

Optical metrology at SASO-NMCC – a success story of the realization of luminous flux unit and spectral radiant flux scale supporting lighting industries and energy efficiency applications

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Motivation

Lumen realization is a crucial aspect of modern lighting systems, as it helps standardize the light output of lighting devices, enabling comparison and compatibility across various technologies. It also helps in understanding power efficiency, as manufacturers can express how efficiently a light source converts electrical power into visible light.

Lumen realization has a significant impact on energy efficiency and sustainability, as it allows manufacturers to gauge the energy efficiency of different lighting products. LEDs and OLEDs, for example, have significantly higher luminous efficacy compared to traditional lighting, leading to lower energy consumption and reduced carbon footprint. Understanding the lumen output of lights under varying conditions helps optimize energy usage.

Lumen realization directly impacts the ability to design efficient and comfortable lighting environments in homes, offices, streets, and commercial spaces. Proper illumination levels, uniformity in lighting, and lighting aesthetics and ambiance are achieved by specifying lighting systems in terms of lumens.

Accurate lumen realization directly benefits consumers by helping them make informed decisions about lighting products, such as choosing the right lighting options that balance light output and energy consumption. Lumen values are now commonly used in product labels for light bulbs, making it easier for consumers to compare the light output of different products. Energy-efficient lighting standards, such as Energy Star and EU energy labels, heavily rely on luminous flux measurements to indicate how efficient the light is at producing visible light.

Lumen realization plays a pivotal role in shaping lighting regulations and building codes, such as building codes and light pollution control in urban planning. With more accurate lumen realization, innovation in lighting technology continues to accelerate, with smart lighting systems adjusting lumens in real-time based on user preferences or environmental factors like natural daylight. Advanced optical designs are being designed for optimal lumen output using specialized optical components.

The accurate measurement of lumens has contributed to the growth of the global lighting industry, with innovations in various applications such as automotive lighting, architectural lighting, retail lighting, and smart cities. The role of lumen realization remains critical in global standards development, marketing, and product differentiation.

Instrument and Automation

The National Metrology Institute of Saudi Arabia (SASO-NMCC) has built a three-axis goniophotometer/spectroradiometer combined at one facility to assess the photometric characteristics of light sources and realize the luminous flux unit “lumen”. With the new goniometric system, the integration of the illuminance values $E(\theta;\gamma)$ measured on the goniometric spherical surface is used to calculate the total luminous flux output by a light source at both cap-up and cap-down mounting positions. Using two standard sources for luminous intensity and TSRF, the system's internal calibration is carried out. Compact light sources' luminous intensity distribution values, $I(\theta;\gamma)$, can also be measured by the system that was built.

Direct realization of total spectral radiant flux scale from 350 nm to 850 nm with an expanded uncertainty ($k = 2$) of (1.2~2.8) % using the developed gonio-spectroradiometer could be done. Reducing the total radiant flux scale to total luminous flux, total radiant flux, and color quantities such as chromaticity and correlated color temperature to test the optical performance of LED and OLED luminaires/modules can be made optimally as well as relevant standard applications as standard lab.

Automation (Gonio-photometer/spectroradiometer Systems Control & DAQ)

Our newly established goniometer system comprises many components and equipment. It is type-C goniometer that home-made designed to fulfil the needs of our laboratory applications, including standard application as national metrology institute (NMI) and the relevant industrial applications. It is fully automated using C++ codes and purpose-targeted mathematical algorithms. The system equipped with both photometer ($f1' < 3.0\%$) and spectroradiometer (CCD based type) with the heads of both of them installed in a flexible way that can be easily used for variety of applications including average luminous intensity distribution (ALI) with high angle resolution (± 0.1 deg). System comprises rotational motors, automatic voltage regulator (AVR), photometer readout unit, scanning controller, connection unit, DC highly stable power supply, standard shunt resistor, digital multimeter, sourcemeter among other components. Figure 1 shows the main parts of the system, its main components and the alignment procedures using two built-in perpendicular lasers, while figure 2 show snaps of software GUIs for better visibility of both equipment used and software environment. Software is well prepared to allow control, including full and stand-alone modes, data acquisition and visualization as well as drawing the 2D charts of luminous intensity distribution.

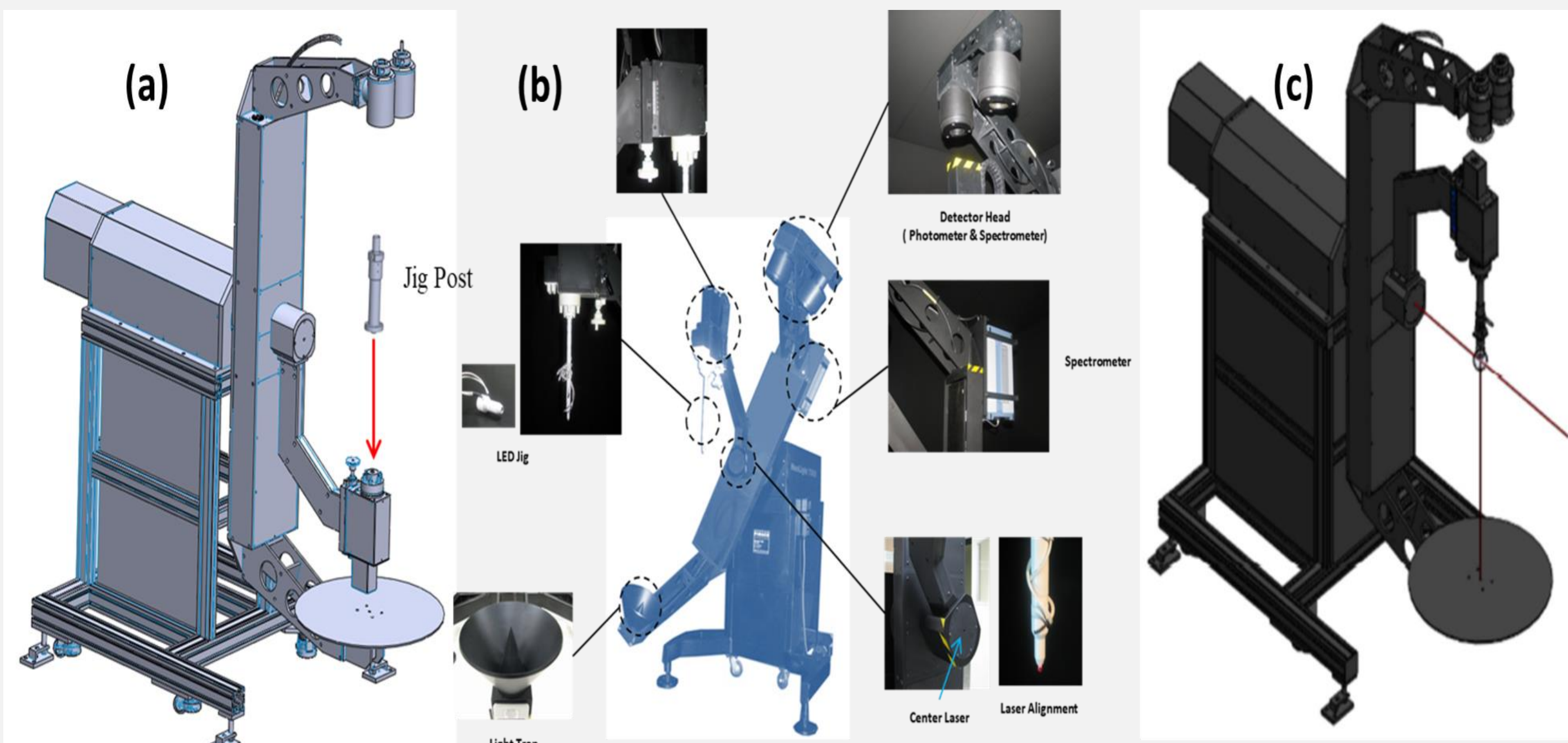


Figure 1. Schematics of the SASO-NMCC goniophotometer/spectroradiometer system [1]

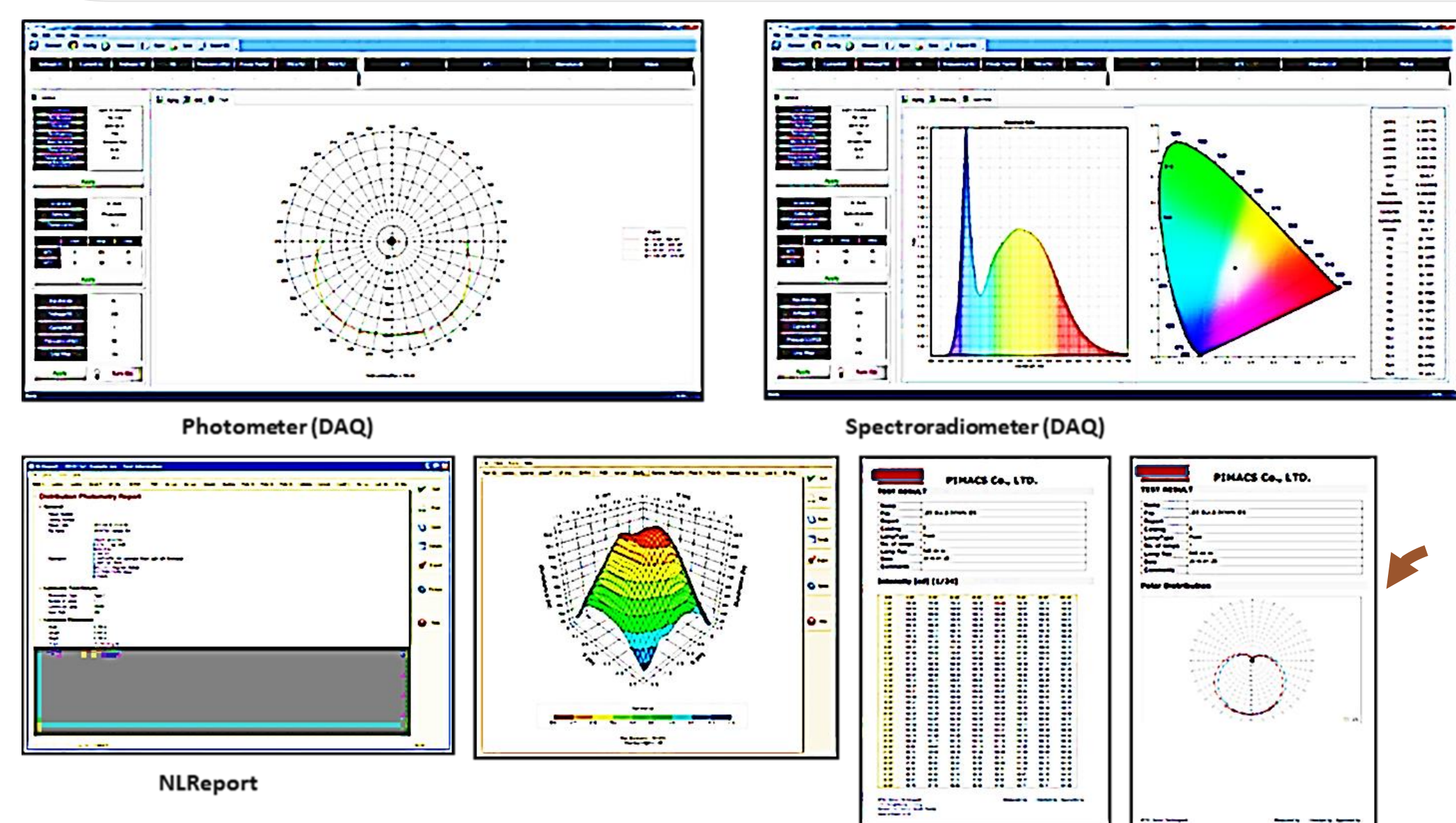
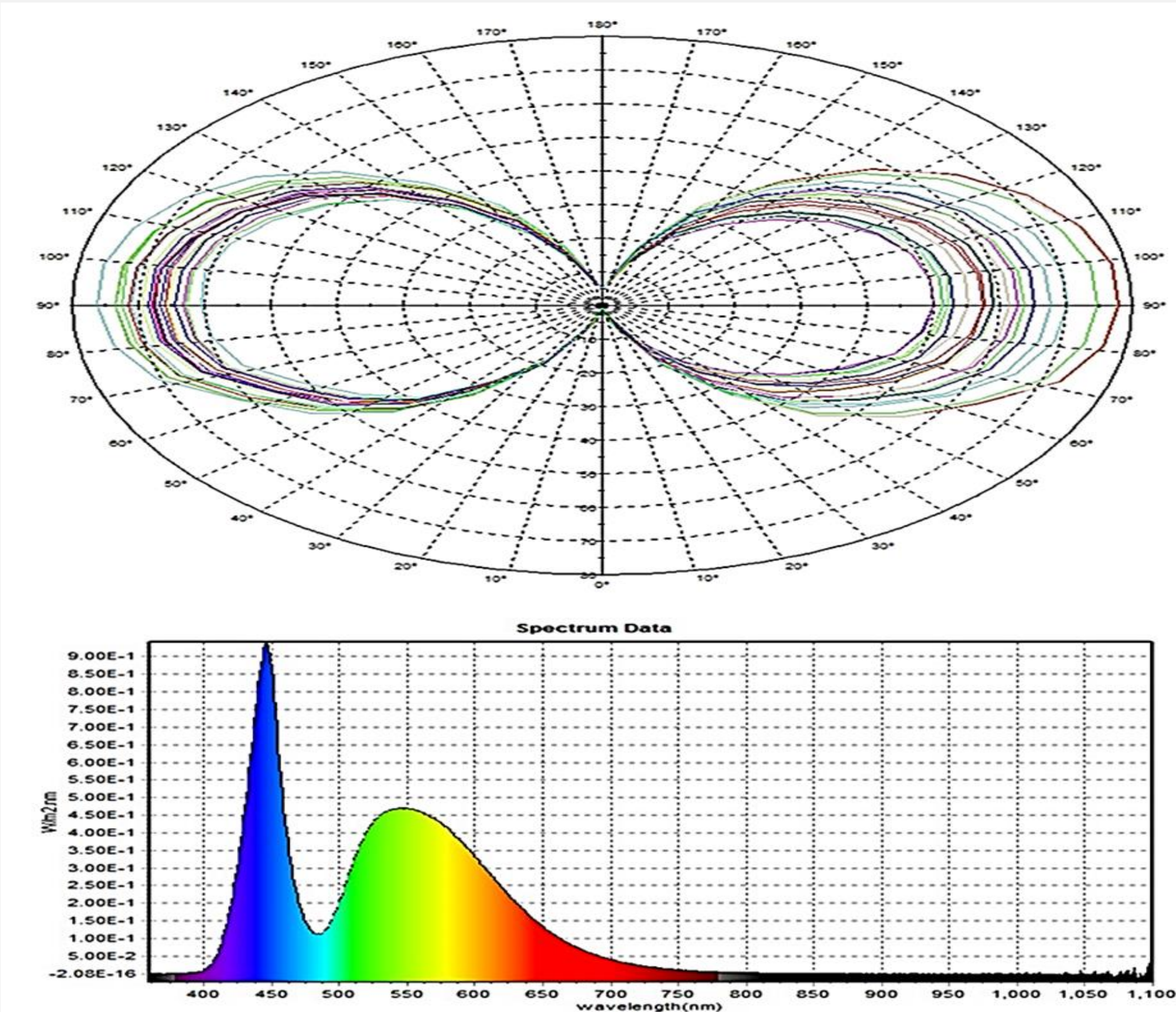


Figure 2. GUIs and output reports by home-made automation (control and DAQ modules) code using C++ [1]

Metrological Needs (unit realization and measurement traceability) and Industrial Applications

- In addition to industrial applications for absolute calibration of light sources and luminaires with obtaining the full profile of its lighting and colorimetric characteristics, SASO-NMCC developed a new facility for the realization of total luminous flux (TLF) units and total spectral radiant flux (TSRF) units.
- Measured in lumens (lm), flux is a vital photometric number that is critical to a nation's economy and associated energy efficiency applications. It shows how much light a lamp emits into an area. The remarkable increase in the luminous efficiency of solid state lighting (SSL) has increased the need to measure the entire luminous flux of SSL. SSL color measurement and total luminous flux measurement are both required in industry.
- The light sources, luminaires, system implementation, and lighting usage are some of the variables that affect a lighting system's energy efficiency. The performance of the lighting can be greatly affected by the selection of the appropriate lights as well as the surrounding surroundings. In order to quantify the total light flux using numerical integration, goniophotometers are commonly employed to measure luminance and luminance intensity distributions.
- The selection of light sources, luminaires, system implementation, and lighting usage are some of the variables that affect a lighting system's energy efficiency. Designers may maximize their lighting systems and raise overall energy efficiency by being aware of these variables and employing goniophotometers skillfully.



Top: The spatial distribution of luminous intensity of test lamp. Bottom: Spectral power distribution of the standard lamp acquired by the spectroradiometer at the maximum intensity angle of test lamp.

[1] Khaled M. Ahmed, Development of novel goniometric system for lumen realization and measurements of light sources with detailed uncertainty analysis, Measurement: Sensors, 2025, 101821.
[2] CIE S 025/E:2015 Test Method for LED Lamps, LED Luminaires and LED Modules CIE International Standard S 025/E (Vienna: International Commission on Illumination), 2015.
[3] IES LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products (New York: Illuminating Engineering Society).
[4] Goodman T M, Moore J R, Pearce N C and Murray D K, The establishment of a new national scale of spectral total flux Proc. CIE the 22nd (Melbourne, Australia) vol 1 pp 50–3, 1991.
[5] Zong Y and Ohno Y, Realization of total spectral radiant flux scale and calibration service NIST Proc. CIE the 26th (Beijing, China) vol 1 pp 179–82, 2007.
[6] Neves S, Teuber A, Sperling A and Lindemann M, Stability of array spectroradiometers and their suitability for absolute calibrations Metrologia 49 S48–52, 2012.

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