A Low Cost Compact CCD Grating Spectrometer

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[Abstract] A spectrometer is a tool for accurate photopic measurements. The grating spectrometer developed by Lighting Sciences Canada Ltd. (LSC) consists of a slit, a transmission holographic grating, a lens, and a CCD camera. A frame grabber equipped in a computer digitizes the NTSC signal from the CCD camera. The system is relatively small (12.7 cm x 17.8 cm x 30.5 cm) and light weight (5.4 kg). The system will measure lumen output of modern fluorescent or compact fluorescent lamps more accurately than conventional filter-based photometers.

I. Introduction

There is a strong demand among optical scientists and engineers for a general purpose measuring instrument. The instrument developed by Lighting Sciences Canada (LSC) can be used as a spectrum analyzer in light source studies, as a spectrometer for measuring transmission, reflection and absorption, or as a spectroradiometer with calibrated optical probes. The design of this spectrometer is innovative, yet low-cost, compact, and portable. It provides flexible solutions for optical measurements.

II. Instrument Design

A. Hardware Design

The instrument layout is shown in Figure 1. The system consists of an entrance slit, a transmission grating, a lens (f = 25 mm), and an aperture. The slit assembly can be quickly changed. The focus and aperture size are adjustable. A holographic transmission grating with 600 groves per millimetre is fixed in front of the lens. The light beam is dispersed by the grating, focused, and then detected by a 610 x 488 pixel CCD camera. The NTSC signal from the CCD camera is digitized by a frame grabber equipped in an IBM-AT compatible microcomputer. An optical fibre probe with a coupler can be connected to the instrument to allow remote spot luminance and colour measurement and analysis. This enhances the instrument's flexibility.

The design uses a grating combined with a CCD camera to eliminate the need for a complicated mechanical drive. This reduces the cost, size, and weight of the spectrometer system.

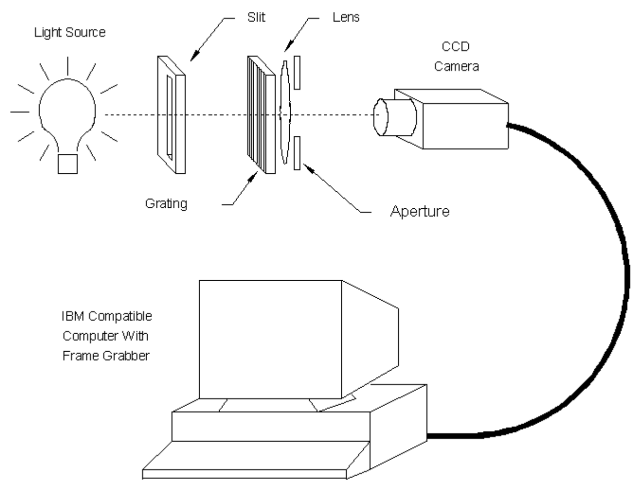

Fig. 1 Spectrometer Schematic Diagram

B. Software Design

The software which controls the operation of the spectrometer is written in the Turbo C++ environment. It can be used on any IBM-AT compatible PC with a DOS operating system and VGA graphics. The software combines functions so that one key or mouse selection can carry out individual applications without switching between menus or requiring large amounts of keyboard entry.

The spectrometer obtains the spectral data from the digitized NTSC signal from the CCD camera. The wavelength scale is along the horizontal pixel axis. The vertical column values are summed to obtain spectral data for each wavelength value. This summation process enhances the resolution of the spectral data by a factor of sixteen.

Figure 2 shows the main menu screen of the software. By selecting different submenus, the software will lead the user into different functions of the system. As seen in Figure 2, the following working modes can be selected: emission measurements of radiant sources (GREY LEVEL, POWER CORRECTED), transmission, absorption, and reflectance measurements. The user can capture a set of spectral data, graphically display it, and print it out. In addition to spectral and power results, the system can also obtain information such as: colour co-ordinates, colour temperature, luminance, and colour rendering index (CRI)[1].

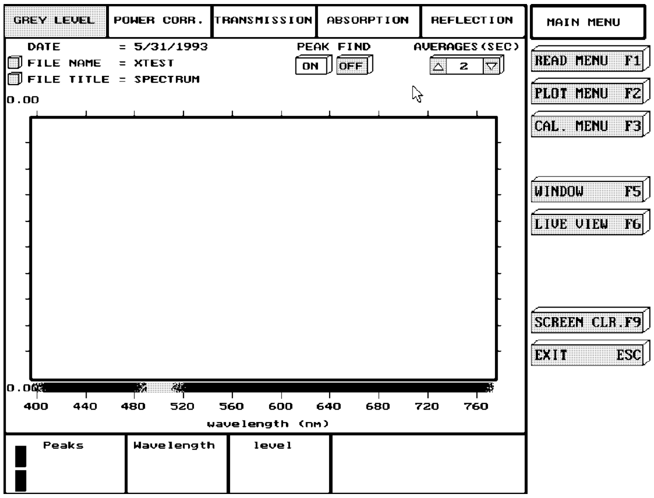

Fig. 2 Main Software Menu

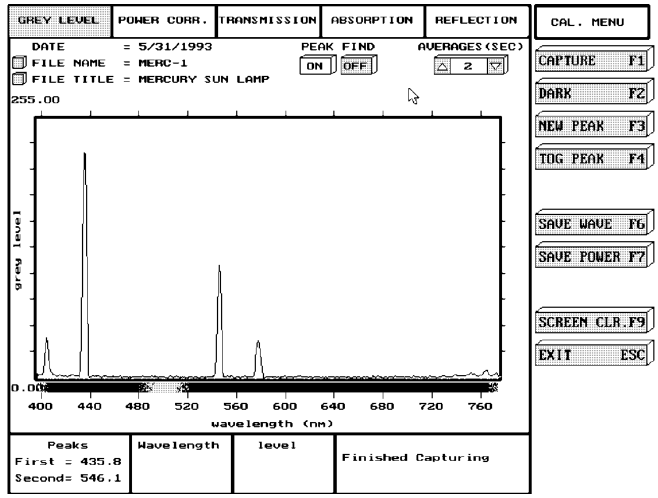

Fig. 3 Software Calibration Menu

III. CALIBRATION METHODS AND RESULTS

A. Wavelength Calibration

The calibration procedures begin with the wavelength calibration. Light sources with known spectral lines (wavelength range 380 nm - 1100 nm), such as a mercury lamp or a laser, can be used for wavelength calibration. Figure 3 shows a wavelength calibration using a mercury lamp. The system automatically utilizes the two known mercury spectral lines and performs a linear interpolation of the wavelength scale. If other known wavelength sources are used, the NEW PEAK function, shown in the CAL.MENU (Figure 3), can be selected . The calibration software requests two peaks in general but can also use a single known spectral line (such as a laser) for quick wavelength correction.

Experimental results show that the wavelength calibration of this spectrometer is stable and highly repeatable.

B. Spectral Irradiance Calibration

The second step of the calibration is the spectral irradiance calibration. This requires a calibrated lamp with a continuous irradiance curve within the measurable wavelength range, such as an incandescent lamp. Figure 4 shows an irradiance calibration using a quartz halogen lamp. The system utilizes the known irradiance values and compares them to raw spectral data measured using the calibrated lamp operating under its specified electrical parameters. Spectral responsivity factors are derived and stored for future applications[2].

$$S(\lambda) = \frac{V(\lambda)}{s(\lambda)}$$

$S(\lambda)$ = *spectral responsivity factors*

$V(\lambda)$ = *spectral irradiance values of the calibrated lamp*

$s(\lambda)$ = *raw spectral data*

Spectral irradiance measurements of an unknown light source are accomplished by multiplying the raw spectral data by the previously stored spectral responsivity factors of the spectrometer.

$$X(\lambda) = s(\lambda)\ x\ S(\lambda)$$

$X(\lambda)$ = *unknown spectral irradiance*

IV. SYSTEM PERFORMANCE

Extensive experiments and test measurements have indicated that the LSC spectrometer has a high performance in a wide range of applications. The typical instrument performance of the LSC spectrometer is summarized as follows:

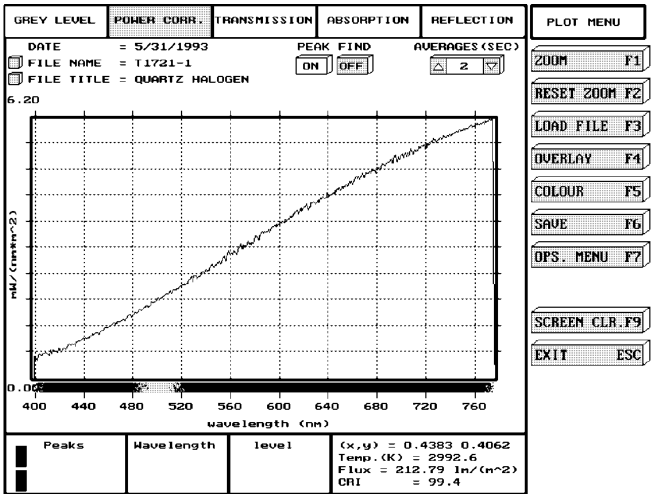

Fig. 4 Irradiance Calibration Example

1) *Wavelength Range:* measuring from 380 nm to 1100 nm

2) *Spectral Accuracy:* ± 0.5 nm

3) *Wavelength Resolution:* < 1.0 nm per CCD pixel

4) *Repeatability:* The standard deviation of repeat measurements over a 20 minute period is not greater than 0.5%

5) *Digital Resolution:* 8 bit A/D

6) *Optical Head External Dimensions:* 12.7 cm x 17.8 cm x 30.5 cm (5" x 7" x 12")

7) *Optical Head Weight:* 5.4 kg (12 pounds)

V. TYPICAL APPLICATIONS OF THE INSTRUMENT

The LSC spectrometer is able to provide a wide range of applications. It can be used as:

1) A measurement device in spectral and power studies of light sources, such as: light bulbs, light emitting diodes (LEDs), lasers (including telecommunication semiconductor lasers), plasma, and compact fluorescent lamps (see Figure 5)[3].

2) An analytical device in optical filter studies and characterizations.

3) A tool for quality control of light source production lines, i.e. an instrument used in process monitoring and control.

4) A particularly useful device for colour analysis of surface samples, such as paper, textiles, and printed samples.

5) A measurement tool of source correlated colour temperature (see Figure 6).

6) A remote spot luminance and colour analysis measurement instrument when connected to a calibrated fibre-optic probe.

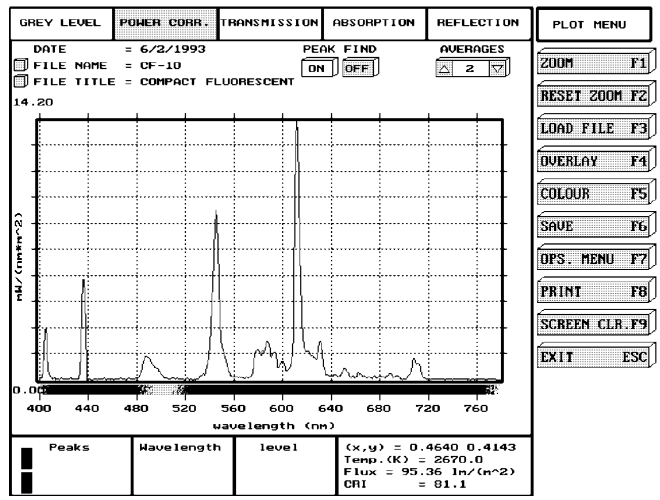

Fig. 5 Power Spectra Of A Compact Fluorescent Lamp

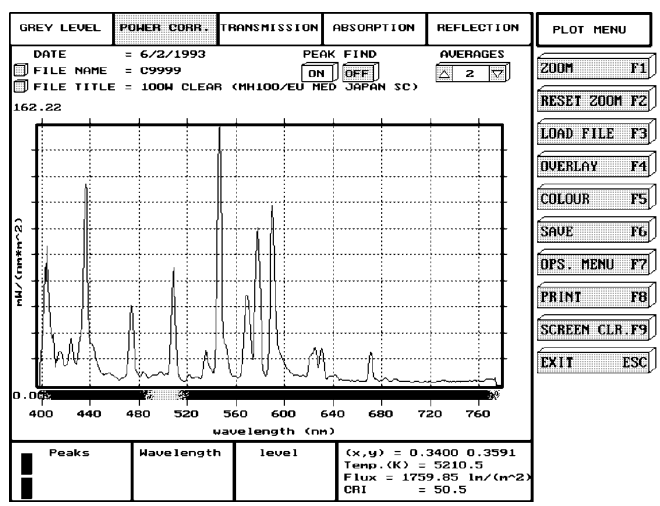

Fig. 6 Colour Temperature Measurement Of A Metal Halide Lamp

VI. CONCLUSION

The LSC spectrometer is a compact, portable and low-cost measuring instrument. There are no moving parts in the system. The measurements are carried out instantly. Results are shown in live and graphic displays. One-key or mouse selectable features make operation simple yet comprehensive.

REFERENCES

[1] Joseph B. Murdoch, Illumination Engineering: from Edison's lamp to the Laser; Macmillan Publishing Company, 1985

[2] IES Lighting Handbook: Reference Volume, Illuminating Engineering Society of North America, 1984

[3] M. J. Ouellette, Photometric Errors with Compact Fluorescent Sources, National Research Council Canada, 1992