Publishable Summary for 20NRM01 MetTLM
Metrology for temporal light modulation

Overview

LED-based lighting contributes to energy saving and the reduction of the environmental impact of lighting. However, LED lamps can show fluctuations in the light output known as temporal light modulation (TLM) which could, above certain limits and under certain conditions, impact the health, well-being and safety of people. The new EU Ecodesign 2019/2020 'Single Lighting Regulation' sets limitations on TLM. The overall aim of this project is to create the metrology infrastructure for the measurement of TLM in LED lighting and the visual effects induced by TLM, known as temporal light artefacts (TLAs). This project will develop and validate measurement methods for quantitative measurement of TLAs, such as flicker and the stroboscopic effect, and it will advance the development of a metric for the phantom array effect. The project results will underpin the development of standardisation on TLM and will provide the lighting industry, instrument manufacturers and market surveillance authorities with undisputable results of their TLM measurements.

Need

LED-based lighting is ever increasing, and the market is estimated to be worth more than 35 € billion in 2022. The ongoing transition to LED lighting is an important step in achieving the European goals on improved energy efficiency. However, LED lighting may show temporal variation of the light output, covering a large range of waveform shapes and frequencies. This temporal variation can often be perceived by humans. And as stated by the International Commission on Illumination (CIE) in TN 006:2016: "can lead to a decrease in performance, increased fatigue as well as acute health problems like epileptic seizures and migraine episodes". Also, distorted perception of moving objects could give rise to safety concerns, for instance, in traffic or work environments.

The three types of TLAs, caused by variations in light output, as defined in the TN 006:2016 by the CIE, are: i) flicker, which is the direct perception of temporal changes of the light output; ii) stroboscopic effect, which is observed as a discretised motion of moving objects resulting from illumination by a temporally modulated source; and iii) phantom array effect (or ghosting), which corresponds to a change in perceived shape or spatial position induced by saccadic eye movements across a temporally modulated light source. While metrics for flicker and the stroboscopic effect have been recommended by CIE, the metric for the phantom array effect is still missing due to a lack of the required research.

The need for worldwide harmonised TLM measurements has been recognised by the CIE. The European Commission has explicitly required the development of standards for the measurement of flicker and stroboscopic effect (Mandate M/519, Ares(2013)205169), and in 2021 the new EU Ecodesign 2019/2020 'Single Lighting Regulation' will come into effect. In view of public health and safety, the regulation will introduce limits on the allowed modulation of light sources for flicker and the stroboscopic effect. To demonstrate compliance with the regulation, lighting industry, measurement instrument manufacturers and market surveillance authorities need to be able to perform reliable, mutually comparable measurements of these TLAs. However, the metrology infrastructure to provide validated and SI-traceable measurements of TLM and TLAs is currently not available and international agreed standards do not exist.

Real scenes and life environments, such as offices and tunnels, are often illuminated with a combination of multiple light sources and daylight presenting an effective luminance pattern of high contrast and an inhomogeneous distribution of TLM parameters. Mapping the TLM of such environment would require multiple measurements with a single spot TLM measurement device. Such measurement procedures are inefficient and do not provide a full assessment regarding TLA perception. Multispectral cameras could map the spatially distributed TLM as seen from an observer's position. This provides a promising approach to map spatially resolved TLM and thereby to judge about the perception of TLAs in illuminated scenes. Although commercial state-of-the art image sensors, used in industrial cameras and imaging luminance measurement devices

(ILMDs), already contain fast modes that provide the needed temporal resolution, methods for the evaluation of spatially resolved TLM are not yet available. Also, light sources comprised of multiple temporally modulated coloured LEDs potentially induce colour TLM, often leading to the perception of colour-breakup in the phantom-array effect. Although spectroradiometers have become widely available for spectral measurements, a framework for spectrally resolved TLM measurements is missing.

Objectives

The overall aim of this project is to create the metrology infrastructure required for the measurement of TLM and to contribute to the development of standardisation on the measurement of TLM. The specific objectives of the project are:

1. To establish methods for traceable TLM measurement of individual light sources and luminaires with a focus on flicker and stroboscopic effect. These should be based on IEC TR 61547-1 and IEC TR63158 and include: (i) methods for generating and measuring optical waveforms in the time-domain and power spectra in the frequency-domain, (ii) calibration and characterisation of TLM measurement devices and the evaluation of uncertainty budgets, (iii) quality metrics (e.g. frequency response, dynamic range of signal) for the classification of TLM measurement instruments.
2. To validate the traceable TLM measurement methods, developed in Objective 1, through an interlaboratory comparison between metrology institutes and industry, whilst ensuring compliance with the new EU Eco-Design 2019/2020 regulation. To develop a recommendation on associated standardised measurement conditions.
3. To develop novel methods for measuring TLM of the illuminated environment in extended scenes (e.g. offices, roads or tunnels) and for multispectral TLM measurement of light sources.
4. To develop a model for the visibility of the phantom array effect based on perception experiments that measure the visibility threshold for various lighting conditions (e.g. modulation frequency, amplitude, shape of the modulation and light level). This model should be shared with CIE TC 1-83 or its successor in a suitable format that enables its use in a future metric for the phantom array.
5. To facilitate the take up of methods, technology and measurement infrastructure developed in the project by the standards developing organisations (e.g. CIE) and end-users (e.g. regulatory bodies, lighting industry and instrument manufacturers). This should include providing input to CIE TC 2-89 and CIE TC 1-83 (or its successor) and support for a new CIE TC for addressing the measurement of spatially resolved TLM and colour TLM.

Progress beyond the state of the art

Standardised and validated methods for traceable measurement of TLM are currently not available and measurement conditions have not yet been defined. Methods for testing equipment for flicker and the stroboscopic effect have been developed (IEC TR 63158:2018 and IEC TR 61547-1:2020), but these do not consider SI traceability or the measurement uncertainty for these quantities. So far, the efforts of national metrology institutes (NMIs) to provide SI traceability to TLM measurement devices and sources have been very limited and do not cover the TLA metrics for short-term flicker severity (PstLM) and stroboscopic visibility measure (SVM) used in the EU Ecodesign regulation.

This project will deliver validated methods and measurement conditions for traceable measurement of temporal light modulation for flicker and the stroboscopic effect, and it will support the development of standardisation on TLM measurement. It will contribute to the development of TLM measurement capability at NMI level. The developed TLM calibration methods will be validated by an interlaboratory comparison. The project outcomes will be summarised in a publicly available good practice guide (GPG), which will support CIE in the development of standardisation of TLM measurement via CIE TC 2-89 'Measurement of Temporal Light Modulation of Light Sources and Lighting Systems'. The overall goal is to provide stakeholders with reliable measurement results and well-underpinned measurement uncertainties for their TLM measurements, which is a prerequisite for the implementation and enforcement of regulations on modulated light sources.

Currently only single dimensional TLM measurement devices are available to measure TLM locally. However, for the phantom array effect, the spatial luminance pattern is important and imaging techniques are nowadays widely used to characterise lighting situations regarding its time-averaged luminance distribution. This project will investigate high-speed imaging as a new approach to measure the TLM distribution of structured luminaires and in extended scenes. This work is expected to contribute to a next generation of TLM measurement instruments.

With Red, Green, Blue (RGB) modulated displays and multispectral Red, Green, Blue, White (RGBW) or tuneable white luminaires colour-dependent temporal light modulation is also gaining attention. Measurement methods to quantify colour (or spectral) TLM are currently not available. In this project, methods to assess colour- and (multi)spectral TLM will be investigated and demonstrated.

A metric for the phantom array effect has currently not yet been defined. Although several studies on the human perception of the phantom array effect have been executed, there is currently insufficient scientific evidence available to serve as a base for a definition of the phantom array effect.

This project aims to develop a model for the visibility of the phantom array effect based on representative perception experiments that measure the visibility threshold for various lighting conditions. This model should contribute to the definition of a suitable metric for the phantom array effect.

Results

Methods for traceable and validated measurement of temporal light modulation (Objectives 1 and 2)

Based on the models given in IEC TR 63158:2018 and IEC TR 61547-1:2020, uncertainty components, which affect TLM quantities for flicker and the stroboscopic effect, have been identified. To propagate these uncertainties, from the time domain to PstLM and SVM, models have been built. Using these models, sensitivity coefficients for uncertainty propagation have been determined for various waveforms. This uncertainty analyses will be an input to calibration of TLM measurement devices.

Typical performance of measurement devices can be expressed in quality indices, which characterise how a physical effect influences the instrument’s reading. For TLM measurement devices quality indices have been defined for frequency response and dynamic range of signal. The next step is to characterise measurement devices according to the new quality indices using LED- and laser-based facilities, which will be adapted for this purpose. Quality indices can be used for instrument classification, helping prospective instrument buyers selecting suitable TLM measurement equipment.

Novel methods for TLM measurement (Objective 3)

In an experimental study, conducted in an environment illuminated with multiple light sources, image sequences at frame rates of 8 kHz and 4 kHz have been taken with RGB cameras. For each colour channel of the cameras, (namely, red, green, and blue,) the TLM waveforms have been extracted, for a region of interest marked in the image sequences. The results reveal the operation principle of tuneable white LED-based lamps, which consist of coloured LEDs, and underlined the need to evaluate spectrally and spatially resolved TLM measurements.

Measurements taken with an imaging luminance measurement device (ILMD), on different lamps and luminaires, demonstrated the feasibility of TLM measurements with such devices. The measurement modes used will be improved and further developed.

Model for the visibility of the phantom array effect

The work related to this objective has not started yet.

Impact

This project will directly impact the lighting industry, measurement instrument manufacturers and market surveillance authorities. The new EU Ecodesign 2019/2020 'Single Lighting Regulation', which entered into force in 2021, puts limits on the allowed modulation of light sources for flicker and the stroboscopic effect. To demonstrate compliance with the regulation, reliable and mutually comparable measurements of TLAs are needed.

The first project's results, related to calibration of TLM measurement devices, have been presented at the CIE Midterm Meeting hosted by MyCIE, the Malaysian CIE committee. Results presented here include propagation of uncertainties and the assessment of a facility developed to accommodate the characterisation and calibration of TLM measurement equipment. Latter contribution has been selected for possible publication in special conference issue of the journal Lighting Research and Technology.

A project website has been launched: https://www.mettlm.eu/. On this website about 48 people have registered to receive a periodic project update via email. Registrants include EU Member State representative, government experts, test organisations, manufacturers of measurement instruments, NGOs and other associations. In addition, potential stakeholders have been engaged in online meetings, evaluated their needs. Direct engagement with about 7 stakeholders confirmed the need for standardized measurement methods for TLM. To generate further awareness of the project the objectives results have been presented at CIE, DIN, IEA SSL Annex and TC-PR.

Impact on industrial and other user communities

The availability of reliable TLM measurements and related temporal light artefacts is important for the lighting industry, because the EU Ecodesign 2019/2020 regulation sets limits for flicker and the strobo scopic effect of the light sources and luminaires they bring to the market. The project outcomes will support the lighting industry in its efforts to demonstrate compliance of lighting products with the regulation. Similarly, market surveillance authorities will benefit from the availability of metrological methods and calibrated TLM measurement instruments, which is required for them to fulfil their role to enforce compliance with the regulation.

The project will provide novel methods using luminance and radiance imaging measurement devices to measure TLM of extended scenes or large area luminaires and displays. This work could be especially relevant to end users who want to measure the quality of lighting in field installations e.g., in an office space under mixed lighting conditions or on a building façade. A metric for the phantom array effect will provide the automotive industry, the entertainment industry and lighting manufacturers with a quantitative measure for the visibility of this effect. This will enable them to improve lighting products such that the visibility threshold for the phantom array effect is not exceeded, enhancing the safety and consumer appreciation of their products.

To promote the uptake of the project's outcomes by the lighting industry and instrument manufacturers, the consortium will invite stakeholders from these sectors to participate in the interlaboratory comparison.

In the first 9 months of the project the consortium started to build LED and laser based facilities to characterised and calibrated TLM measurement devices. The first commercially available TLM measurement devices have been tested against the facilities. Further characterisation and calibration of TLM measurement devices is foreseen to support regulatory compliance assessments. Preliminary tests were conducted on several (commercially available) TLM sources, using a variety of imaging devices, demonstrating the benefit of imaging TLM measurement modes.

Impact on the metrology and scientific communities

The project will strengthen the knowledge and measurement capabilities of national metrology institutes on the characterisation and calibration of TLM measurement devices and TLM sources. This will enable NMIs to establish calibration services of TLM measurement devices and/or reference sources for their stakeholders. The project will publish a set of representative computer-generated and real-life waveforms and the corresponding values and measurement uncertainties for flicker and the stroboscopic effect. This will allow scientists and metrologists involved in TLM measurement to validate their models and uncertainty calculations. Within the project, novel techniques for measuring temporal light modulation of complete scenes will be investigated, based on high-resolution time-resolved and spatially resolved imaging. The development of metrology for this type of measurement is new and challenging and is expected not only to impact the field of TLM measurement, but also the wider field of metrology for time and spatially resolved photometry. The project will impact the research field on human perception of TLM. In particular, it will progress scientific knowledge on the phantom array effect with the work on the development of a metric for this TLA. More generally, the developed metrology on TLM measurement will support ongoing research on health, performance and safety effects of TLM.

In the first 9 months of the project two presentations have been given at the CIE midterm meeting, 2021, on behalf of MetTLM. In the first presentation, a laser-based TLM calibration facility is evaluated for characterisation of TLM measurement devices, in relation to the Ecodesign 'Single Lighting Regulation'. In the second presentation, showed the findings of sensitivity analyses of TLM measurements to noise and sampling frequency.

Impact on relevant standards

The project will contribute to the work of the technical committee under the CIE, TC 2-89 "Measurement of Temporal Light Modulation of Light Sources and Lighting Systems". One of the project deliverables is a GPG on metrological methods, instrumentation and conditions for calibration of TLM measurement devices, which will contribute to an international CIE standard on TLM measurement. CIE is the Chief Stakeholder of the project and the involvement of TC 2-89 in the stakeholder board of the project will ensure that CIE needs will be met and that project results are taken up effectively. Since CIE and CEN have a formal agreement on technical cooperation, it is expected that CEN will adapt the CIE standard once available. This will help CEN to respond to the mandate issued by the European Commission (Ares(2013)205169), requiring the development of standardisation on LED lighting and the development of standards for flicker and the stroboscopic effect. This project aims to deliver a significant contribution to scientific data on the sensitivity for the phantom array effect and the development of a metric for this TLA. This will contribute to the work of CIE TC 1-83 (or possibly a new CIE TC) that is tasked with visual aspects of time-modulated lighting systems. Other standards and guidelines that may be impacted by this work are IEC TR 63158:2018 and 61547-1:2020.

The project's outcomes will be disseminated to standardisation bodies via the involvement of project partners in technical committees such as CIE TC 2-89, CIE TC 1-83, CEN 169, ISO 274, IEA 4E SSL Annex and two new TCs of CIE that will responsible for the revision of ISO/CIE 19476 on the "Characterization and performance of illuminance meters and luminance meters", which will include characterisation of photometers with relation to TLM, and the revision of CIE S 025/E:2015, which specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires.

In the first 9 months of the project the consortium was actively involved in the following standardisation committees: TC 2-89, CEN TC 169, ISO TC 274 JWG1, and DS-061. On behalf of the MetTLM consortium direct input has been provided to the draft technical report of CIE TC 2-89.

Longer-term economic, social and environmental impacts

The project outcomes will support the execution of the EU Single Lighting Regulation that protects EU citizens against potentially negative health, performance and safety effects resulting from modulated light sources like LED lighting. Having only compliant light sources on the market protects people against these potentially negative effects like decrease of performance, fatigue, eye strain or more severe effects like migraine episodes or epileptic seizures.

This EU regulation currently focuses on light sources that produce flicker or the stroboscopic effect and will be revised in 2024. The availability of a metric for the phantom array effect may serve as the basis for the incorporation of this temporal light artefact in the revision of the regulation. Requirements on dimmed light sources, known for exhibiting TLM, will probably also be included in the revision.

The project indirectly contributes to energy saving and reduction of the environmental impact of lighting by supporting regulations that put limits on the allowed TLM of light sources. The ability to enforce compliance with regulations, based on appropriate standardisation, will be supportive to the adaption of LED lighting by the public and the phase-out of incandescent lighting. This serves European and international goals on energy saving and reduction of the emission of greenhouse gasses. End users such as building owners and governmental organisations will benefit from the outcomes of the project, since it supports them in their efforts to save energy and cost by using efficient lighting.

List of publications

There are no publications at this early stage.

Project start date and duration:	1 May 2021, 36 months
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Internal Funded Partners:	External Funded Partners:	Unfunded Partners:
1. VSL, Netherlands 2. Aalto, Finland 3. PTB, Germany 4. RISE, Sweden	5. CSTB, France 6. DTU, Denmark 7. ICCS, Greece 8. TU-E, Netherlands 9. VHK, Netherlands	10. GGO, Germany 11. LMT, Germany 12. Signify, Netherlands