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Metrology Impact of Advanced Driver Assistance Systems

Paola Iacomussi; INRIM, Italian National Metrology Institute; Torino, Italy

Abstract

Metrological applications to road environment are usually focused on the characterization of the road, considering as measurands several characteristics related to the road as a whole or the performances of single components, like the road surface, lighting systems, active and/or passive signaling and obviously vehicles equipment. In current standards approach, driving on the road means to navigate "visually" (for a human being driver), the characterizations are mostly photometric performances oriented for given reference conditions and reference observer (photometric observer observing the road from assigned points of view, with given spectral sensitivity). But considering the present and future technological trends and knowledge on visual performances, characterizations based on only photometric quantities in reference conditions as described in the current standards would be not fully suitable, even for human driver visual needs.

Nowadays research on components and systems for advanced driver assistance are evolving, following different paths toward different solutions: it is not possible, nor useful to define strict constraints as it has been done previously for road applications measurements. The paper presents the current situation of metrological characterization of road environment and components, on laboratory and on site using mobile high efficiency laboratories, and suggests to use ADAS (Advanced Driver Assistance System) for diffuse mapping of road characteristics for a better understanding of the road environment and maintenance. The suggestion has the additional advantage of minimizing measurement costs, but for its full applicability, the reliability and metrological performances of installed devices and of the measurements performed by ADAS are a priority.

Introduction

Current standards approach considers driving on roads a *visual navigation task*, the driver makes its three main tasks simultaneously, relying on visual perception to control: *the position* (adjusting speed and location of the vehicle to keep in proper lane of the carriageway at the desired speed), *the situation* (reacting properly to changes in the environment), and *the navigation* (choosing the correct way to complete the journey).

European Standard for road lighting (EN 13201 series [1], [2]) recognizes road luminance as the key parameter to obtain adequate vision conditions and traffic safety to satisfy the aforesaid needs for visual navigation. The visual performances of the driver are taken into account considering the luminance that bring a contrast *threshold value* that ensures the obstacle (of a given reflectance) perception by the 50%+1 of the observers population.

The road luminance is directly related to the direction of the incident luminous flux and its amount, to the direction of view of the driver, and to the reflection characteristics of the road surfaces. The sensitivity of the observer is ensured referring all measurement to the Reference Photometric Observer: an observer having the spectral sensitivity described by the V(λ) function (photopic human sensitivity) [3].

For motorized traffic EN 13201-2 [1] specifies, for the assigned road class, the required values of average road surface luminance, overall luminance uniformity, and longitudinal luminance uniformity that allow the obstacle perception ensuring the *threshold detection value* of a mean *human observer*. The values were established during on site subjective tests, made in the fifties and sixties, with the tools (road pavements and road lighting, including lighting sources) of those times, using 2D shaped objects of given reflectance (50%) evaluated by static observers at about 80 m. The design of every road lighting system is based to ensure compliance with the aforesaid values furthermore, all road lighting system are calculated (number of luminaires, source intensity, and spacing) considering the reflectance properties of road pavements of the same times. For this last issue, the European Community funded the SURFACE research project, within EMPIR funding program, to provide metrological research and reference values for current road pavements reflectance behavior. Instead, unfortunately, no large subjective tests and researches are currently planned to test new reference values for human observer luminance threshold, testing current road pavements, lighting systems (LED), and factual conditions of observation.

Moreover, it is possible to argue that drivers not necessarily have to be considered to have the same sensitivity of Reference Photometric Observer, that is representative of a human observer adapted to daylight conditions, or contrast threshold sensitivity as stated in founding subjective tests in obstacle detection using static observers in the sixties. The entire regulatory framework for performance assessment of road elements and systems (lighting, signaling, marking, etc) is based on the performance and needs of human observers, with the exclusion of mechanical performances of course. The needs of a human driver can be obviously, very different from those of an artificial system. The current situation sees a clear regulatory framework for the minimum maintained performance of all necessary elements on the road, however measured under conditions that may not be optimal, nor significant for artificial systems, nor even for the actual situation because based on conditions not longer representative.

If we continue to consider driving as a mainly visual task, the decline of the conditions of observation is one of the main factors affecting safety decay: the decline can affect the observer (aging of the driver, or of the device, including its frame) or the environment (worst condition of observation, performance decay of the environment signaling). Public roads infrastructures should ensure, as far as possible, safety conditions in all different scenarios including night, day, adverse weather, as well the support to drivers with impaired viewing condition. To improve road safety conditions by the improvement of visual perception means working also on active and passive road signage and marking, cars/drivers sensing, and installing innovative road lighting systems.

By 2050, persons 65 years and older will likely account for 28,1% of the total population of European Union. Older people take part in road traffic, either by walking, driving a car or riding a bicycle: older driver has a fatality rate seven time larger than other age [4]. To improve the safety of elder users, actions embrace infrastructural and vehicle design improvements among latest, Advanced Driver Assistance Systems (ADAS) can play a relevant role in compensating for physical limitations. Unfortunately infrastructural improvements for the elderly are more expensive than implementing measures on vehicles, for example a revolutionary lighting system able to compensate for elder visual limitations needs a long path before its implementation on roads: requirements identification also by the definition (by research and subjective tests) of new road luminance levels and spectral requirements, study on impacts on other road users, time for general agreement and standardization approval, then the design and engineering of a product and, finally the implementation on few selected roads (the mean lifetime of a road lighting system is several tens of years). Working on vehicle measures and driver assistance systems is clearly more rapid and effective approach. EU recognizes the advantages in implementing ADAS in new cars, forcing new regulations coming in to action from 2022, with enforcement by 2024 of new mandatory safety features. The Commission expects that the proposed measures will help save over 25000 lives and avoid at least 140000 serious injuries by 2038 [5].

Road Metrology

Roads are designed (and verified) to ensure performances related also to mechanical quantities, usually listed in national laws to enforce the implementation of correct road design, because these characteristics are directly linked to national infrastructure safety. This is the case of :

- geometries of the road, namely slope, tilt, curvature, planarity, etc
- geometrical and technical characteristics of road safety barrier and restraints systems
- technical and mechanical characteristics of road pavements

In the standardization framework of road performances the metrological characterizations of road elements and systems as well of several vehicle equipment, are photometric performances oriented, obviously not considering the above mechanical qualities. Current standards focus on visual performances of all different road elements related:

- vehicle headlamps, for the need to reduce the glare of oncoming traffic, have obvious limitations on power and on spatial luminous intensity distribution,
- signaling (both of vehicle and on road), for the need of visibility and readability, has given colors (chromaticity regions to ensure visual impaired observer colors recognition), lighting intensity distribution, and retro-reflectance performances
- road pavements are tested for their spatial distribution of the reflected light (luminance coefficient for given lighting directions and observation)
- luminaires of road lighting systems are tested for their spatial luminous intensity distribution to ensure visibility, not glaring observers and providing assigned luminance and other quality parameters values on roads.

Obviously, several of the above quantities (both mechanic and photometric) lose their effectiveness on safety at the increase of the speed, the number of vehicles on the street, the complexity of the scenario or the worsening of the observer performances.

All photometric requirements listed in the standards are related to human driver visual performances: standards consider the reference photopic observer [3], having a sensitivity equal to V(λ) (photopic curve, the condition of adaptation of the human eye to day lighting levels), for given geometrical conditions of observation related to the position of a reference observer, that simulates a driver in a car with, for road luminance measurements, the eyes at 1,5 m from the ground and an angle of observation of 1° and, for road marking measurements, the eyes at 1,2 m from the ground and angle of observation of 2,29°. Respectively the two conditions of observation imply a viewing distance of 85,9 m and 37,5 m. In the first case, a distance without vehicles interposed not realistic in urban environment. While mechanical and geometrical performances are more related to other mechanics quantities like driving speed, vehicles performances, and artifacts, not to human being.

Even if we continue to consider driving as a *visual* task, owing to current technologies and knowledge on visual perception, the term *visual* should not be considered only in reference to the human sensitivity anymore, or to the reference *photopic* observer: a larger spectrum of sensitivities and observation geometries more suitable to actual driving situations must be taken into account. For instance, on sensitivity: CIE in 2010 defined the sensitivity of the human eye in *mesopic* visual condition [6]. *Mesopic* is the actual condition of adaptation of the human eye during nighttime driving with artificial lighting. It has been shown that, in principle, it would be really suitable to design road lighting system considering human visual performance at mesopic adaptation [13]. But unfortunately, mesopic algorithm is not easily applicable in road lighting because its strong dependency on the adaptation field, spectrum included, and the actual difficulties of its definition in complex urban scenes, and CIE suggests its applicability only to peripheal vision [8]. Instead, tunnel lighting is an interesting and factual field of application.

Road elements, like retroreflectors, signalings, luminous sources (luminaires, Lamps, and LED), and road pavements are characterized for their photometric performances in laboratory or on site. Usually laboratory tests are made for: the formal approval for road installation, virtual modeling, or for design software database. This is the case of retroreflector coefficient of luminous intensity (minimum maintained values for approval), luminaires luminous intensity distribution (light distribution around the luminaire for software for lighting design) or road pavements luminance coefficient (the parameter describing the reflectance geometrical behavior for software for lighting design), or for mechanical quantities the pavement surfaceanalysis (like roughness, macrotexture, evenness, skid, resistance, etc...).While on site measurements, made directly on the road environment and in the condition of installation, are important and even essential for actual performance assessment.

Usually, especially in the past, on site verification was carried out with static methods with operators on the road carriageway, with the related safety issues), costs and time consuming. The optimization of the costs as well the need to improve measurement accuracies and do measurements at high efficiency, forced the development of mobile laboratories able to do the measurements of the quantities of interest at high velocity (very useful for periodical measurements), without the need of closing the road (that would have a relevant economical impact on the costs) and with no risks for operators.

On site metrology: Mobile laboratories

A mobile laboratory is a laboratory installed on a vehicle able to do measurement on site with no compromises on measurement accuracies. Not all mobile laboratories are able to do dynamic measurements. On site measurements, made directly on the road actual conditions, are mostly performed:

- at the approval stage of the system, in order to verify the compliance of the effective performances with the design expectations and with standard requirements;
- during the life of the system at given intervals, for verifying the degradation of the characteristics and for defining a maintenance program to ensure compliance to minimal requirements

Obviously, the metrological requirements are different in the two aforesaid conditions:

- at the approval stage, the measurements should be carried out with suitable uncertainties and referred to the relevant normative situations, in order to avoid appeals especially in case of a negative assessment of the installation
- periodically during the life of the system, possibly also through special geometries, provided that they produce repeatable results with suitable uncertainty levels

Several mobile laboratories for dynamic road characterization are available on the marked. Some of them have been developed by research centers and are available as prototype, others are built using commercial measuring devices for dynamic measurements. INRIM developed a mobile lab (Tiresia) for road lighting assessment [10] for the National Road Administration of Italy (ANAS), and currently is under revision to increase its metrological performances. The INRIM laboratory made the annual mapping of all tunnel lighting installations of ANAS as by Italian national requirement and is able to perform measurements up to 90 $\mathrm{km\,h^{-1}}$. The common approach for mobile labs is that the labs should be able to operate with moderate traffic at suitable measurement uncertainty [12], during assessment of the infrastructure, comparative campaigns, maintenance check, to be repeated regularly with low costs. A not exhaustive list includes laboratories for the evaluation of:

- macrotexture, evenness and skid resistance of road surfaces;
- road lighting, road luminance, and luminance uniformities also of tunnel walls;
- road marking and vertical signals retroreflection intensities;
- stratigraphy of road superstructures and thickness;
- bearing characteristics of road surfaces;
- topography of the roads...

All mobile laboratories available are able to operate static or dynamic at low or moderate speed (around 70 $\mathrm{km\,h^{-1}}$). Even if it seems a relevant velocity, it would be not enough for a regular mapping of all roads in a country, ensuring also the significance of the mapped values (some performances can not be established by single sampling).

For some of the above described measurable quantities, especially the ones related to the photometric performances, European standard already acknowledges the possibility to do measurements with mobile labs as proof of compliance [9] . But, for measurements of photometric quantities of road lighting in motion, CEN document [9] requires:

- for every point of measurement the possibility to define the position of the photometric detector in terms of height and distance (cross-sectional and longitudinal) with reference to a known point (as an example, the edge of the road);
- the adoption of procedures for reducing the effects that the vehicle can have on the measures (electronic noise, reflection of the light, shadow, etc.);
- the use of adequately characterized photometric detectors.

The last point is particularly important, because it regards also the manual measurements. A usual calibration in simple photometric units (like luminance toward a CIE Illuminant A reference source) is necessary but not sufficient. Actually, in this particular application, the operating conditions have a great influence on measurement uncertainties. Measurements done with an accredited laboratory (in accordance with ISO/IEC 17011) [11] under ILAC organizaton (Inernatonal Laboratory Accreditation Organization) are officially and internationally recognized, having legal validity. ILAC has several requirements in order to acknowledge the accreditation: the compliance to the ILAC requirements (verified by a recognized organization) is the assurance of reliability of the measured data.

Road Maintenance

Road maintenance can be done at different timing:

- Frequently, were small tasks are done routinely
- Periodically, were large to medium tasks are done with several years interval
- Urgently, with repairs that need immediate actions

Obviously, optimization models allows the best costs ratio for the first two categories,as well assure preventive actions minimizing the immediate repairs actions. Maintenance budgets have been reduced significantly by spending cuts in public spending resulting from the financial crisis. According to the International Transport Forum [14], investment in road maintenance has been declining as a share of total road spending especially over the last years, especially after the financial crisis of 2009. ERF, European Union Road Federation, states that [15] [16]:

the fact that many European road infrastructures have now reached a critical age, as well as the constant evolution of road traffic, could lead to an irreversible decline of the quality and service levels.

Governments and road authorities have in recent years increasingly focused their efforts on the vehicle and the driver, often neglecting the huge road safety benefits that can be achieved by investing in road infrastructure.

On site measurements for maintenance purposes

Considering the mobile laboratories able to do dynamic measurements, an obvious application would be the road mapping for maintenance check of national infrastructures. The European road network consists of about 5,5 million of km, a really large common infrastructure. But even the mapping of a single country road infrastructure would require a lot of time. Namely the Italian road infrastructure is about 900000 km, considering a measuring speed of 90 $\mathrm{km\,h^{-1}}$ of a mobile lab able to do dynamic measurements and manage large amount of data, the mapping using a single unit would require 10000 hours of working, a too large amount of time not mentioning problems like subsequent data analysis, weather conditions impact, and reliability of measurement due to the stochastic approach of single measurement shot.

Considering the time consumption and the drop down common to all EU countries of investment in maintenance and controls, the diffuse mapping of road infrastructure is not done continuously. But in the next future more and more vehicles equipped with ADAS will drive the roads. If the data continuously acquired by ADAS would be available to road management authorities both the above problems of amount of time for mapping and stochastic approach would be solved.

Different data descriptive of different road properties or road environment characteristics, can be acquired by single ADAS vehicle. It would be very advantageous for several application, including road pavement maintenance, because it will allow the optimization of maintenance costs and the selection of the most useful and convenient approach among different maintenance models approach. Road lighting energy saving would benefit, too: tunnel lighting standard requires to check glaring conditions outside the tunnel and adapt tunnel lighting entrance accordingly to driver condition of adaptation (this is the case of a tunnel entrance with sun in front or in at the back of the driver), because it is necessary to assure contrast threshold independently from the luminance of the surroundings. Usually the occurrence and impact of glaring conditions during the year are evaluated trough stochastic approaches of solar path, elevation and weather conditions, or by the measurements of camera in front of the tunnel or extrapolating single measurement. The data from ADAS would provide a full description of the glaring conditions at the tunnel entrance and the entrance lighting would be adapted to actual visibility conditions, because this lighting is 24/7 working the energy saving can be of huge impact, especially in countries with large number of tunnels.

But the reliability of data would became the biggest obstacle to ADAS data usage. Automotive industry is extremely cost sensitive and needs a clear understanding of performance and reliability of the installed sensors in their actual environment, to date available standards are unsatisfactory or not applicable to ADAS use cases, as well it would be not possible to apply current standard and procedure for accreditation, namely to follow ISO 17025 [13]: it would be impossible nor convenient to calibrate in absolute units the system readings nor considering every single ADAS as a sort of accredited lab following the ISO 17025 requirements.

One possible solution, given the large variability of ADAS systems would be to define reference conditions for testing metrological capabilities, especially reliability, and to start soon a new normative path to establish proof of requirements. To achieve this goal, detectors and the whole system (software included) must have great stability and repeatability, low sensitivity to climatic conditions and to aging, as well high reproducibility. But the approach cannot be at component levels for witch performance criteria already exist, a general and new coordinated NMI (National Metrological Institute)- Industry approach to sensors and algorithms fusion performance and reliability estimation is needed.

The characterization procedure shall be simple but adequate to application requirements and real operating conditions. It is obvious the necessity to have high reliability on measured quantities that cannot be achieved only trough SI quantities calibrations in reference conditions but needs dedicated characterization methodologies able to test camera responsivity to environmental factors and therefore setting the reliability and uncertainty of camera evaluations. The normative organizations should support with definition of new methodologies and requirements for this special case of *”diffuse laboratories”*.

The first human casualty with AV, occurred in 2016 because an autopilot system failed to distinguish a white tractor-trailer crossing an highway against a bright sky, the same situation occurred in 2018 when a system was unable to recognize a pedestrian among a dark road background. Both situations highlight a contrast evaluation lacks for the given condition of usage. Contrast is recognized by standard regulations as one of the main safety parameters: road lighting should provide enough contrast for the discrimination of obstacles (the aforesaid threashold value), detection of the road path by road marking with high contrast compared to road surface and so on.

Contrast is a relative measurement (a ratio between two luminances), so an absolute calibration of the camera in luminance units ($\mathrm{cd\,m^{-2}}$) would be not needed, but camera response and reliability for different key parameters as well uncertainty evaluation are needed. Usually, image camera performances are mostly based on their technical specifications and do not acknowledge the environmental peculiarity of driving, including lighting levels and environment: e.g. flare influences of outside view sources, sun glare, lighting, weather conditions, aging not only of the sensor but also of the lens and protective enclosures. For example, in road lit environment, LED sources flicker, humans do not perceive the flicker of a LED car signal, of LED streetlight or of active signalling, but a digital camera do and LED flicker can led to misidentifying the actual situation.

More metrological research and support to industry and standardization bodies are needed to identify the relevant attributes and related performances for autonomous systems sensors and the involved sensor fusion algorithms to establish reliability and to support ADAS as valuable contribution to road safety also trough infrastructure mapping.

Conclusions

Currently mapping road infrastructures for maintenance purposes has a great impact on budget of road authorities. ADAS represents a suitable candidate for diffuse mapping, increasing the possibilities of measuring and mapping in real time the actual situation of road infrastructures, but high care should be posed to establish and proof the reliability of the data. It means the definition of some test reference condition to verify ADAS systems, and new methods for data validation and normative requirements for accreditation. This approach would increase reliability of data, open new market opportunities for accredited laboratories and help road authorities solving the problem of costs for mapping the actual situations. A huge and coordinate effort, even at normative level, is needed to define the relevant conditions and parameters to monitor. This task would be really suitable for a consortium of research institutes, industries involved in Autonomous Vehicle sensors development, standardization organizations and road authorities.

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Author Biography

Paola Iacomussi received her BS in Physics from the University of Torino. She is a Researcher, firstly in the automotive industry and then at INRIM, the Italian National Metrology Institute, “Nanoscience and Material Dept.”. She works on source-materials characterization and perception. Her metrology expertise is in measurement methodologies for the evaluation of lit environments using digital detectors, material and source characterisation and visual perception. She is the coordinator of European Funded project SURFACE and adjunct professor at the University of Torino.

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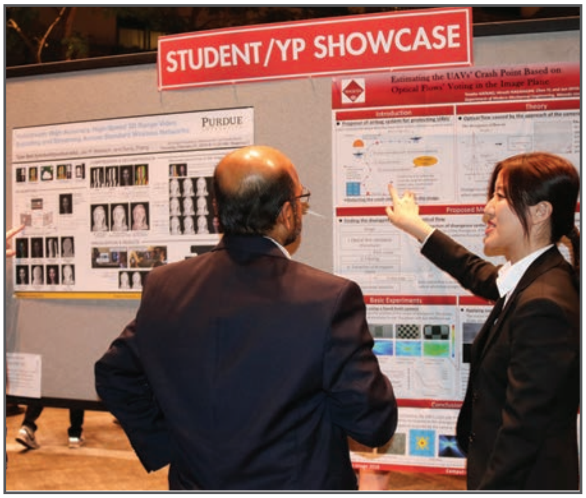

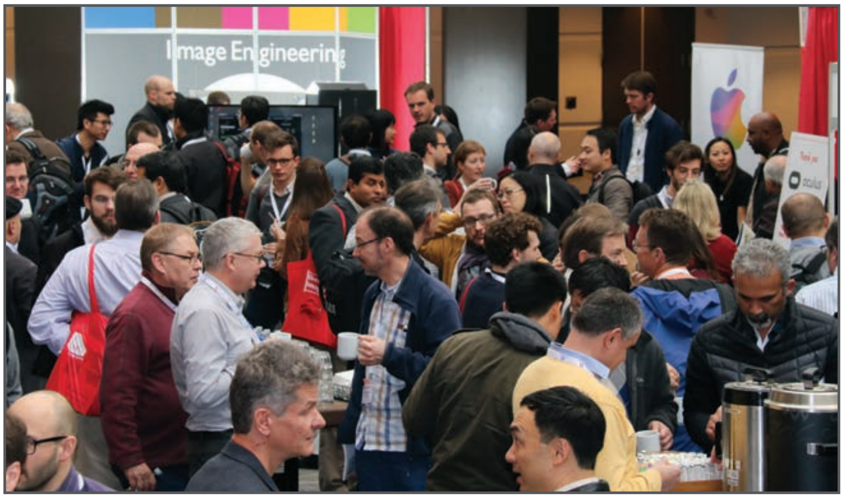

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