Definition and validation of a methodology to identify the road surface anomalies on the streets by measuring the noise and vibration

Vincenzo Barone, Domenico Walter Edvige Mongelli, Antonio Tassitani

***Abstract*—**This work was developed in order to introduce an automatic methodology for detecting anomalies on the road pavement, using informations provided by a noise dosimeter and a vibration dosimeter also synchronized with a smartphone equipped with geo-locator (GPS). There are already studies relating to this topic, especially developed to identify objects located in the subsoil or to recognize the stratigraphy of bituminous conglomerates composing the asphalt road paving, but no one has studied in deep in an appropriate way the possibility of identifying road surface anomalies through the analysis of sound pressure levels or acceleration levels that can be registered on board of a vehicle that runs along a stretch of road. In this regard, this survey methodology, once tested and validated, allows to identify road anomalies in a specific route, making a single survey and through the combined use of measuring instruments.

***Keywords*—**sound pressure levels, GPS, road surface anomalies.

I. Related Work

THE scientific literature, to date, has not addressed thoroughly the phenomenon and possibility of using the temporal variation of the sound pressure's levels and/or the variation of the temporal vertical acceleration as a methodology for mapping anomalies on the street. Many studies, as shown by [1], have been developed to find buried objects. The basic methodology is the same as the one in this project and it is based on the attenuation of the electromagnetic waves or on the difference between the generated waves and the predefined vibration.

Significant applications of the georadar on the field of roads purely date back to the late 80's and early 90's.

The first studies regarding the possibility to consider this instrument to measure the thickness of the conglomerate of tar in the streets' infrastructure was credited [2]-[3].

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The last couple of years all the research has been centered in the analysis of the phenomena trough the variation of acceleration relevant to the presence and roughness on a specific street path. Such application is often linked to a particular accuracy of the measurement of the accelerometer.

This methodology has been developed by [4].

The value and quality of the surface of the street is based on the impulse of vertical acceleration. The time derivative of acceleration in a second $d(a_{zmax} – a_{zmin})$, has been calculated as the difference between the maximum value and the minimum value of vertical acceleration, in a unit of time.

As described in [4], following the experiments on the street, a threshold was determined which consists of maximizing the real events (RP) and minimizing the false events (FP), such threshold was identified at $3.0 m/s^3$.

A later experience based on measuring the streets' anomalies calculating the difference of the sound of the pressure in time, from a smartphone was conducted by [5].

The study has created a base for a methodology that allows the identification of the lack of continuation of the street and the degree of danger through collecting sound measurement data and a simultaneous geo localization of the path.

During the experimental phase, a threshold was identified from the minimum differences of sound pressure so that a false result could be minimized from those created by the effects of the sound the vehicles. In other words, the same experiment has demonstrated that there are no conditions that depend on the type and operative system used on the devices.

On the field of environment acoustics, the state of the art has noticeably helped the phenomenon. The most accepted and experimental models to forecast the sounds generated from traffic allow to calculate the LAeq, from the data given by vehicular flow. Generally all methods consider the following variables:

- Traffic data (emissions) like the number of vehicles and their composition (light, medium or heavy);
- Speed of the vehicles;
- Slope and pavement of the street.

One of the models used in Italy in the urban areas is the one provided by the CNR. The model takes into consideration as the sound index the medium energetic level Leq. This model correlates the different vehicular flow, from light to heavy, the distance from the measurement point from the centerline and a series of corrective coefficients that take into consideration the speed of the traffic flow, the buildings and the pavement without considering the present traffic conditions in the infrastructure and its characteristics.

The regressive models developed [6]-[7]-[8]-[9]-[10] suggest a model with a similar structure than the previous ones integrating it with a corrective coefficient that considers the standard conditions like the presence of intersections with a stoplight or a vehicular flow that circulates at less than 30km/h.

Other models like the one proposed by [11], the model proposed by [12], and the model presented by the Ministry of Transportation and Communication from the State of Ontario, only consider the variables in play: the flow and percentage of heavy vehicles, introducing as an added variable the slope of the path being analyzed. This model that is simple, and with a limited field of application, provides results that are comparable to the previous models described. An evolution in the field of the same type of models, at the end, has been addressed by [13] it proposes the same independent variables adding later a corrective parameter, the typology of roadways.

The numerical type models that have been developed by several scientific structures worldwide are based on the regressive models and are applied to singular infrastructure segments, assigning a main point. Between the most representative models we find the one given by the French structure CETUR, [14] (NMPB - Nouvelle Métode de Prevision du Bruit).

Finally, as shown by [15], two sensors, the triaxle accelerometer and the sound level meter, that smartphones have, were used for a suitable methodology to precisely and accurately identify the presence of any anomaly on the streets: holes, bumps, etc.

The methodology that was described by [15] contemplated the use of two sensors, using an equation (1), if they were not used at the same time, verifying the equation (2), when certain conditions from the equation were verified (3) and (4), summarized in the flowchart in Figure 1.

$$\frac{d\Delta A_{Acc_z}}{dt} > 3 \wedge \frac{d\Delta A_{Acc_z}}{dt} < 10 \wedge \frac{ddB}{dt} > 2 \qquad (1)$$

$$\frac{d\Delta A_{Acc_z}}{dt} > 3 \wedge \frac{d\Delta A_{Acc_z}}{dt} < 10 \wedge \frac{ddB}{dt} > 2 \qquad (2)$$

where:
$d\Delta Acc_z$: vertical acceleration difference (*z* axis) [m/s^2];
ddB: sound level difference [dB];
dt: time difference [s].

$$\left(x_{EP_i}; y_{EP_i}\right) \in C : \begin{cases} x = x_{EC_i} + r \cdot \cos(t) \\ y = y_{EC_i} + r \cdot \sin(t) \end{cases} \qquad (3)$$

where:
x_{EPi}: longitude of the probable event *i-th* [m];
y_{EPi}: latitude of the probable event *i-th* [m];
x_{ECi}: longitude of the event that is certain *i-th* [m];
y_{ECi}: latitude of the event that is certain *i-th* [m];
r: radius of the buffer C [m];
t:] 0;360° [.

$$\left(x_{EP_{i+1}}; y_{EP_{i+1}}\right) \in C' : \begin{cases} x = x_{EP_i} + r \cdot \cos(t) \\ y = y_{EP_i} + r \cdot \sin(t) \end{cases} \qquad (4)$$

where:
x_{EPi+1}: longitude of the probable event *i-th +1* [m];
y_{EPi+1}: latitude of the probable event *i-th +1* [m];
x_{EPi}: longitude of the probable event *i-th* [m];
y_{EPi}: latitude of the probable event *i-th* [m];
r: radius of the buffer C'[m];
t:] 0;360° [.

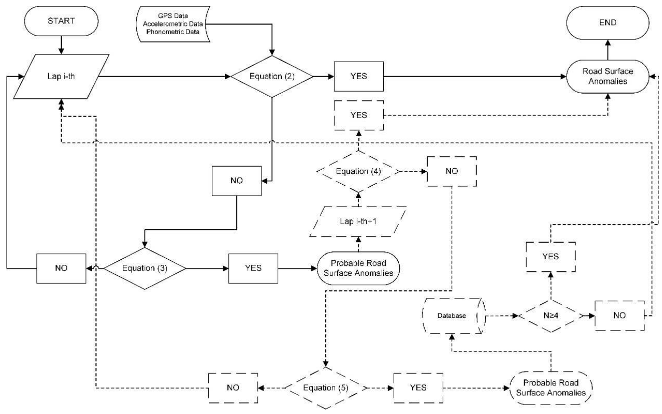

Fig. 1 Methodology flowchart

II. Instruments and Analysis Software

The instruments used in this work, to map the anomalies on the street are the following:

- **Smartphone Samsung Galaxy S Gran Duos S7562**: to state the acceleration on the smartphone and to geo locate the route;
- **Smartphone Samsung Galaxy S4 I9505**: to map the sound pressure levels equivalent to *LAeq* and *LCeq*;
- **Noise Dosimeter WED007:** to establish the levels of sound pressure that are equivalent, measuring various sizes of *LAeq*, *LCeq*, *LCpk*, etc. The main characteristics are reported in Figure 2. The acquisition of the data obtained from WED007 was done by the dB Trait Software, version 5.4, given by the manufacturer. The software allows acquiring and exporting the data registered on the instrument.

	Leq / Lp channel	Peak channel
Precision class	Class 2	
Linearity domain	80 dB	50 dB(C)
Dynamic range	2 40-120 dB / 60-140 dB	1 (fixed) 93-143 dB
Frequency weightings	A and C in //	C or Z
Measured magnitudes	LAeq, LCeq, LASp, LAFp, LCSp, LCFp LASpmax, LAFpmax	LCpk, LZpk
Configuration	Tc, Lc, LCutoff, Q, LAXMax	135, 137 and 140 dB
Peak counting	-	Yes
Calculated magnitudes	Lex,d, EAT, Dose, SEL, LAvg, TWA, Projected Exp., Projected Dose, Lxx	
Integration time	from 1s to 60s	-

Microphone: type MCE321 class 2, 11 mV/Pa, 9mm, weight < 10 g
Operating temperature: -10°C / + 50°C (0-95% RH)

Fig. 2 Technical characteristics of WED007 Noise Dosimeter [User Manual WED007 – 01dB]

- **Vibration Dosimeter VIB008**: to obtain data, according to European regulations 2002/44/EC, bandwidth limit of the frequency-weighted RMS acceleration in m/s^2 (*a*), and frequency-weighted RMS acceleration *Wd*, *Wk*, *Wh*, filter, in m/s² (*aw*), over the *x*, *y*, *z* axis, etc. The main characteristics are in Figure 3. The acquisition of data registered from VIB008 was carried out with the dB Maestro version 5.5, software, provided by the manufacturer. This software allows the acquirement and exportation of relevant data saved on the instrument.

	Whole body mode	Hand arm mode
		
Linearity domain	70 dB	70 dB
Dynamic range	0.04-120 m/s²	0.5-3000 m/s²
Frequency weightings	Wd, Wk, 1/1, 1/3	Wh, 1/1, 1/3
Broad-band weighting	0.4 - 3700Hz	
Display resolution	0.01	0.01
Recorded magnitudes	Band-pass acceleration Weighted acceleration Band-pass and weighted peak and peak-to-peak acceleration Peak factor Equivalent acceleration Daily exposure Mobile RMS vibration MTVV Vibration dose VDV Seat efficiency SEAT (option)	Band-pass acceleration Weighted acceleration Band-pass and weighted peak and peak-to-peak acceleration Equivalent acceleration Daily exposure
Configuration	Transducers Units m/s², g Integration time Reference duration Time constant	Transducers Units m/s², g Integration time Reference duration
Alarm, overload counting	Yes	Yes
Calculated magnitudes	Av, aeq, A(8), A(8)v, VDV, Fc, MTVV SEAT(option) Measurement time, calculation time	Av, A(8) Measurement time
Integration time	From 1s to 60s by steps of 1s	From 1s to 60s by steps of 1s
Spectrum (option)		
Octave	1 Hz - 2kHz	1Hz - 2kHz
1/3 octave	0.8Hz- 2.5kHz	0.8Hz- 2.5kHz
Signal mode (option)		
Sampling frequency	256-8192Hz	256-8192Hz
Pre-trigger	Depends on the calibration frequency From 0 s to 16 s	Depends on the calibration frequency From 0 s to 16 s
Maximum duration	-	-
Post-trigger	-	-

Operating temperature: -10ºC / + 50ºC (0-95% RH)

Fig. 3 Technical characteristics of VIB008 Vibration Dosimeter [User Manual VIB008 – 01dB]

III. Methodology

The methodology described below allows the mapping of the data to be carried out automatically for the anomalies found on the street's surface, taking advantage of the information given by the noise measurer and the vibration measurer. The data acquired is contemporarily being geographically tracked by the internal GPS of the smartphone. The methodology of the investigation showed on Figure 4 allows the discovery of the anomalies of the street through the use of two instruments.

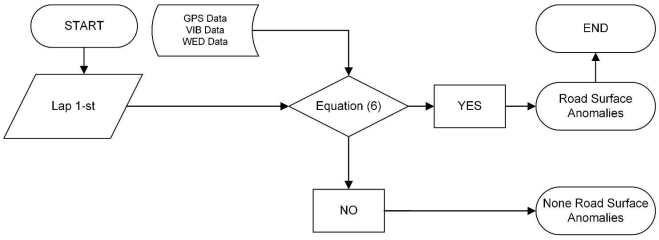

Fig. 4 Methodology Flowchart

The equation used in the methodology to identify the anomalies is described below. To define the threshold a preliminary study was carried out based on the number of Right Road Surface Anomalies (R.R.S.A), and on the number of Lost Road Surface Anomalies (L.R.S.A.), and on the number of False Road Surface Anomalies (F.R.S.A.).

Tab. 1 Right Road Surface Anomalies R.R.S.A.

R.R.S.A.						
		$d\Delta Acc_z/dt$ [m/s^3]				
		1,5	**2**	2,5	3	3,5
dLAeq/dt [dB/s]	1,5	1692	1670	1620	1582	1423
	2	1675	**1661**	1562	1485	1302
	2,5	1650	1595	1526	1371	1264
	3	1624	1580	1430	1292	1232
	3,5	1602	1482	1357	1251	1207

Tab. 2 Lost Road Surface Anomalies L.R.S.A.

L.R.S.A.						
		$d\Delta Acc_z/dt$ [m/s^3]				
		1,5	**2**	2,5	3	3,5
dLAeq/dt [dB/s]	1,5	108	130	180	218	377
	2	125	**139**	238	315	498
	2,5	150	205	274	429	536
	3	176	220	370	508	568
	3,5	198	318	443	549	593

Tab. 3 False Road Surface Anomalies F.R.S.A.

F.R.S.A.						
		$d\Delta Acc_z/dt$ [m/s^3]				
		1,5	**2**	2,5	3	3,5
dLAeq/dt [dB/s]	1,5	56	2	0	0	0
	2	34	**0**	0	0	0
	2,5	21	0	0	0	0
	3	6	0	0	0	0
	3,5	0	0	0	0	0

The threshold that allows an unequivocally determination of the street's anomalies are those that have the maximum number of R.R.S.A. and have a zero in the F.R.S.A. (5). Such threshold has been determined for a value of 2 m/s^3 , for acceleration and 2dB/s for the pressure level of sound.

$$\begin{cases} R.R.S.A. = Max \\ F.R.S.A. = 0 \end{cases} \tag{5}$$

The equation that follows combines the information received from the instruments and it confronts it with the values of the threshold reported above. The anomalies are reported when the conditions from the equation are verified at the same time (6).

$$\frac{d\Delta Acc_Z}{dt} > 2 \wedge \frac{dLAeq}{dt} > 2 \tag{6}$$

where:
$d\Delta Acc_z$: difference of the acceleration in the z axis [m/s^2];
dLAeq: difference in the sound level [dB];
dt: time difference [s].

IV. Experiments, Validation and Final Results

The investigations have been conducted in along street path that is in excellent conditions and is about 5.0 km long with a non-homogeneous pavement due to artificial stone bumps. The test site chosen is in the Municipality of Rende (Calabria, Cosenza), along the main road (Figure 5).

Fig. 5 Test site (Main Road, Rende)

The first step was to individualize and catalogue through a Road Safety Inspection (R.S.I.) the presence of anomalies, holes, cracks, bumps, etc., through the route, proceeding then to geo reference it. (Figure 6).

Fig. 6 Particular anomaly along the test site

Along the road that is the subject of this study, 30 anomalies were individualized that coincide with the number of bumps present.

Subsequently, further experiments were carried out using an SUV and a Land Rover Freelander, which have permitted data to be obtained automatically of the anomalies on the street along the test site. In this phase, the experiment has been conducted using the instruments that were described before proceeding to fix the smartphones inside the main cabin of the car with a rubber support as to reduce to a minimum the vibrations, a VIB cushion is attached to the dashboard of the car (Figure 7) and the WED transducer has been place close to the driver's ear (Figure 8).

Fig. 1 Position of the VIB cushion on the dashboard

Fig. 2 WED transducer on the driver

Along the test site there were 30 reliefs that correspond to the 30 laps that allowed obtaining a useful and ample data base for the validation of the proposed methodology of this work.

The data obtained has been synchronized with the instruments using the atomic time.

The acquired data has been complied and uploaded to a Global Information System (GIS) using the open-source platform Quantum GIS. This has allowed the creation of a map that represents the registered anomalies with the VIB and WED instruments applying the before mentioned methodology described in Figure 4. The points that were verified by the equation (6) have been represented by the GIS and identified as Road Surface Anomalies (Figure 9), as described in Figure 4.

Fig. 3 Individualization of the road anomalies along the test site through the proposed methodology

The methodology has allowed individualizing with a single experiment 93.15% of the anomalies that exist along the test site with a loss percentage of 6.85%. At the same time, using the methodology described in Figure 4 the smartphone has registered 31.17% of the anomalies that exist along the test site, with a loss of 68.83%. The results that were obtained justify the simplification of the flowchart in Figure 4 compared to that described by Astarita et al., 2014 [15], if the precision instruments VIB008 and WED007 are used.

V. Conclusions

The methodology developed and validated in the current work, allows to precisely identify the presence of anomalies in the street along a determined path, allowing on the one hand the administration to monitor the conditions of the road, and on the other for the user to know beforehand what anomalies are present in the road he might need to go through using a GIS system. This allows the administration to better plan road maintenance works with relative cost reductions. The present methodology unlike the one proposed by the same authors in [15], allows to faster define and geo locate the anomalies by just carrying out one test. This is possible thanks to the use of high precision instruments that guarantee a better sensibility and certainty of the data compared to the smartphones. Naturally the use of the current methodology may only be carried out by the street infrastructure administration that must be properly trained on how to use the instruments and how to use the data acquired. However if the infrastructure administration is not able to map out the anomalies, it is possible to refer to the methodology in [15] that provides a continuous update of the information from the road users themselves. Finally, the combined use of both methodologies guarantees, on the one hand, the administration a constant update on the quality of the infrastructure using the mapping made by the users, and on the other, the same users can use the information given by the administration regarding the roads.

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References

[1] G. Leimbach, and H. Löwy, "Untersuchung eines geologischen Untergrundes mit Georadar", Deutsches Patent-und Markenamt: 16.

[2] E. G. Fernando, and K. R. Maser, "Development of a Procedure for the Automated Collection of Flexible Pavement Layer Thicknesses and Materials: Phase I: Demonstration of Existing Ground Penetrating Radar Technology", Florida DOT State Project, 1992, 99700-7550.

[3] K. R. Maser, "Pavement characterization using ground penetrating radar: State of the art and current practice", ASTM SPECIAL TECHNICAL PUBLICATION 1375, 2000, pp. 313-326.

[4] V. Astarita, R. Vaiana, T. Iuele, M.V. Caruso, V.P. Giofrè, F. De Masi, "Automated sensing system for monitoring of road surface quality by mobile devices" Procedia-Social and Behavioral Sciences, 2013 pp.

[5] Festa, D. C., Mongelli, D. W. E., Astarita, V., & Giorgi, P. (2013, July). First results of a new methodology for the identification of road surface anomalies. In *Service Operations and Logistics, and Informatics (SOLI), 2013 IEEE International Conference on* (pp. 192-197). IEEE.

[6] S. d'Elia, F. Crocco, and D. Mongelli, "An integrated prediction model to define the level of noise in urban areas", 4th WSEAS International Conference on Urban Planning Transportation UPT2011, Corfu Island, Greece, 2011, 399-404.

[7] V. Barone, F. Crocco, and D. Mongelli, "A mathematical model for traffic noise prediction in an urban area", 4th WSEAS International Conferense on Urban Planning and Transportation UPT2011", Corfu Island, Greece, 2011, pp. 405-410.

[8] Aloe, V. Barone, F. Crocco and D. Mongelli, "Mathematical Modelling of Road Traffic Noise in Urban Centers", 7th WSEAS International Conference on Energy & Environment (EE '12) Kos Island, Greece, July 14-17, 2012, WSEAS Press 2012, pp. 228-233.

[9] Aloe, V. Barone, F. Crocco and D. Mongelli, "Traffic Noise Forecasting Tools: A Mathematical Model", 7th WSEAS International Conference on Energy & Environment (EE '12) Kos Island, Greece, July 14-17, 2012, WSEAS Press 2012, pp. 234-239.

[10] Mongelli, D. W. E. (2013, July). An integrated prediction model for traffic noise in an urban area. In *Service Operations and Logistics, and*

Informatics (SOLI), 2013 IEEE International Conference on (pp. 198-204). IEEE.
[11] CETUR, Guide du Bruit des Transports Terrestres – Fascicule, Prévision des niveaux sonores, 1980.
[12] D. Griffiths and F. J. Langdon, "Subjective response to road traffic noise". *Journal of Sound and Vibration* 8.1, 1968, pp. 16-32.
[13] R. Gambart, H. Myncke, and A. Cops. "Study of annoyance by traffic noise in Leuven (Belgium)."A*pplied Acoustics* 9.3, 1976, pp. 193-203.
[14] CERTU, SETRA, LCP, CSTB, Nouvelle Métode de Prevision du Bruit (NMPB). Ruotes 96, 1997.
[15] Astarita, V., Festa, D.C., Mongelli, D.W.E., Tassitani, A. (2014, October). "New methodology for the identification of road surface anomalies". In *Service Operations and Logistics, and Informatics (SOLI), 2014 IEEE International Conference on* (pp. 149-154). IEEE.

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