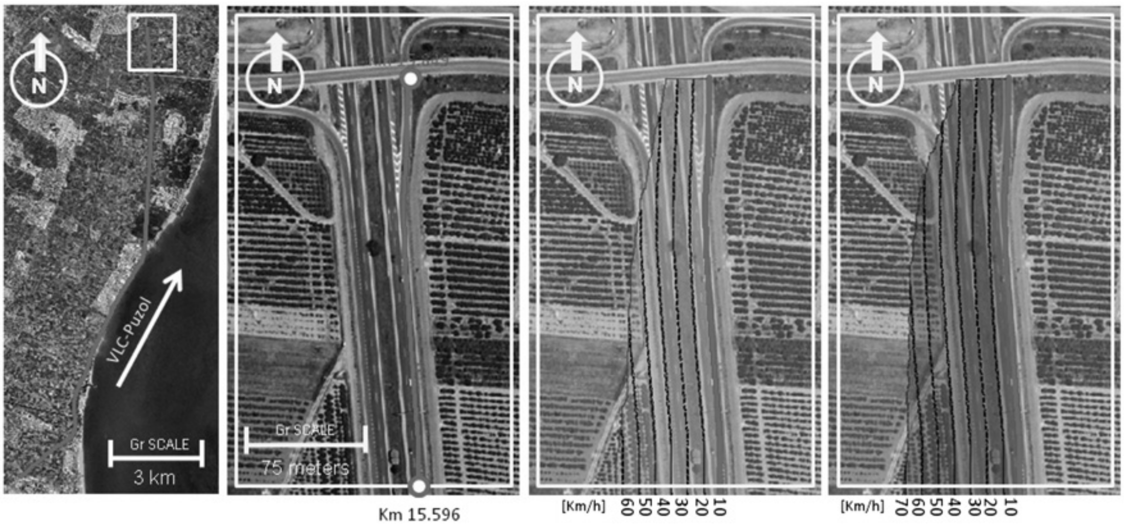

Fig. 6 *Delimitation of the study area (images 6a and 6b). Graphical representation of acquired speed in km/h by driver B in its day 3 and day 4 of the experiment (images 6c and 6d)*

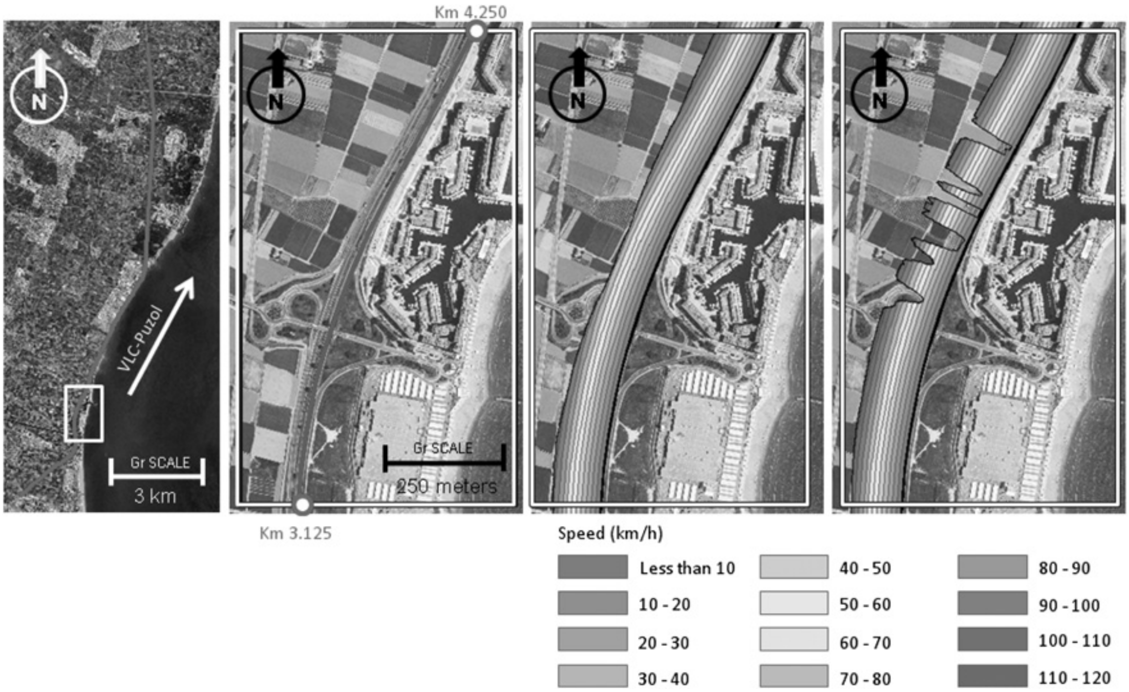

Fig. 7 *Delimitation of the study area (images 7a and 7b). Graphical representation, type histogram, of acquired speed in km/h by driver C in its day 3 and day 4 of the experiment (images 7c and 7d)*

driver C in day 3 (Fig. 7*c*) was more constant than during day 4. The fluctuations represented in day 4 are probably due to traffic congestions.

The representation of naturalistic driving data is a very important issue because it allows a correct interpretation of the data. Once the position of all points is georeferenced, a cartographic representation of the information can be achieved, which produces an added value over more traditional methodologies. This type of representation allows a clear and visual analysis, which plots the variability of the data in a clearer approach than the one derived from mere statistical analysis. Similarly, the mapping of data allows associating the data to a determined spatial event that can totally or partially explain the variability obtained in the data. On the basis of such studies, clear patterns can be established of how some events influence over determined physical parameters, such as certain traffic signs or the presence of exit lanes and/or the incorporation of vehicles on highways. A more thorough analysis of the speed parameter in road traffic taking into account the positioning (spatial component of the data) will allow us to determine the subjective visibility and credibility of traffic signs by drivers regarding their degree of compliance.

4 Conclusions

The naturalistic driving observation is an experimental method with great potential in road safety. Its own methodology generates large amounts of information to help addressing the phenomenon of driving behaviour from different points of view.

One of the best ways to show the information provided by naturalistic observation is the cartographic representation. This requires positioning information on each captured point. However, because of the long exposure of this kind of experimentation combined with the inherent errors in satellite positioning systems, this often implies not to have any information relative to the positioning.

In this paper, an innovative method has been proposed for retrieving positioning information in a naturalistic driving experiment, where the inherent characteristics in this method require devising an automated procedure. The exposed method has the advantage to be entirely innovative and automatic. This allows us to estimate the positioning of large volumes of data quickly and with a high level of accuracy. The obtained results are optimal, as in approximately 50% of the cases the positioning error was lower than ±1.5% of the route length.

Once the positioning of each point has been recovered, the physical parameters on the collected data can be characterised via cartography representation. The examples given in this paper focus on the acquired speed parameter. It can be observed how the mapping is suitable for this type of experiments as it provides a clear representation both for critical situations (positive situations) and for normal driving patterns (negative situations).

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