New trends and applications of modern spectroradiometers

Steffen Goerlich, Thomas Morgenstern, Gudrun Bornhoeft

September 2005

1 Operating mode of spectroradiometers

Spectroradiometers are used for the measuring the basic light measuring values - luminance/ radiance, illuminance/ irradiance, luminous/ radiant flux and luminous/ radiant intensity. Furthermore they can determine colorimetric data like chromaticity, Correlated Color Temperature (CCT), Color Rendering Indeces (CRI), peak wavelength and color purity. Therefore spectroradiometers provide more information than filter instruments. A drawback is the longer measurement time, compared with filterdevices.
The fundamental step of the measurement is to determine the spectrum of the measuring sample. This spectrum has to have both axis (wavelength as well as intensity) in absolute values. All mentioned measuring data can be calculated from this spectrum. The following scheme shows the main parts of a spectroradiometer and the main steps of the calculation.

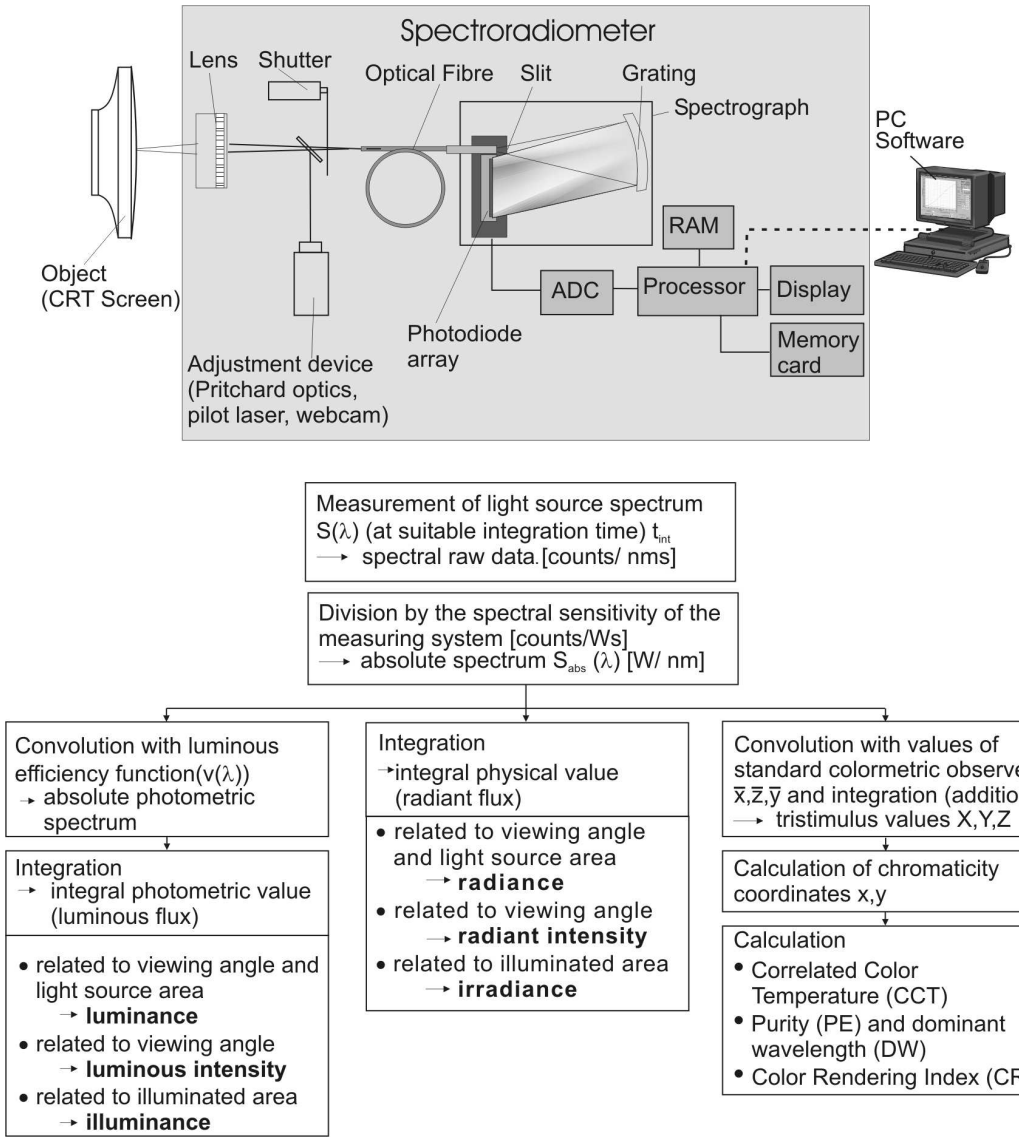

Figure 1: Scheme of a spectroradiometer and the radiometric calculation

The main differences between a spectroradiometer and a simple standard spectrometer are the following:

- Calibration of sensitivity in one or different radiometric units
- Mechanical shutter for dark compensation
- Automatic adaption of integration time according to intensity level of the sample
- Special measuring heads for different radiometric values
- Software calculation algorithms for radiometric, photometric and colorimetric values

The calibration of the spectrometer sensitivity can be done with a lamp standard, which is traceable to a national standard organization (e.g. NIST; NPL or PTB). Usual sources are integrating spheres with halogen lamps for luminance calibration, fiber bundles with calibrated output for luminous flux calibration and luminous intensity lamps. 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,	Traffic lights
Electroluminescent, OLED,)	Room illumination
Phosphors	Illumination in architecture models
Metal Halide lamps	Practical courses
Surgery illumination	
Discrete LED classification	
Digital projectors	

Table 1: Applications of spectroradiometers

2 Single channel instruments

Spectroradiometers are available for more than 20 years. Current instruments are characterized by a high flexibility for the adaption to the application, by usage of modern electronic devices like photodiode arrays and using a widespread software with extended analysis possibilities. The following figure shows two actual instruments. The spectraval CAM, containing a touch-screen terminal with internal PC. So measuring values like CRI or CCT can be obtained from the instrument itself.

Figure 2: CS-1000 of Minolta and spectraval CAM of JETI GmbH

Display measurement is possible with such instruments. To guarantee the reproducibility of the measuring results, it is necessary to synchronize the measurement to the displays frequency. The following table shows some parameters of both instruments and a unit described below:

Parameter	***Minolta CS-1000***	***JETI spectraval CAM***	***JETI specbos 1201***
Wavelength range	380 780 nm	350 850 nm	380 780 nmt
Optical resolution	5 nm		9 nm
Luminance range	$0.250000 cd/m^2$ (illum. A)	$5...70000 cd/m^2$ higher values with optional filter)	$270000 cd/m^2$
Target adjustment	Viewing through optics (Pritchard type)	CCD camera and display of measuring object	Pilot laser
Standard lenses	two, variable focus	one, variable focus	one, fixed focus
Aceptance angles	1	0.21.8	1.8
Weight	4.7 kg	1.8 kg	300 g

Table 2: Selected parameters of spectroradiometers

Modern instruments are equipped with powerful new interfaces (e.g. Blue Tooth, WLAN). This relieves the transmission of the obtained measuring data to a PC for monitoring purposes.
Another trend is the miniaturization of the instruments. Fig. 3 shows the specbos 1201 of JETI Technische Instrumente GmbH. This small unit (140mm x 58mm x 34mm) can output the measuring values directly via the USB interface (virtual COM port). So it can be easily applied for quality control in production processes. It can be integrated into host measuring systems without big customization effort. The instrument can be used in luminance as well as in illuminance mode. Furthermore it is possible to adapt it to an integrating sphere for luminous flux measurements.
An example for the application of such miniaturized spectroradiometers is the individual inspection of light sources during production. This is particulary interesting for measuring special lamps, e.g. constant color termperature lamps. The instrument can be installed directly at the production line of these lamps in small measuring boxes. But it is necessary to stop the lamps for some seconds to proceed the measurement.

Figure 3: Miniaturized spectroradiometer specbos 1201

3 Multichannel Instruments

Another trend in spectroradiometry is the development of multichannel instruments. There exist miscellaneous applications with more than one object which has to be measured simultaneously.
Examples are:

- Homogeneity test of digital projectors
- Burn in tests of lamps
- Quality test of LED populated electronic boards
- Goniometric measurement of light sources

One possibility is to use one spectroradiometer and to switch between the different measuring positions, e.g. with a fiber optic switch. This solution has two significant disadvantages - the measuring times of each individual measurement step will be added, resulting in a long measuring time (furthermore the measurements are not fully simultaneously) and the switching errors contribute to the total measuring and reproducibility error.
Another way is to use as much spectrographs as necessary and drive them separately, only controlled by a master. An example for such a solution is the multichannel spectroradiometer MCR-n of JETI GmbH. It can be equipped with up to 12 channels, each working as a separate radiometer.

Parameters of the system are:

⇒	Channel number	2 .. 12
⇒	Integration time	10 ms .. 60 s
⇒	Read out time	4 .. 20 ms
⇒	Repetition rate	up to 10 Hz
⇒	Interfaces	USB; RS232 and CAN (optional)
⇒	Measuring values	Spectral radiance, Integral luminance/ radiance
		Chromaticity coordinates x,y; u',v'
		Correlated Color Temperature
		Dominant wavelength
		Color purity
⇒	Spectral range	380 nm .. 780 nm
⇒	Resolution	9 nm (FWHM)

The following figure shows a 9-channel spectroradiometer in the test of a digital projector. The projector shows 9 fields with different colors, which are measured separately. It is possible to measure the ANSI-lumen of a projector with the same setup. The illuminance at nine fields is measured, averaged and multiplied by the projected area.

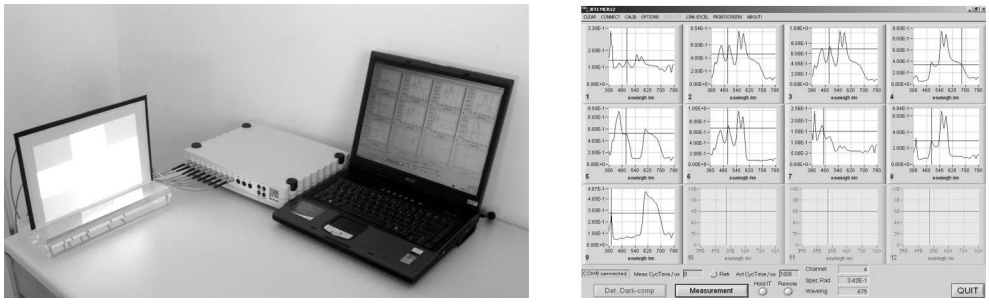

Figure 4: Spectroradiometric measuring set up of a digital projector and the resulting spectra

The main task of this measuring arrangement is to monitor the color homogeneity of the projected image. Minimal differences in the chromaticity coordinates can be observed. Such detailed quality control is not possible with filter instruments or radiometric cameras.
The MCR-n is not only able to measure continuous light sources, but also pulsed ones. In this case one has to input the pulse length of the measuring object and the adaption of the integration time will be done automatically. This procedure guarantees precise and reproducible results.

Another application of multichannel radiometers is the quality test of LED equipped PCBs. The instrument can be equipped with a measuring holder, which guarantees that each fiber is directly in front of a LED on the board. The main advantage is again the precise colorimetric measurement which cannot be achieved with another technique.
Goniometeric setups are designed for the measurement of the spatial distribution of light emitted from a source. Such instruments contain a radiometric detector which is moved around the test object or vice versa. This procedure is time consuming and needs a high mechanical effort to obtain a precise movement of the detector. Especially the long measuring time is the reason that such instruments are only used for selected measurements in the quality control of lamp production. The measuring ports of a multichannel spectroradiometer can be arranged at defined angles around the tested source to proceed measurements on selected positions. In quality control this time saving procedure can be used to increase the number of controlled pieces significantly.

4 Summary

The poster shows some development trends of modern spectroradiometers and some examples of applications for single and multichannel instruments. These instruments provide a variety of measuring results, which are obtained from the measured absolute spectrum of the sample under test.
The new possibilities of the instruments allow a 100% quality control of light sources and related products directly in the production process.