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Machine-readable data for measurements of total luminous flux using goniophotometer: a step toward digitalized metrology

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***Abstract* – The transition to digital metrology requires structured and machine-readable data for traceable measurement systems. This article presents a methodology for developing machine-readable data formats IES/LDT for total luminous flux measurements from Type C goniophotometers. A proposed data model aligns with digital calibration certificate (DCC) projects, enabling improved traceability, automation, and interoperability. IES (Illuminating Engineering Society) files are ASCII text files that contain photometric data for lighting fixtures. They are machine-readable and contain detailed information about how light is distributed from a fixture, including luminous intensity, distribution angles, and other relevant information. Lighting design tools and rendering software can use this information to accurately simulate how a fixture would behave in a virtual environment. An actual case study from an SASO-NMCC (National Metrology Institute of Saudi Arabia) illustrates how these methods enhance calibration and function with smart lighting systems.**

Keywords: Digital Metrology, Machine-readable, DCC, energy efficiency, modern lighting, total luminous flux, average luminous intensity, space measurements, IES format.

1. MOTIVATION

Since it shows how much light a lamp emits into a space, the measurement of luminous flux, or lumen, is essential for both economic growth and energy efficiency. Solid state lighting's (SSL) luminous efficiency is driving up the need for total luminous flux measurement. To replicate the amount of illumination and beam pattern on a surface, goniophotometry is used to create photometric data files that can be incorporated into lighting design software [1-3]. Light sources, luminaires, system realization, and lighting usage are some of the variables that affect a lighting system's energy efficiency. Goniophotometers, which can accommodate either 2 π or 4 π motion depending on their design, are commonly used to measure luminosity and luminosity intensity distributions. Goniophotometers come in three varieties: stationary light sources, fixed-head goniophotometers, and fixed-head goniophotometers that rotate the light source only on one axis. Each type has its limitations and can result in inaccuracies. To ensure accurate goniometric measurements, lamps must be mounted in the intended orientation and the burning direction remains constant with respect to gravity. By understanding these factors and using goniophotometers effectively, designers can optimize their lighting systems and improve overall energy efficiency [1-2].

A precise measurement of the total luminous flux is crucial for lighting performance. Traditional calibration certifications are not made to function well with digital systems and can be read by humans. The shift to machine-readable outputs is consistent with global digital metrology initiatives. By combining digital formats with goniophotometers, photometric traceability can be modernized.

IES files and digital metrology are crucial in modern lighting engineering, enabling accurate simulations and digitalization. IES files, developed by the Illuminating Engineering Society (IES), describe light distribution characteristics of luminaires, aiding in architectural lighting design [1-5]. Conversely, digital metrology is concerned with digitizing measurement procedures while guaranteeing data interoperability, accuracy, and traceability. It improves accessibility, decreases manual data transfer, and facilitates well-informed decision-making. Light meters and other measuring devices are guaranteed to be accurate by digital calibration certificates (DCC). Advanced lighting systems and automated quality control procedures are being produced as a result of the integration of digital metrology with smart manufacturing and the Internet of Things. When combined, they make the lighting engineering workflow more effective [6-15].

Lighting system digitization is a quickly developing trend that provides smart lighting solutions with new features, enhanced user experience, and energy savings. In order to enable features like human-centric lighting and Internet of Things integration, this shift entails switching from traditional, analog lighting technologies to digital ones like LEDs and intelligent controls. Energy efficiency and sustainability, smart lighting applications, and digitalization enablers like photonics, data analytics, artificial intelligence, and cybersecurity are important facets of digitalization. Smart street lighting networks in smart cities, urban digital twins, and smart highway lighting are a few instances of lighting that has undergone digitalization. Standardizing communication protocols, comprehending user preferences, cutting costs, and implementing strong security measures are among the difficulties. On the other hand, lighting system digitization is a revolutionary trend that could completely change lighting solutions and result in more user-friendly, efficient, and sustainable options [5-13].

2. GONIOPHOTOMETRE MEASUREMENT PRINCIPLE AND DIGITALIZATION

A Type C goniophotometer is used to measure the luminosity intensity at different angles. The total luminous flux is determined by integrating the angular intensities over a sphere. The photometer head's spectral response, electrical stability, geometry, and ambient conditions all have an impact on accuracy. Calibration is done using standard lights that can be linked to national luminous flux standards.

IES and LDT files are essential in digital metrology of lighting, providing a traceable, structured, and machine-readable representation of lighting characteristics. They serve as digital counterparts to photometric measurements, enabling verification of luminous intensity distribution, integration into lighting simulation software, development of digital calibration certificates, and automated conformity assessment. Key contents of IES/LDT files include luminous intensity distribution, total luminous flux, beam angles and cutoff, luminaire geometry, and test lab and equipment metadata. These files offer data traceability, machine-readability, quality assurance, and integration with digital calibration certificates. Thus, interpreting and managing IES/LDT files within a digital metrology framework supports automation, transparency, and interoperability in lighting calibration and certification workflows.

3. SYSTEM DESIGN AND AUTOMATION SOFTWARE FOR MACHINE-READABLE DATA FORMATS TO FACILITATE DCC INTEGRATION

Our recently constructed goniometer system is made up of numerous parts and apparatus. This home-made type-C goniometer was created to meet the requirements of our laboratory applications, including the standard use at the National Metrology Institute (NMI) and the pertinent industry uses. Using C++ code and specifically designed mathematical algorithms offers full automation and control of the system, including the output files. Both photometer (f_1' <3.0%) and spectroradiometer (CCD based type) are included in the system, and their heads are positioned in a flexible manner that makes them suitable for a wide range of applications, such as average luminous intensity distribution (ALI) with high angle resolution (±0.1 deg). Geometrical design and occupied space dimensions of the system are shown in figure 1.

Among other parts, the system includes rotational motors, a DC extremely stable power supply, a standard shunt resistor, a digital multimeter, a sourcemeter, a photometer readout unit, a scanning controller, a connecting unit, and an automatic voltage regulator (AVR). The system's primary components and alignment processes using two integrated perpendicular lasers are depicted in Fig. 1, while Fig. 2 provides alignment process realization. Figure 3 presents screenshots of software graphical user interfaces for improved visibility of the software environment and employed equipment. With features like complete and stand-alone modes, data collection and visualization, and the ability to create 2D charts of the distribution of luminous intensity, the software is ready to enable full control and machine-readable output files.

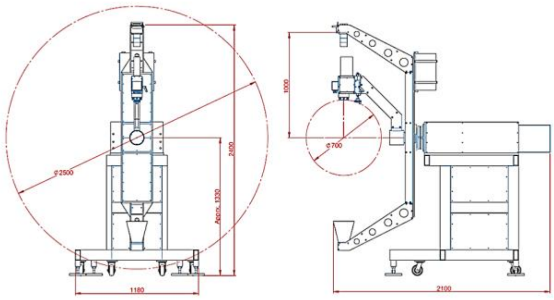

Figure 1. Geometrical design and dimensions of the custom-designed goniometer for light efficiency applications.

The change in luminous intensity with angle from a light source is measured by a goniophotometer. For lighting goods, goniophotometers are frequently used to create "photometric data files" in the IESNA (.ies) or EULUMDAT (.ldt) formats. The testing of general or architectural lighting goods, UVC germicidal lighting, vehicle lighting (headlight and marker), flashing visual alert systems, road traffic signals, and airfield and aviation lighting are among the uses for goniophotometers. There are motion goniometer stages of IES types A, B, and C available, and some models can be converted between motion types. Because of its intrinsic versatility, a single goniophotometer can be used to test directional vehicle lighting as well as general lighting goods.

The creation of photometric data files is among the most frequent tests we are asked to complete at Photometric Testing. The contents of an EULUIMDAT file are a mystery to many people. Photometric data files are used to measure the total luminous flux and luminous intensity of a light source. Total luminous flux is the total amount of light emitted from a light source, corrected for the human eye's spectral response. It is measured in lumens, while luminous intensity defines the amount of lumens in a given direction, per solid angle. A typical photometric file at Photometric Testing contains luminous intensity values for different angles and the input electrical power that the light source consumes (Watts).

There are three formats for photometric data files: IES, EULUMDAT, and TM-14. The IES file is the most common format in North America and widely used in Europe. EULUMDAT, also known as LDT, is the de-facto industry standard photometric data file in Europe. Despite its drawbacks, LDT files are still widely used and most customers request their data in both formats.

The IES and LDT formats can be formatted as absolute or relative files. Absolute photometric measurements record luminous intensity values, while relative measurements measure candela values of the luminaire but the total luminous flux of the lamp is measured separately from the luminaire itself. This allows for the measurement of the efficiency of the luminaire by comparing the bare lamp lumens to the lumens of the luminaire. However, relative photometry can lead to misleading results due to the thermal performance of an LED. Luminous intensity data needed for photometric files is generated by a goniophotometer, which measures luminous intensity at each angle at a set distance. Most photometric files are generated by an automatic goniophotometer, which rotates the device under test through two axes. The data presented in photometric files is useful for lighting designers to observe both the total light output and the angular spread of the light output. Text files called IES and LDT (EULUMDAT) are used to characterize a light source's beam pattern. They can be used as inputs to determine the patterns of light intensity in complex lighting scenarios using a variety of free optical analysis applications.

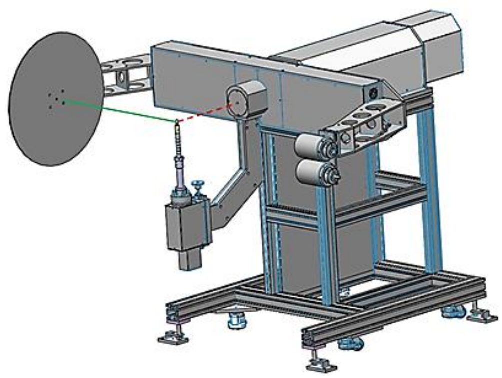

Figure 2. Alignment process visualization (automated and remotely controlled).

3.1. Use and investigation of IES/LDT files:

IES files are ASCII text files used to represent photometric data for lighting fixtures. They are machine-readable and contain detailed information about light distribution, including luminous intensity, distribution angles, and other characteristics. These files enable lighting design software and rendering programs to accurately simulate fixture behavior in a virtual environment. IES files are formatted in a specific format defined by the IES standard, with key components including file version, luminaire, manufacturer, photometric data, and angular data. Data elements include luminous intensity, angular data, lamp information, fixture geometry, and other relevant data. IES files are machine-readable, software compatible, accurate simulation, energy efficiency optimization, and reduced prototypes. They enable virtual prototyping, reducing the need for physical prototypes and mockups. Overall, IES files are a standardized, machine-readable format that enables lighting professionals to accurately simulate and analyze the photometric behavior of light fixtures in various applications. Examples of optical design software that employ IES and LDT files for scene design with various light sources are Dialux and Relux. Although LED component beam patterns can also be imported, the database repositories for these tools are mostly focused on luminaires. If an investigation does not require the near field features of the light source, IES files can be used as inputs to raytracing algorithms. Using these files (also known as apodization) has the benefit of allowing for arbitrary ray count adjustments.

4. SOFTWARE DESCRIPTION

The code of our software prepared using C++. Our software GUI, as shown in figure 3, is divided into four main areas:

1- Toolbar, 2- Current Status, 3- Command/Test and 4- Measurement.

Where, Toolbar comprises connect, configure, measure, open and save file and export IES files. Connect button is used to connect the devices and check for initialization. Config button is used for operating the photometer and spectrometer. Measure button is used to start the measurement based on the entered information. Open is used to load a saved file. Save is used to save the currently measured data. Export IES button is used to export the measured data in IES format.

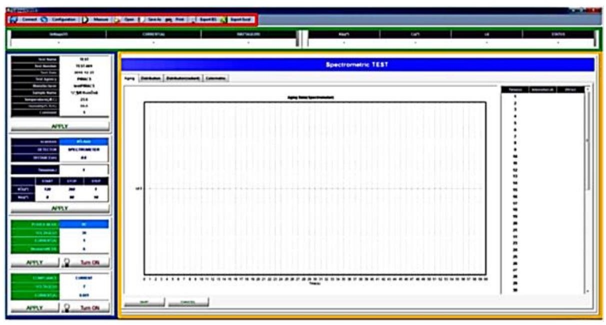

Figure 3. Graphical user interface (GUI) and its components. Red: Toolbar, Green: Status bar, Blue: Command/Test (Settings) modules and Yellow: Measurement results area.

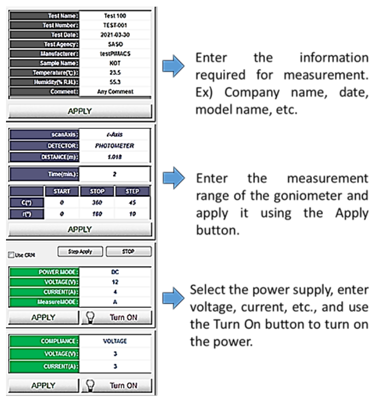

Figure 4. Command/Test modules for setting parameters with control buttons and boxes to set all parameters during scans and measurements.

Moreover, Current Status module displays various data, including the current goniometer position. While, Test Information/Parameter displays test information and sets various parameters to be used in the test. The Measurement module displays measured light distribution data. The configuration varies depending on the selection of the photometer or spectrometer. As shown in figure 4, the Command/Test area comprises many control modules that are shown and described in the figure. Figures 5 through 8 show the GUIs of different modules and working functions of the software as well as snaps from the output files and their formats.

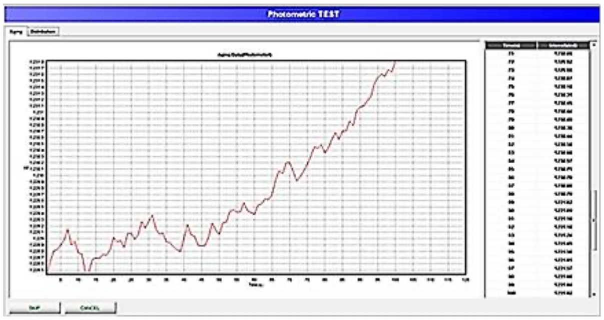

Figure 5. Aging window for optimal stability control.

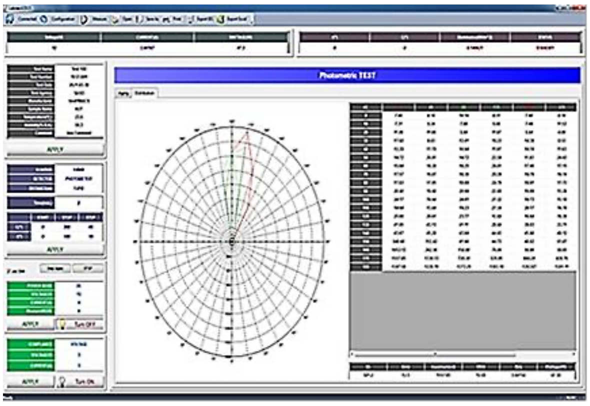

Figure 6. The measured intensity distribution data displayed in the grid and all data shown on the right columns, where each column represents azimuthal angle.

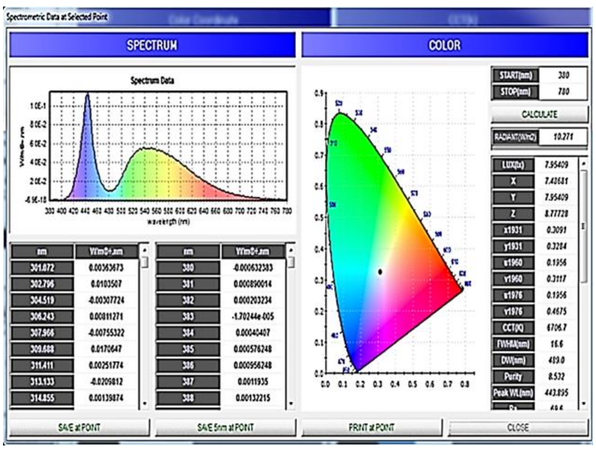

Figure 7. SpecData: the spectrum and color data concluded from the measured spectral data.

5. CONCLUSIONS

Modern lighting engineering relies heavily on digital metrology and IES files, especially when it comes to simulation and digitization. The Illuminating Engineering Society (IES) created IES files, which are standardized text files that carry light fixture photometric data. This allows software to simulate lighting accurately. Conversely, digital metrology is concerned with digitizing measurement procedures to guarantee data interoperability, accuracy, and traceability, particularly in the context of smart manufacturing and the Internet of Things.

For luminous flux, machine-readable calibration findings enhance digital integration, automation, and traceability. Advantages such as facilitating automated calibration processes - facilitating interaction with intelligent sensor networks Complies with future DCC structures can be counted. Future difficulties like; international schema harmonization required Data security version control and Limitations of legacy hardware need to be considered and challenged. For more openness, the results were connected to a traceability database built on the blockchain. The amount of time needed to generate reports dropped by 70%.

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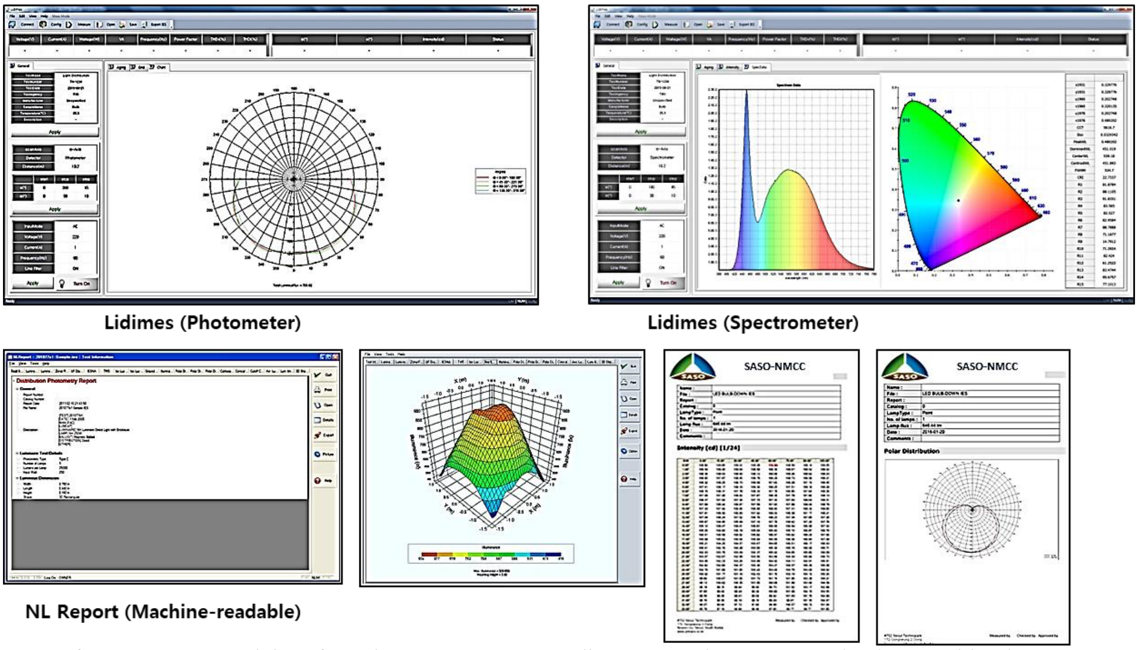

Figure 8. Software DAQ modules for photometer, spectroradiometer and 3D spectral charts with the output results in form of NL reports and IES (machine-readable) format.

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