{HiDyn}

Publishable Summary for 21NRM01 HiDyn
Support for the standardisation of luminance distribution measurements for assessing glare and obtrusive light using high-dynamic-range imaging systems

Overview

Luminance distribution measurements with high dynamic range (HDR) are required for various applications (e.g. measurement of new LED- or laser-based car headlights, obtrusive light and glare evaluation of indoor and outdoor scenes) where high contrast levels exist simultaneously in one image. Imaging luminance measurement devices (ILMD) and red-green-blue (RGB)-based cameras are often used for such assessments. HDR measurements are then achieved by post-processing image sequences, but standardisation and uncertainty statements are usually absent, which makes it impossible to fully explore the potential and limits of these systems. This project aims to develop procedures for using HDR imaging measurement systems in luminance distribution measurements and glare assessment, standardise the determination of the instrument performance, including associated uncertainties, and select an HDR algorithm adequate for SI-traceable measurements. This is expected to support relevant legislations on glare and obtrusive light mitigation with traceable and trustable field based HDR luminance measurements, contribute to a proper assessment of lighting installations regarding safety and discomfort from glare and obtrusive light sources, and increase working place ergonomics as well as safety levels in roads suffering from glare from lighting installations and environmental impact of obtrusive light.

Need

The complexity of the human visual system allows adaptation to extremely dark and bright lighting conditions. Due to its very large dynamic range for lightness perception (11 orders of magnitude of luminance), humans can safely and comfortably navigate the world, and perform tasks involving vision in lighting environments with very high luminance contrast. However, some lighting environments can be disturbing for some tasks and may pose issues regarding safety. Therefore, it is necessary to study these environments and adapt them to more adequate lighting. In particular, unsuitable distribution or extreme luminance contrast can produce glare, a vision condition in which there is discomfort or a reduction in the ability to see details or objects, and spill light with certain attributes, which can be obtrusive and give rise to annoyance, discomfort, distraction or a reduction in ability to see essential information such as a traffic signal. The evaluation of glare or obtrusive light, and other visual aspects important for safety and comfort, rely on experiments presenting a high luminance contrast. The characterisation of such scenes requires measuring instruments specifically designed for these conditions. In the recent years, an increasing number of research fields and industry applications have been using HDR imaging technologies. However, there is currently no metrological certainty obtained with measurements performed using commercial HDR imaging measurement systems, and glare and obtrusive light evaluations using such systems are not SI-traceable, which can lead to major shortcomings in safety and comfort for many visual activities. Additionally, as expressed in the 2019 revision of the EU's Green Public Procurement Criteria for Road Lighting and Traffic Signals, obtrusive light is an important issue for wildlife (high insect mortality, disruption of the migration of birds) and human quality of life (sleep pattern disruption), as well as for astronomical observations.

CIE recognised the need for further work on this field and submitted two documents to EURAMET identifying a lack of traceable SI calibration, poor long-term stability, and inadequate relative spectral responsivity, as well as the need for the calibration and characterisation of HDR-cameras used for luminance distribution measurements.

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The measurement of luminance distribution covers such a broad range of topics, that the diversity of stakeholders' sectors requiring reliable guidance for traceable HDR imaging luminance measurements is immense (e.g. CIE, CEN, national metrological institutes (NMIs), designated institutes (DIs), ILMD manufacturers, scientific community, end-users of HDR imaging systems dealing with quantitative glare and obtrusive light evaluation and all the communities impacted by obtrusive light, glare and high-contrast luminance scenes).

It is necessary to make references available to characterise HDR imaging measurement systems, and to establish instruments' requirements to guarantee traceable HDR luminance measurements as well as to demonstrate the comparability of the results. The latter includes the characterisation of the stray light produced inside the camera. It is necessary to improve the estimation of the uncertainty by the proper evaluation of these sources of error and related examples are beneficial to ensure competence of operators of such measurement devices. Existing HDR algorithms must be evaluated from a metrological point of view, in order to provide a recommendation, if not of a single HDR algorithm, at least of the requirements they need to fulfil for traceable luminance measurements and assessments of glare and obtrusive light. Finally, guidelines on the determination of uncertainty budgets for HDR luminance imaging measurements, as well as glare evaluation, are required to support European stakeholders and feed the work of standardisation bodies (e.g., CIE and CEN).

Objectives

The overall goal of this project is to enable the traceability and characterisation of HDR imaging luminance systems, and to support the standardisation of luminance distribution measurement methods, which are required for glare, light pollution, and other lighting assessments. This will involve developing HDR luminance standards required for the characterisation of HDR imaging measurement systems and developing metrics and guidelines for the determination of the associated uncertainties.

The specific objectives of the project are:

1. To develop luminance reference standards (i.e. sources) with high dynamic contrast pattern (covering at least 6 orders of magnitude) in order to characterise the dynamic range and spectral mismatch for different types of commercial instruments that are available for luminance distribution measurements (e.g. ILMD, RGB matrix sensor cameras). This should be based on the recommendations stated in CIE 232:2019 and CIE 244:2021 and allow the reliable assessment of glare and obtrusive light.
2. To model and verify HDR luminance measurements (including non-linearity, internal stray-light, and lens flare), with the objective of reproducibly determining the input data required for the models (average luminance, luminous surfaces, if required contrasts in the glare source, peripheral angle). To define the requirements for traceable instrumentation and to demonstrate the inter-comparability of HDR luminance measurements (in general and between different camera technologies), including the effect of its uncertainty on glare assessment.
3. To develop an algorithm for (i) generating an HDR-luminance image from a sequence of multiple raw images and (ii) enabling traceability of relative images scaled to one or a few traceable spot measurements of the scene.
4. To develop guidance on the determination of uncertainty budgets for HDR luminance imaging measurements of single pixels and integral values (e.g. evaluation region, illuminance) as well as glare evaluation, according to existing standards EN 17037:2019 [2], EN 13201-2:2015 [3] and EN 12464 1:2011 [4]. This should include a report on the relevance of existing quality indices and test methods regarding HDR imaging luminance systems.
5. To contribute to the standards development work of CIE TC 2-86, CIE TC 2-95, CIE TC 3-57, CIE TC 4 58, TC 8-18, CEN TC 169, and the resumption and continuation of the work of CIE TC 2 59 and CIE TC 4-33 (both inactive), to ensure that the outputs of the project are aligned with their needs, communicated quickly to those developing the standards and to those who will use them (e.g. manufacturers of RGB sensors and cameras), and in a form that can be incorporated into the standards at the earliest opportunity.

Progress beyond the state of the art and results

This project builds on and will progress beyond different projects.

In the EMPIR project 19NRM02 RevStdLED, the traceability of luminance imaging measurement devices has been addressed by a training and a published good practice guide. The general model of evaluation and uncertainty budget for luminance measurements is picked up in this project as a foundation. However, RevStdLED aimed to reduce its complexity for selected individual applications relevant to test laboratories, and namely does not consider RGB matrix cameras nor HDR imaging systems for which the uncertainty contributions will have different significances. In this project, 21NRM01 HiDyn, both are considered and will be used to complement the good practice guide of RevStdLED with a supplement.

In the EMPIR project 18SIB03 BxDiff, HDR imaging systems had been used for studying the relation of reflectance measurements at different scales, on texturised, structured and translucent materials. However, BxDiff did not addressed the standardisation of an HDR algorithm nor the development of a reference source with luminance contrast. Both will be implemented by this project by also considering the experience from the studies and evaluating measurement data already at hand by partners from the consortium.

In the EMPIR project 20NRM01 MetTLM, the research regarding imaging devices focusses on spatial resolved temporal light modulation (TLM) measurement modes of luminaires and extended scenes, and vivid examples demonstrating its feasibility using ILMDs and RGB matrix cameras. In this context, high contrast luminance scenes or sources will be included in the targeted measurements. This project will benefit from the experience gained in MetTLM and collaborates on the HDR measurement of TLM sources also by demonstration for errors of imaging luminance measurements caused by TLM and by giving guidance how to avoid them. This development of guidance about HDR imaging luminance measurements of field scenes presenting TLM will be included in the good practice guide of this project and thereby extend the state of the art.

Objective 1: High contrast reference luminance standard source of at least 6 orders of magnitude

In this project, a type of high contrast reference standard source of at least 6 orders of magnitude is developed, simultaneously presenting luminance levels about 0.1 cd/m² to about 100 kcd/m² or more, and a light trap of <0.01 cd/m².

The requirements for the reference source were agreed within the consortium. An internal report has been written, although it is still subject to revision. Existing experimental or commercial technologies suitable to be used for the development of the reference standard sources were examined and their different properties collected in a specification matrix. A commercial LED-based light source that includes a light mixing chamber was selected as the basis for the reference luminance source. A modular light source including straylight reduction and optional neutral density filters as a configuration parameter has already been developed. These prototypes realise luminance values from around 0.5 cd/m² to 160 kcd/m², which can be varied in steps by setting the hardware configuration and in addition within about half an order of magnitude by tuning the electrical operation condition. A measurement of a test scene based on two of these prototypes of the reference source and a light trap has been carried out using three ILMDs, showing above 5,8 decades of contrast in the luminance images, but the intermediate luminance’s are significantly affected by straylight from other sources inside the scene. After revising the initial design regarding this, seven artefacts (light sources) providing luminance values from around 0.1 cd/m² to 100 kcd/m² were manufactured and photometrically characterised.

The luminance of the sources will be determined with an expanded uncertainty no larger than 1 % for the brightest source and no larger than 2 % for the dimmest one. This type of standard source will cover the needs for testing and characterisation of measurement systems with narrow and wide measurement fields via a modular design concept. It will be designed and developed to meet the requirements of luminance dynamic range for applications and measurement needs of the relevant standards and documents, like CIE 232:2019, CIE 150:2017, and CIE TN 014:2023.

Objective 2: Validation of HDR luminance measurements

Characterisation procedures using the reference luminance standard source and beyond will be developed. They will allow the validation of the assessment of glare and obtrusive light, and the metrological demonstration of the comparability of evaluations by different HDR imaging technologies. At least three types of HDR imaging measurement systems will be tested (ILMD, commercial DSLR, camera based on an RGB matrix sensor). The comparability of measurements by these device types will be investigated though laboratory and field tests using the characterised systems.

Objective 3: Harmonised HDR algorithm for traceable HDR luminance measurements

This project will go beyond the state of the art by developing a dedicated HDR algorithm which will include functionalities that are missing from existing algorithms (e.g. estimating the uncertainty by considering also contributions from external standards which are beyond intrinsic information, like pixel signal noise, and by minimising uncertainty based on such traceable information) and will serve the metrological needs of HDR imaging measurements, including the propagation of uncertainties. It will be implemented in source code that will be distributed under an open-source license. Relevant HDR algorithms were preselected from the literature and implemented in code (MATLAB). A methodology for evaluating HDR algorithms was developed and tested for identifying HDR algorithms that are able to perform well for traceable luminance measurements. The proposed methodology is being adopted by the involved partners and will be improved in the future if necessary. This will be presented at the 30th Quadrennial Session of the CIE in Ljubljana (September 2023). On the other hand, an analytical study on the impact of the signal-to–noise ratio on the performance of the preselected HDR algorithms was presented during the first progress meeting held in Prague.

Objective 4: Uncertainty estimation of HDR luminance measurements, propagation to glare and obtrusive light assessment, and relevance of existing quality indices

This project will develop a model and a good practice guide for the uncertainty propagation of luminance measurements and of glare and obtrusive light evaluation using HDR imaging systems. It will be developed using data from the characterisation of the investigated HDR imaging technologies and demonstrated with the newly developed reference standard source, and field measurements. The part of the model regarding the uncertainty propagation in glare and obtrusive light assessment will be validated using dedicated measurements in well documented lighting installations. The model will be directly implemented with the algorithm developed for HDR processing.

A measurement model has been proposed in an internal report, where the different parameters relevant for errors and thus uncertainties in HDR imaging luminance measurements are described in detail. Details of this model are under discussion considering also findings form preceding work about estimating uncertainty contributions, i.e. the ILDM configuration checklist and training material from the EMPIR JRP 19NRM01 RevStdLED.

The identification of the relevant parameters that should be taken into account in the uncertainty analysis of glare evaluation has been considered. The key components of glare metrics have been identified in the relevant standards and technical reports. An internal report was created which will be used for ongoing activities in the uncertainty evaluation on the measurement of glare and obtrusive light.

Outcomes and impact

Attached to the CIE annual meeting 2022 in Athens, Greece, a stakeholder meeting was held in which this consortium, its objectives, planned implementation, and deliverables were introduced and the needs as well as important aspects of this project were discussed. An updated status of the project and results was reported to stakeholders in an oral presentation by the coordinator in the annual meeting of the Euramet TC-PR in January 2024. The project's stakeholder committee currently includes 21 institutions (standardization bodies, organizations, national metrology institutes, universities, companies) that have declared interest in the projects results. In the first eighteen months of the project representatives of the consortium gave 3 presentations in scientific conferences and have attended and contributed to several meetings of ten relevant national and international standardisation Technical Committees, including the CIE TC 2-86 "Glare Measurement by Imaging Luminance Measurement Device (ILMD)" in which meeting on 25th of May 2023 the evaluation of HDR algorithms performed by the project where presented.

In an onboarding meeting for newly hired employees, who have joined the consortium after the kick-off meeting, an overview of the projects technical aspects was provided, which the newcomers agreed was very useful. During a one-day internal consortium training event held at CMI, Prague, a practical introduction to the developed reference source prototype and its measurements using a spot luminance meter and ILMDs was given as a tutorial. This clarified details regarding handling and operation of the developed reference source and also covered setting up a scene with HDR luminance contrast and performing measurements using the prototypes. In addition, sessions on lab-based measurements using the seven revised luminance sources for colleagues from three participants are being run in March 2024. This includes an outdoor measurement session at the LED catwalk of TUB, Berlin.

Outcomes for industrial and other user communities

HDR imaging measurement systems have been used in industry for more than 30 years for production monitoring and for the generation of ray data from luminance images. Due to the missing traceability, they were only used to analyse relative changes between consecutive HDR measurements made under the same conditions. Traceability would make HDR measurements from different measurement systems and varying conditions comparable. Different end-users e.g. manufacturers of luminaires and ILMD manufacturers would benefit from this traceability by a more flexible application of HDR measurement systems. Authorities currently do not assess photometric glare neither from road lights nor from workplace lighting during daylight nor from façade shading systems, although citizens often complain about inappropriate installations which produce discomfort to pedestrians and disturbing glare within properties and dwellings. On-site glare and obtrusive light evaluation cannot be accomplished by relative measurement and without standard procedures and affordable measurement devices. With the results of the project, it will be possible for the first time to ensure the reproducibility and comparability of these kind of measurements, even for non-standardised measurement geometries on site. To promote the uptake of the project outputs, the consortium will organise workshops for industrial stakeholders and end-users and promote these online, at standardisation meetings and via the stakeholder committee.

Outcomes for the metrology and scientific communities

This project will provide tools, in the form of guidelines, open design guides and open-source software, which are all necessary for the realisation of traceable measurements and for a proper assessment of uncertainty in the process of capturing, processing and combining a sequence of low dynamic range (LDR) images to an HDR luminance image, and of assessing glare and obtrusive light. These results will help NMIs to offer new characterisation services for HDR imaging luminance measurement systems and to develop activities for in-situ measurements of scenes requiring a glare or obtrusive light evaluation.

The project will also, for the first time, provide a metrological basis for scientific results to be comparable and reliable, in the field of glare assessment, where there is a lack of metrological considerations. Thanks to the procedures and recommendations developed for measuring high luminance contrasts, scientists will have the tools to improve device characterisation and to validate the traceability of their measurements. To support the adoption of these new tools, this project will provide hands-on training in the correct handling of HDR imaging luminance meters. To promote the uptake of the project outputs, the consortium will organise a workshop for the research community and promote this online, at standardisation meetings and via the stakeholder committee.

So far two proceeding papers related to scientific presentations given by members of the consortium in the CIE Quadrennial Session 2023 conference had been published as open access literature:

- Schrader, C., Ledig, J. “SPECTRAL DEPENDENT NON-LINEARITY OF CHARGE ACCUMULATING PIXEL MATRIX SENSORS”, Proceedings of the 30th CIE SESSION”, CIE 2023, doi:10.25039/x50.2023.OP077
- Sáez, Á., Ferrero, A., Ledig, J., Schrader, C., Gevaux, L., Dupiau, A., Maltezos, E., Antonopoulos, M., Rezazadeh, Y., Bouroussis, C., “FRAMEWORK FOR EVALUATION OF PROCEDURES FOR HDR LUMINANCE IMAGING MEASUREMENTS, Proceedings of the 30th CIE SESSION”, CIE 2023, doi:10.25039/x50.2023.PO033

Outcomes for relevant standards

This project provides input to upcoming standardisation. This is achieved by participation and contribution to several technical committees of the CIE (e.g. CIE TC 2-62, TC 2-86, TC 2-95, TC 8-18, JTC 12). This will indirectly influence standards developed by other standardisation bodies, such as the International Organization for Standardization (ISO), the Comité Européen de Normalisation (CEN) and the International Electrotechnical Commission (IEC). The results of this normative research project will provide the necessary conditions for the application of the latest CIE reports e.g. CIE 244:2021 and CIE TN 014:2023. Research on glare and human vision strongly depends on the setup and characterisation of test scenes with extremely high and very low luminance levels at the same time. These scenes can only be measured and quantified via imaging systems that offer HDR functionality, yet not standardised nor metrologically validated. The known deviations are too large at the moment and critically not covered by corresponding uncertainty contributions. Only a correct classification and limit definition of different camera systems based on an associated uncertainty assessment will close this serious gap. With the results of the project, it will be possible to reproducibly test the existing glare assessment models for the first time, and make recommendations for their application. This is an elementary step towards effectively combating discomfort glare. Several current TCs of CIE will benefit from the results of this project, in particular those related to the work involving applications of ILMDs. For this reason, CIE was selected as the Chief Stakeholder. In addition, new TCs are expected to be proposed to exploit the scientific results of this project. To promote the uptake of the project outputs by the standardisation community, the consortium will organise a dedicated CIE workshop under the CIE Midterm Meeting & Conference in 2025.

Longer-term economic, social and environmental impacts

Light pollution, obtrusive light and light emission are currently gaining enormous societal and political importance. The massive replacement of traditional lamps by LED-based light sources with much higher luminous efficacy often encounters rebound effects and, in the scope of obtrusive light, even backfires due to the enormous luminance of these new light sources. The massive insect mortality, the constantly increasing number of people suffering from low sleep quality, the climate protection-driven necessity to use light only where it is really needed - and to use high luminance points in connection with this - make a clear photometric characterisation of the outdoor lighting installations regarding their obtrusiveness and glare indispensable. However, this will only be possible when a measurement technology exists for such situations to be evaluated on site. Traditional spot luminance meters are completely unsuitable for today's LED luminaires to fulfil this task since they cannot sample the complex angular distribution, plurality, and the temporal and spatial character of the outdoor light scenes. The uptake of the results of this project will enable for the first time a metrologically-based field assessment of glare, which in the longer term will make possible to mitigate the future risks of inadequate evaluations of glary and obtrusive situations, and therefore will have a major impact mainly on public safety but also concerning environmental protection, biodiversity and visual comfort.

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		01 October 2022, 36 months
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Associated Partners: 8. EPFL, Switzerland, 9. METAS, Switzerland		