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Low-cost smartphone-based speed surveying methods in proximity to traffic calming devices

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Abstract

The study is aimed at investigating the effectiveness of two smartphone applications for surveying speeds of moving objects. These applications are used for urban speed measurements. Once the most reliable application was selected among the available ones, its outputs were calibrated by using the speed from the GPS system mounted on the test vehicle as a benchmark. Thereafter, an experimental test was conducted for monitoring the influence of a raised crossing on the vehicle speeds in the urban environment, by using the selected smartphone application.

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Keywords: Low-cost speed surveying; Smartphone application; Speed radar cam; Raised pedestrian crossing

1. Introduction

Contrary to the rural environment, urban crashes are increasing. In Italy, 75 % accidents occur in cities [1], often involving vulnerable users. In order to attenuate them, and to improve the urban quality of life, vehicle speeds should be lowered through specific interventions, also aimed at decreasing the severity of accidents.

While on the one hand the introduction of traffic calming measures is one of the most appropriate solutions to this problem, on the other hand regulations dedicated to the design of these measures are scarce. This slows down their diffusion and implementation. In several European countries, studies relating to traffic calming measures and the decrease in both vehicle speeds and accidents [2, 3, 4, 5] were conducted. Moreover, design guidelines including results from those studies were produced as well [6, 7, 8]. However, each geographic area promotes its own road design and construction criteria, related to specific physics (e.g. materials used), behavioural, and cultural variables;

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leading to experimental results eventually not replicable in other areas. For the effectiveness assessment of a traffic calming device, with respect to crash reductions, before-after studies over long periods [9] may be needed. The assessment of the vehicle speed reductions may require shorter times instead, but also several field observations.

A summary of recent studies specifically inquiring into the influence of traffic calming devices, providing a vertical alignment variation, on vehicle speeds, is provided in Table 1.

Table 1: Studies on the effect of some traffic calming devices (generating a variation in the vertical alignment) on vehicle speeds

Reference source	Instrumentation /technology used	Traffic calming device	Effects on speed
Agerholm et al., 2016 (Denmark) [10]	*Logger GNSS*	sinusoidal bumps (h = 10 cm; L=100 cm)	-8%
Gitelman et al., 2016 (Israel) [11]	*Laser speed gun*	bumps (h = 8-10 cm) and raised pedestrian crossings (h=15 cm)	V_{mean} = 25/30 km/h V_{85}<50 km/h
Gonzalo-Orden et al., 2016 (Spain) [12]	*Mobile RADAR stations*	raised pedestrian crossings versus traditional ones	ΔV = 20 km/h
Moreno and García, 2012 (Spain) [13]	*Passive GPS trackers*	16 raised intersections, 5 bumps and one roundabout	--
Pau and Angius, 2001 (Italy) [14]	*Laser traffic counter*	bumps (h=3 cm; L=60 cm)	-10%
Domenichini L. et al., 2018 (Italy) [15]	*Driving simulator*	raised pedestrian crossings (h=12 cm; L=450 cm; i=3%)	-12/17%
Canale S., Leonardi S., 2006 (Italy) [16]	*Speed camera (Autovelox)*	Sequence of bumps on a road with a longitudinal slope equal to 3%	-15% uphill -20% downhill

Generally, those studies were conducted by employing instruments and technologies associated with not negligible costs. Nowadays, a consistent number of instruments and technologies for vehicle speed surveys are available on the market, as described in the following Section 2. However, most of them are scarcely flexible and rather expensive. In the present study, instruments and free smartphone applications for speed surveys were used. The methods used for the speed surveys through the considered applications; and for selecting the most reliable application, comparing them with a GPS measurement system, are described in Section 3. The calibration curve of the outputs from the selected application was developed and presented in Section 4. The same curve was used to study the effects of a raised pedestrian crossing on vehicle speeds, as discussed in Section 5. Some preliminary indications concerning the correct shape to be used for the device taken into account are then proposed.

2. Traditional technologies and instruments for vehicle speed surveys

A list of the main methods and technologies used for vehicle speed surveys, together with their main advantages and disadvantages, is provided as follows.

Speed measurement systems for a given road section and for aggregated traffic counts:

- *Pneumatic tubes with automatic traffic counting systems*: used for long surveys of vehicle speeds and annual average daily traffic counts. They are sufficiently accurate and inexpensive, but poorly flexible in practice [17].
- *Inductive loop detectors*: generally low-cost and adaptable systems. However, they are scarcely flexible, since they are fixed. Moreover, they may be affected by high maintenance costs, and by the necessity to correlate output data with algorithms used by the control unit.
- *Fixed RADAR stations*: installable on both existing poles and specifically dedicated structures placed on the roadside. They are moderately expensive and can simultaneously survey the speeds of different vehicles in both travel directions. However, surveys are influenced by the inclination angle.

Speed measurement systems with possible continuous surveys and biunivocal link between vehicle and speed:

- *Mobile RADAR stations and LiDAR guns*: used by enforcement officials given their high versatility, precision, and immediate correspondence between vehicles and surveyed speeds. However, they are largely expensive.
- *On-Board Diagnostic (OBD) black boxes*: allowing knowledge of the exact vehicle position and speed through GPS systems. They are often included in insurance policies, and characterized by a sufficient accuracy, if the

device is able to receive inputs from a sufficient number of satellites. However, privacy issues may be raised, and high numbers of devices may be needed for obtaining statistically significant samples.

3. Methods

Methods employed for conducting the study are described here, starting from the presentation of the smartphone applications tested, and then describing the selection of the application employed for the study, and its calibration**.**

3.1. Smartphone applications for vehicle speed surveys

Some smartphone applications capable of surveying vehicle speeds were recently released. Some of them, similarly to OBD systems, record both positions and speeds through smartphone-integrated localization systems. Other applications, such those used in the present work, are capable of converting the smartphone into a "Speed Gun", by means of the integrated camera. In detail, in the present study, two freeware applications were selected, distributed for Android devices: Speed Radar Cam (SRC) and Speed Gun.

The SRC application allows the speed of a moving object to be computed, by measuring the time elapsed between its passage in two small areas identified on the screen. The actual distance between the two areas is known a-priori. Time measurements start each time the application detects a chromatic variation, at the single pixel level, in one of the two small areas identified on the screen. Time measurements end when the chromatic variation is detected in the second area on the screen. If the screen is positioned parallel to the moving object trajectory, an improvement in the accuracy can be obtained (see Fig. 1a). Moreover, for each smartphone type, the distance between the two survey areas should be measured, likely due to the specific focal length of the device.

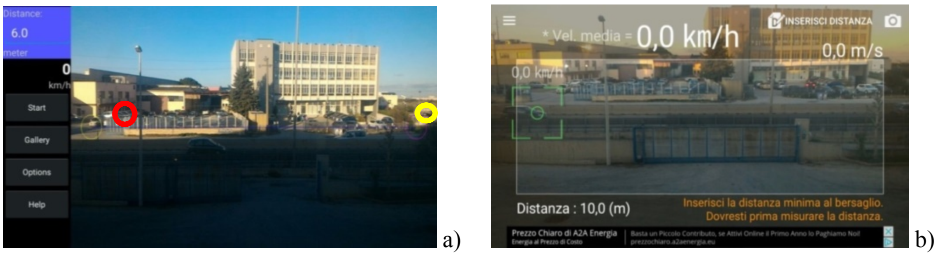

Fig. 1. User interfaces of the applications: (a) SRC; (b) Speed gun

Besides speed measurements, the applications can: provide a complete overview of surveyed data at each passage, choose the relevant unit of measurement, make the size of surveying area on the screen vary, modify the screen resolution, modify the device sensitivity, and modify the survey temporal limit.

The second application *Speed gun* measures the moving object speed by means of a straightforward procedure. In detail, the speed measurement is obtained by: 1) inserting manually the orthogonal distance between the moving object and the camera, 2) touching the screen in the instant in which the object (i.e. vehicle) appears on the screen (this may be the front of the vehicle bumper, or a tyre), 3) dragging the finger on the screen in correspondence to the vehicle movement (not moving away the finger) until the vehicle is outside the screen (Fig. 1b).

3.2. Selection of the application

The first study stages were aimed at selecting the most reliable application to be used for the experimental part.

Stage 1 – Preliminary study. In this stage, the practical aspects related to the two selected applications and the quality of measurements were assessed, together with the analyses of the boundary conditions leading to the reduction in the accidental errors. The following aspects were noticed: 1) Since headlights may activate the SRC surveying system before the actual appearance of the moving object, surveys should be preferably conducted in the presence of daylight; 2) Calibration measurements should be preferably conducted on stretches of flat road, since it is easier to travel on them at constant speeds; 3) A tripod support for the smartphone is essential.

Stage 2 – First survey campaign. The first survey campaign was necessary for identifying the most reliable application among the two preliminary selected applications, based on exploratory surveys.

The surveyed field site is a low-volume volume section in the industrial area of Massafra (Municipality of Taranto, Italy). Two tripods were placed on the roadside. Two identical smartphones were mounted on each tripod, the first with the SRC application installed, the second with the Speed Gun installed.

The vehicle used for the first survey campaign was provided with a GPS navigation device and an analogic speedometer. The driver of the vehicle passed in front of the two tripods for a number of times corresponding to 5 blocks of 10 times (50 times in total). For each of the five blocks, the driver was told to travel at a constant speed of, namely, 10, 20, 30, 40, and 50 km/h. One passenger always accompanied the driver. He had to record the speed indicated on the GPS navigation device (VGPS) at each passage. GPS readings were obtained in presence of a number included between 7 and 9 available satellites, to reduce errors associated to the measures. The differences between the speeds measured by each of the two applications (VSRC = measured by the SRC application, VSG = measured by the Speed Gun application) and the VGPS were then computed. Clearly, GPS readings are affected by errors due to latency, even if surely less than those related to speedometer readings. Descriptive statistics and the frequency distribution of those differences are shown in Table 2 and Fig. 2.

Table 2. Mean values and Standard Deviations (computed over all the tests at different speeds)

	Mean	Standard Deviation
V_{GPS} - V_{SRC} [km/h]	4.46	3.90
V_{GPS} – V_{SG} [km/h]	4.78	10.17

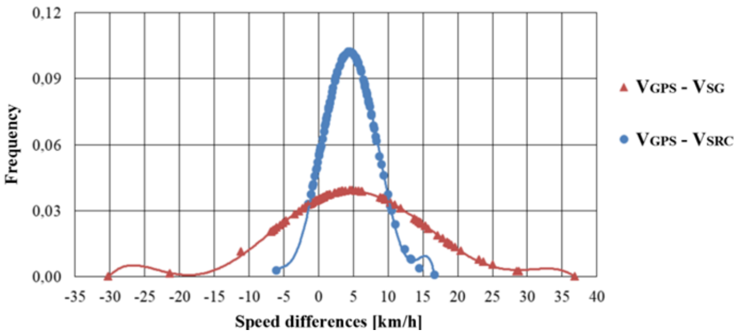

Fig. 2. Cumulative frequency distribution

The obtained results led to the choice of the SRC application. In fact, it shows deviations from the speed measured through the GPS, consistently lower than the ones related to the Speed Gun application. Moreover, the Speed Gun application is characterized by the following main weaknesses: 1) it is often difficult to obtain the shortest distance between the observer and the moving target, and this may lead to highly unreliable measures, 2) the observer must manually follow the moving target on the display. Hence, the remainder of the experimental test was conducted only by using the SRC application.

4. Calibration of the results from the selected application

A second campaign of controlled measurements were conducted, in order to obtain a calibration curve for the speeds measured through the application Speed Radar Cam (SRC). The application was installed on the two previously used smartphones and then, the same measurement procedure described in 3.2 (stage 2) was used again (5 blocks of 10 passages). In this way, a total sample of 150 measurements was available. The deviations of the speeds measured through the SRC application (VSRC) from the GPS navigation device speed (VGPS) were computed. The data were then treated by erasing speed data corresponding to: VGPS > 55 km/h. In fact, 5 passages at five different speeds were conducted (10, 20, 30, 40, and 50 km/h). If an error of ± 5 km/h is accepted for the measured speed corresponding to what should be a "constant" speed traveled by the test drivers, then values less than 5 km/h (not present) and more than 55 km/h can be deemed to be as out of the considered range. In this way, 8 out of 150 observations were excluded from the dataset). Moreover, outliers were identified and erased as well. This was made by further removing data for which the following condition is not met:

$\Delta - \Delta_m \leq 2\Delta_\sigma$ (1)

Where:

$\Delta = V_{GPS} - V_{SRC}$ (km/h), distributed as in Fig. 3;

Δ_m = mean value of the deviations Δ, averaged over all the observations ($V_{GPS} > 55$) = 3.91 km/h;

Δ_σ = standard deviation of the deviations Δ, computed over all the observations ($V_{GPS} > 55$) = 4.47 km/h.

This means that V_{SRC} values for which the related Δ (km/h) is not included in the range: [-5.04; 12.85] were excluded from the dataset used for generating the calibration curve. Hence, 11 observations were further excluded. The calibration curve obtained by plotting V_{GPS} against V_{SRC} for the 131 observations kept after data treatment is shown in Fig. 3. Moreover, deviations Δ were plotted against V_{SRC}, to highlight how Δ varies with travel speed.

It can be noted that the application Speed Radar Cam generally slightly underestimates actual speeds if the V_{GPS} is considered as a benchmark (the slope of the calibration curve is approx. 1.14). Moreover, the deviations Δ increase with the speed increase. In detail, significantly low deviation values were obtained for low speeds.

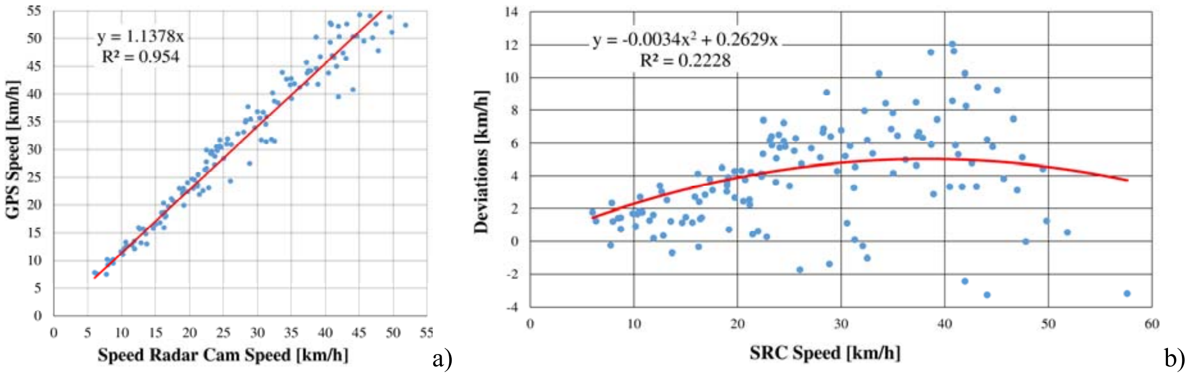

Figure 3: a) V_{SRC} values plotted against V_{GPS} values without outliers; b) Curve of the Deviations

5. Evaluation of the effect of a raised pedestrian crossing on vehicle speeds

For the aim of this study, a raised pedestrian crossing placed on a two-way two-lane urban road in Massafra (Taranto, Italy), having speed limit of 30 km/h, was selected for the speed survey. The raised pedestrian crossing is characterized by the following features: it is 10 cm high, total 550 cm wide, each ramp (on both sides) long enough to achieve a 70 cm raised platform. It is made of asphalt finished with hot press printing and epoxy. Three speed survey stations were used (P1, P2 and P3), placed orthogonally to the vehicular flow in three specific cross-sections: P2 in correspondence with the traffic calming device midpoint, P1 immediately before and P3 immediately after the traffic calming device. Thus, the entrance, passage, and exit speeds were measured through the SRC application.

Table 3: Parameters of the distribution of speeds at the survey stations

	Speed [km/h]		
	P1	**P2**	**P3**
Mean value	20,54	17,52	18,89
Standard Deviation	7,17	7,11	7,07

Figure 4: mean speed profile at the raised crossing

For each survey station, the speeds of 220 vehicles were recorded, leading to 660 total measurements. Each speed measurement was conducted in free flow conditions. Descriptive statistics of the measured speeds at each survey station, calibrated by applying the curve in Fig. 3a, are reported in Table 3.

The diagram of the actual speeds along the vertical alignment of the traffic calming device was extrapolated (Fig. 4). The minimum point of the diagram is placed at approximately 3 m from the start of the ramp leading to the raised platform. Hence, at this point, the estimated reduction in the average speed is approximately 14.5 %, with respect to the entrance speed. This speed reduction is comparable with previous studies in this field (see Table 1).

6. Conclusions

The present study aimed at testing the effectiveness of low-cost methods for surveying urban vehicular speeds. After a preliminary experimental stage, the *Speed Radar Cam (SRC*) application was selected for further analyses. A calibration curve was obtained, by referring to the GPS measures. It was used to estimate vehicular speeds in correspondence with a raised pedestrian crossing. The effectiveness in reducing speeds was measured.

The present study led to the following results:

- The *SRC* application was deemed to be more reliable and accurate than the *Speed gun* application;
- The *SRC* application is sufficiently reliable for low speeds;
- Results in terms of percentage speed reductions from the pilot test using low-cost methods can be compared with the results obtained by previous studies on the effects of traffic calming devices.

Further studies should replicate similar experiments in different conditions, by using different devices and other traffic calming devices, in order to better highlight advantages and disadvantages of the proposed method.

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