Miniaturized Spectroradiometer

Thomas Morgenstern, Gudrun Bornhoeft, Steffen Goerlich
JETI Technische Instrumente GmbH, Jena, Germany

Abstract

This paper describes the basics of spectroradiometric instruments as well as criteria for their choice. Special attention is turned to the recent development of miniaturized spectroradiometers which are suitable for use in quality control processes, even directly at the production line. The requirements for such instruments as well as their advantages and drawbacks are discussed.

1. Introduction

New types of lamps, optical displays, signals and the design of indoor and outdoor illumination play a more and more increasing role in modern technology. Examples are LCD, plasma and LED screens, electroluminescent displays, fluorescent materials, LED illumination of airfields, LED traffic lights, Metal halide lamps etc.

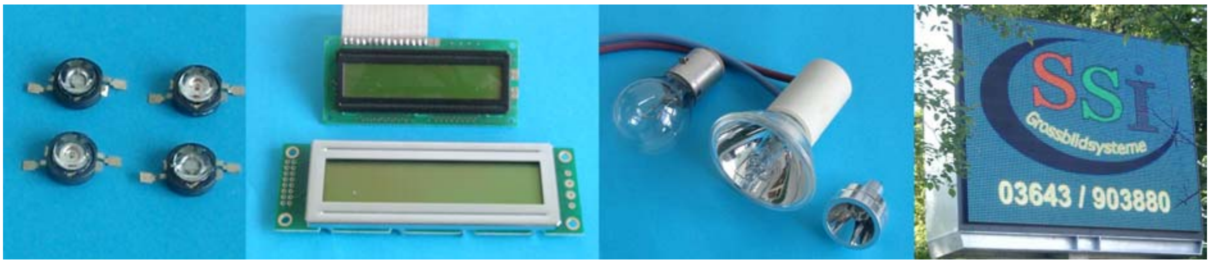


Fig. 1 Selection of measuring objects

Therefore the need for appropriate light measurement instrumentation also increases. This concerns especially instruments, which are suitable for use in the production process. Such instruments have to have the following main properties: Sufficient measurement precision, small size, easy integration into the control system, simple handling, little amount of maintenance and recalibration and an economic price. They can be used for quality control even at assembly lines.
Radiometric and colorimetric measurements can be done with two different set ups – with filter instruments or with spectrometer based instruments. Filter instruments use three detectors with their sensitivities adapted to the three color receptors of the human eye. Advantages are fast measurements and high sensitivity, but they cannot resolve the detailed spectrum. Therefore they provide only a limited range of measuring values as integral luminance and chromaticity. Spectrometer based instruments (spectroradiometers) can deliver more information, e.g. spectral luminance, radiance and Color rendering indeces. If these values are of interest such instruments have to be used.
In the past only laboratory spectroradiometer with well-engineered parameters and equipment were available. Compact miniaturized instruments are also on the market for a short time. JETI Technische Instrumente GmbH has developed such spectroradiometers fulfilling the requirements listed above [1].

2. Applications

Fig. 2 shows spectra obtained from different light sources and measured with the new JETI spectroradiometer specbos 1200.

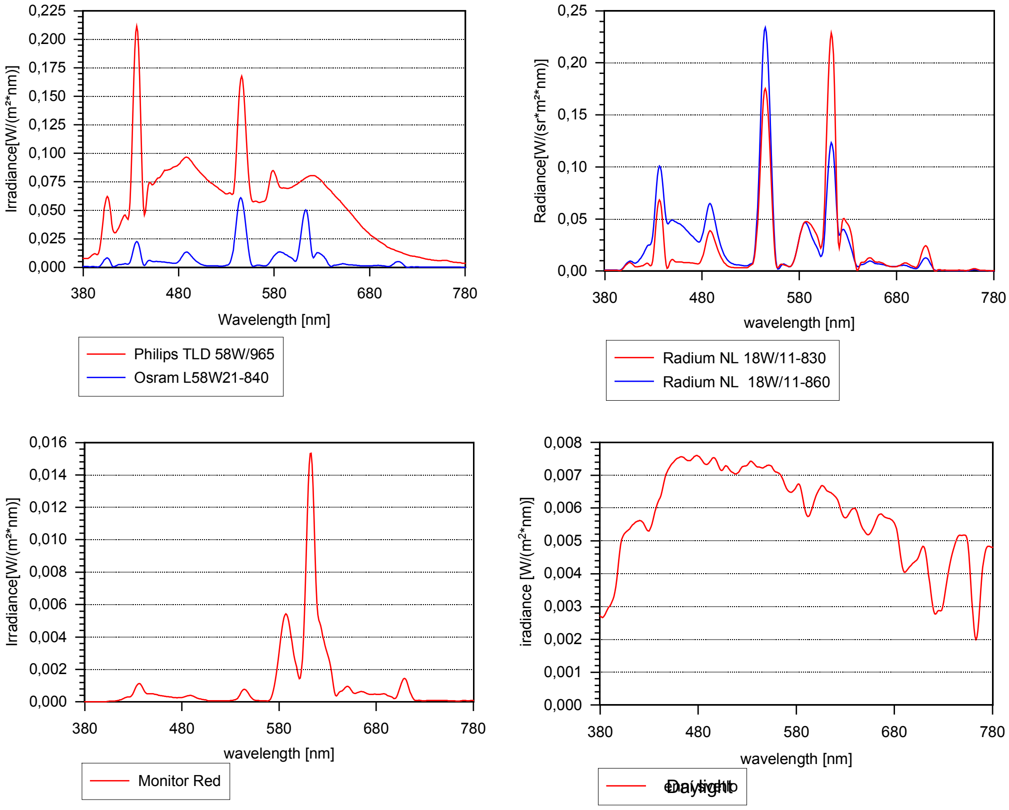


Fig. 2 Spectra of fluorescent lamps, a red CRT screen and daylight

Radiometric and colorimetric measuring values can be obtained from these spectra by the classical calculation schemes. Such values are:

- Integral radiance, spectral and integral luminance
- Chromaticity x y and u´v´
- Dominant wavelength and color purity
- Color rendering index CRI
- Correlated color temperature CCT

Examples for light sources which can be characterized by spectroradiometers are listed in the following table:

Production	**Research/ Monitoring/ Education**
CRT displays	Daylight measurement
Flat panel displays (LCD, Plasma, Electroluminescent, OLED, …)	Traffic lights
Phosphors	Room illumination
Metal Halide lamps	Illumination in architecture models
Surgery illumination	Practical courses
Discrete LED classification	
Digital projectors	

Tab. 1 Applications of spectroradiometers

3. Principle of Spectroradiometers

The basic component of a spectroradiometer is the spectrograph. It determines the primary optical parameters of the instrument, e.g. wavelength range, optical resolution and measuring time.

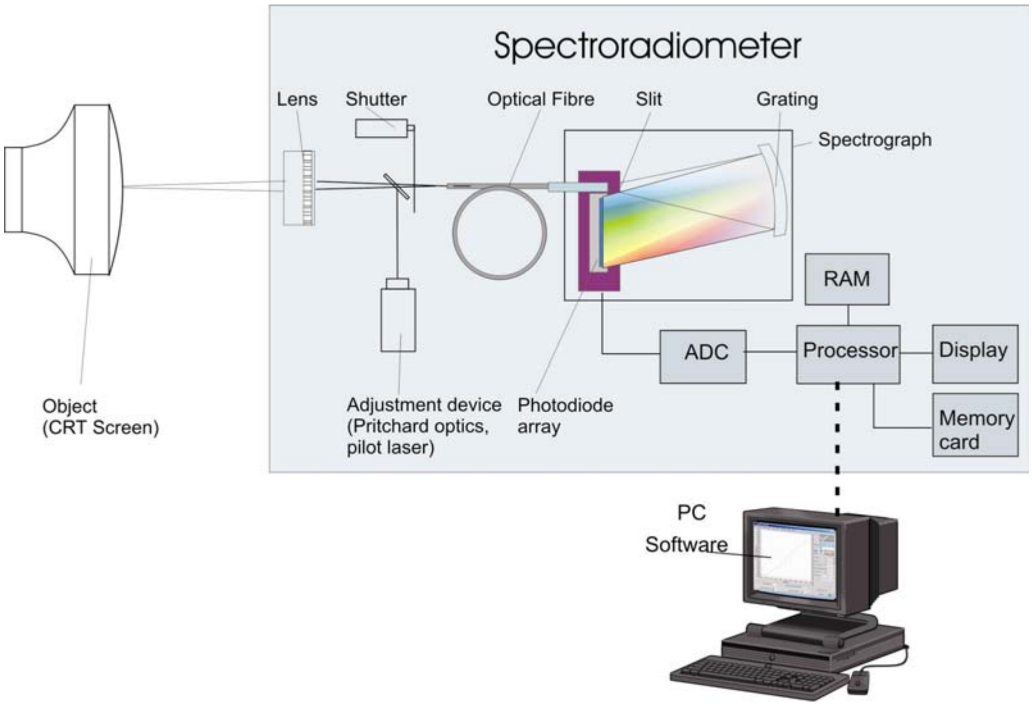


Fig. 3 Scheme of a spectroradiometer

The main difference of a spectroradiometer to a standard spectrometer is the absolute intensity (y) axis of the spectrum.
Standard spectrometers have normally only a calibrated wavelength (x) axis. The relation between the pixel numbers of the array and the real wavelengths is usually given in a polynomical equation up to the 4^{th} order.
Additionally spectroradiometers have to be calibrated with a traceable standard lamp. The spectral sensitivity, which is calculated during this calibration procedure at the manufacturer, is used for the transformation of the measured raw data into the absolute spectrum. This calibration has to be repeated at least every two years to maintain the measurement precision.
Furthermore the following extensions, compared to a standard spectrometer, are arranged to adapt the instrument to radiometric applications:

- special measuring optics (see table 2 below)
- mechanical shutter for dark signal compensation
- calculation of radiometric and colorimetric values

The instrument can be designed as a stand alone or as a PC based version. At present stand alone instruments mainly contain an alphanumeric display for the measuring results. An additional PC software gives the possibility to show the full spectrum, furthermore it is possible to manage the measuring results and to proceed special calculations. The following figure shows a typical radiometric software from JETI specbos 1200. There can be seen the spectrum as well as several colorimetric and light measuring values.

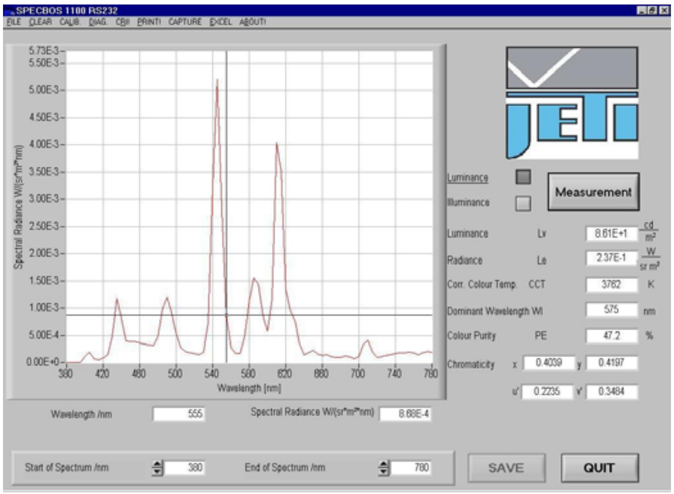


Fig. 4 Sceenshot of a radiometric software

The radiometric software of specbos 1200 has the following additional functions:

- storage of spectra and measuring values in Excel™
- storage of reference spectra in GRAMS and ASCII formate
- basic mathematical operations for the spectra

4. Peculiarities of compact spectroradiometers

The main aim in the development of compact spectroradiometers is to design a precise instrument, which has only the essential features for the measurement. This idea will be demonstrated considering specbos 1200 as example.
The basic unit of specbos 1200 is a small spectrograph with a line array on a read out electronics. It is used the smallest array spectrometer of Jobin Yvon HORIBA (CP 20). The unit is fitted out with a fixed measuring optics generating a diverging field of view of 1.5°.

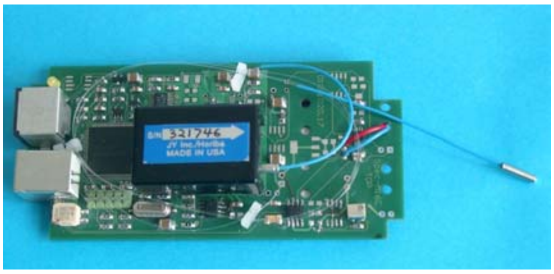


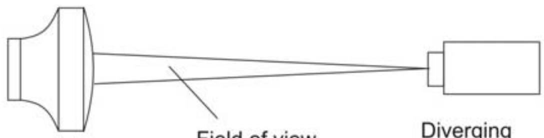
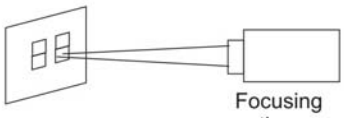
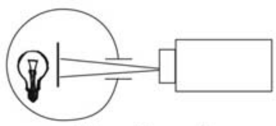
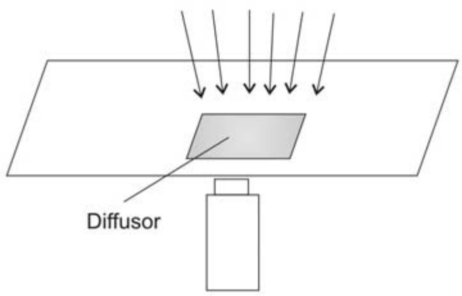
Fig. 5 Array spectrograph with driver electronics

This basic set up can be used for the measurement of luminance and radiance data. The measuring area is not identified by a telescopic system (Pritchard mirror) as in laboratory instruments, but by a simple pilot laser circle on the object, which is projected during the adjustment phase. A mechanical shutter is used for the dark correction. The integration time is adapted automatically to the level of the light source under test. If illuminance and irradiance have to be measured, a diffuser cap used as cosine corrector can be attached to the measuring head. Furthermore the instrument can be attached to an integrating sphere for luminous flux measurements. The radiometric calculations are proceeded on a PC, connected via USB interface. No extra power supply is needed. So the instrument can be used with a laptop for field measurements.

There is also available another version, where the measuring data are provided directly by the instrument. It can be easily integrated to host computer systems in production facilities.
The main advantages of specbos 1200 are its compactness and the easy handling. Furthermore it is much less costly than laboratory instruments.
These advantages make it suitable for quality control in production, but also for usage in education, e.g. in light technical practical.
Of course such compact instruments have not the same flexibility as laboratory instruments, e.g. no exchangeable or focusable optics and apertures and no detector cooling. Therefore some parameters, as the minimal detectable intensity or the minimal measuring area, are limited, compared with other spectroradiometers (see table 3 in paragraph 5).

5. Criteria for Instrument Choice

In general spectroradiometers are designed for different applications. A main issue is the light measuring value, which is of interest. From the following table can be seen which value is used for the characterization of a specific measuring object.

Object	Measurement set-up	Measurement value
Large area Screens and displays		**Luminance** $[\frac{cd}{m^2}]$
Segments of displays		**Luminance** $[\frac{cd}{m^2}]$
Directed light sources (reflector lamps, lensed lamps, LED)		**Luminious intensity** $[cd]=[\frac{lm}{sr}]$
Totalradiation of diffuse light sources (bulbs, fluorescence lamps)		**Luminious flux** $[lm]$
Illuminated areas (work places, digital projectors)		**Illuminance** $[lx]=[\frac{lm}{m^2}]$

Tab. 2 Light measuring values for different applications

Not every spectroradiometer is suited for all applications. Some instruments are only designed for luminance measurements, others include an additional front end (e.g. diffusor) for illuminance measurements and again others are dedicated for Luminous flux measurements (fitted out with integrating sphere).
Another main criterion for the choice of a certain type of instrument are the attributes wavelength range, optical resolution, sensitivity and of course the price. The following table shows selected parameters for three instruments in comparison:

	Laboratory instruments		**Compact Instrument**
Parameter	**Photo Research PR-705**	**Minolta CS-1000**	**JETI specbos 1200**
Spectral range	380 … 780 nm	380 … 780 nm	380 … 780 nm
Standard lenses	one, variable focus	two, variable focus	fixed, divergent
Operation	Stand alone or with PC	Stand alone or with PC	only with PC
Optical resolution	2.5 … 20 nm	5 nm	9 nm (FWHM)
Optical system	Variable focus lens and 4x fixed focus lenses	4 different lenses	Aspherical lens, f=4 mm
Target finder system	Eyepiece, through the lens (Pritchard), CCD camera and monitor option)	Eyepiece, through the lens (Pritchard), monitor option	Circle marking by internal pilot laser
Acceptance angles	2°/ 1°/ 0.5°/ 0.25°/ 0.125°(1° and 0.25° with standard MS-55 lens, others extra costs)	1° (0.14° with special lens)	1.5°
Smallest target diameter	1 mm with 1° aperture,	7.9 mm (standard lens) at 36 cm	5 mm at 20 cm distance
Measurement modes	Spectral radiance (irrad., flux, intensity optional)	Spectral radiance	Spectral radiance, spectral irradiance (optional spectral luminous flux)
Computed values	Lv, Le, 1931 CIE x,y, 1976 CIE u´v´, XYZ, CCT, delta Lv, delta xy, delta u´v´, delta CCT, L*u*v*, L*a*b*, delta E	Lvxy, Lvuv, Lvu´v´, Tduv, Le, dom. WI, purity (2° and 10° observer switchable)	Lv, Le, Ev, Ee, CIE x,y, u´,v´, CCT, dominant WL, color purity, CRI (all in PC software)
Lowest luminance level, standard lens	0.1 cd/m2 @ 1° aperture, 1 cd/m2 @ 0.25° aperture	< 0.25 cd/m2	2 cd/m^2
Measurement range luminance	0.003 … 1700 cd/ m^2 @ 2°, 0.16 … 110 000 cd/ m^2 @ 0.25°	0.01 …. 80 000 cd/ m^2 (illum. A),	2 … 70 000 cd/m^2
Accuracy Luminance	+/- 2 % to NIST @ 2856 K	+/- 2 % +/- 1 digit (illum.A)	+/- 5 % (@ 1000 cd/ m^2)
Repeatability Chromaticity	+/- 0.0005 @ 2856 K	x , y 0.0002 (illum. A)	+/- 0.0005 x,y
Dimensions	233 mm x 124 mm x 163 mm	146 mm x 148 mm x 256 mm	150 mm x 58 mm x 34 mm
Weight	5.6 kg	4.7 kg	300 g
Price of basic unit (approx.)	EUR 43 000	EUR 23 200	EUR 4 500

Tab. 3 Parameter comparison for different spectroradiometers

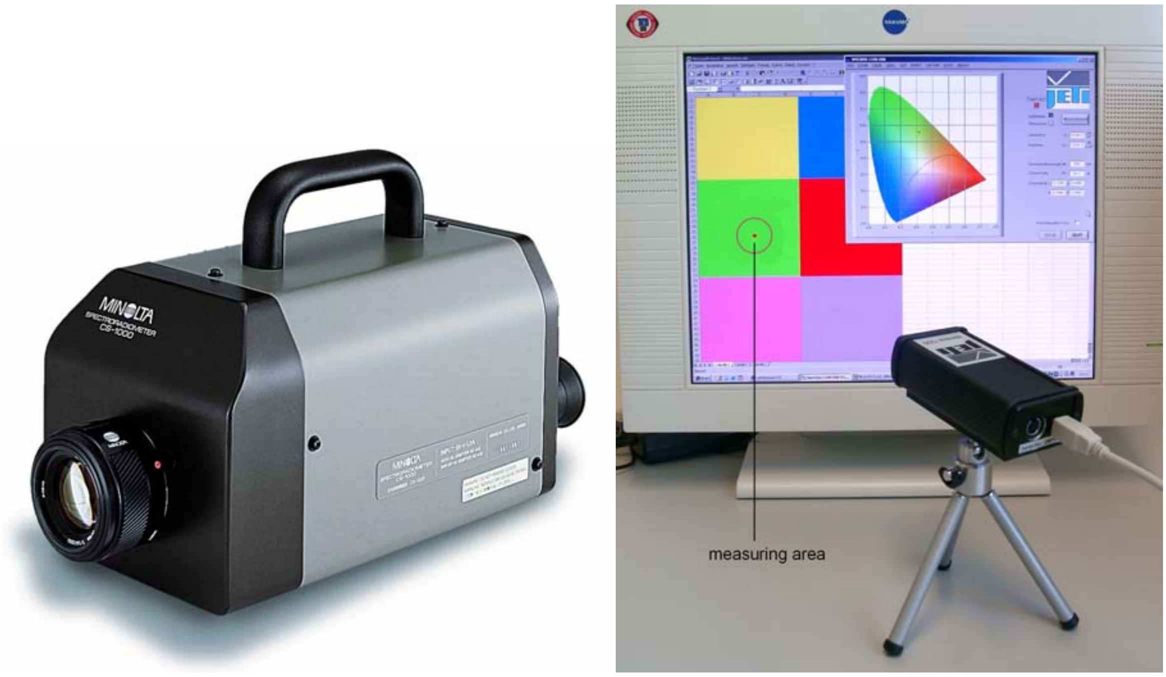


Fig. 6 Laboratory (CS-1000 of Minolta) and compact (specbos 1200 of JETI) spectroradiometer

An additional criterion is the volume and handling of the instrument, especially if the application is under production environmental conditions. In such cases small instruments as specbos 1200 are a good choice, because they can be handled like a sensor. They can be arranged directly at the production line, e.g. for individual inspection of metal halide lamps.

6. Summary

The paper deals with the operation and parameters of spectroradiometers. Furthermore the criteria for the choice of a spectroradiometer type for a certain application are discussed.
A new compact instrument using a miniaturized spectrograph is described. The small dimensions make it especially suitable for the quality control in production, and, in combination with a laptop, for field measurements. Additionally the instrument is interesting for applications in the educational sector due to its easy handling and economic price.

Literature:

[1] Web site www.jeti.com