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Determination of Wavelength Error in Two Calibration Techniques for CCD Spectrometer

Sameh M. Reda[1]
[1]Radiometry department, National Institute of Standards (NIS), Giza, Egypt

Abstrac: The main purpose of this research work is to compare between two different calibration techniques for the spectrometer with CCD detectors. The emission spectra of two calibration lamp sources Hg(Ar) and Xe , and the transmission spectra of Holmium and Didymium standard glass filters are used to obtain wavelength calibration monochromator in the UV, visible, and near infrared spectral regions. Matching the output signal of the monochromator with the standard spectra of the sources and the transmission of the standard glass filters, we are able to determine and calculate the monochromator wavelength error of the obtained spectra. Subsequently, this error can be added to the uncertainty budget in wavelength calibrating of the monochromator. A detailed description of the set-up and how the calculation estimations are done are reported.

Keywords: Monochromator, Calibration, Wavelength Error, Spectral Lamps, Standard Glass Filters, Uncertainty

I. INTRODUCTION

Spectrometers are widely used instruments to measure the spectrum distribution over the range of wavelengths radiation from a broadband source. The wavelength range that is observed is determined by the grating which sets the wavelength of light incident on the central pixel of the CCD array detector [1],[2]. The spectrometer consisted of monochromator with principal components of a collimating lens, grating, focusing mirror, the radiant power detector such as a silicon detector beside the charge coupled device (CCD) image sensor (Fig. 1) [3],[4].

When a user selects the wavelength manually or using program controls the monochromator, there could be a difference between the selected wavelength transmitted and that of actual wavelength counter [5],[6]. The accuracy of wavelength is reliant on the used application and how fast the signal changes its wavelength. In photometry and radiometry applications and the majority of the other spectroradiometric measurements, the monochromator wavelength should be very close to the actual wavelength. The main component responsible for the error in the wavelength is caused by minor misalignments of the gratings or by angular drive offset [7].The mechanical error is removed by using the CCD detector although its accuracy has limitations [8]. The wavelength calibration of the instrument is performed by scanning through the grating angles and measuring a spectrum with known wavelengths. A comparison of the measured values of the wavelengths with the known values constitutes a wavelength calibration of the spectrometer [9]. By scanning a monochromatic line source (e.g. laser or Hg lamp) and subtracting the difference of the expected wavelength from subsequent settings in this case the absolute error could be corrected [5],[10]. Holminm oxide glass filter is commonly used as a wavelength standard for testing the accuracy and calibration of spectrophotometers [11]. It has a number of desirable features that have made it a commonly used wavelength standard. It does not induce a slit positioning error as atomic emission lamps may. It also compact, easy to use, and most importantly, stable over long periods of time [12].

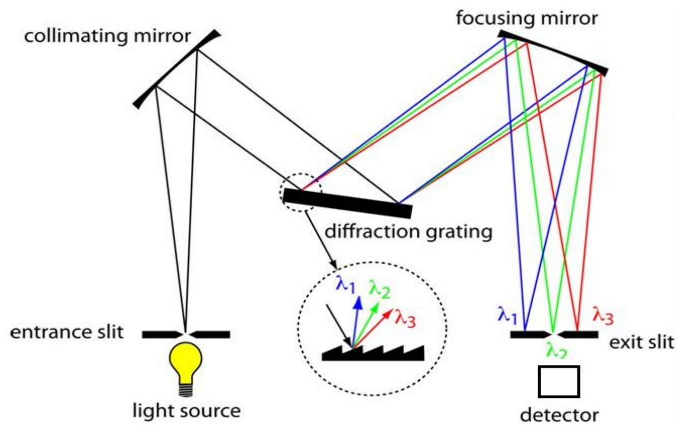

Fig. 1 Schematic diagram for single monochromator.

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Mercury and xenon pencil lamp sources are used to calibrate the wavelength of spectroscopic instruments such as monochromators. Narrow intense lines from the excitation of a number of rare gases and metal vapors are produced [5]. These pencil calibration lamps emit narrow and discrete defined wavelengths in region UV to IR and they have excellent stability. It's noticed that as long as the envelope of the lamps does not react with the rare gases in the lamp, there should be no significant variation in lamp output with age [13]. Holmium oxide is the most commonly used glass filter. It provides an accurate and easy way to test wavelength accuracy. This standard gives a series of lines in the visible region with poor absorption peaks into the UV region [14] [15][16]. Didymium glass produces sharp, stable peaks over the range of 290 to 870nm [14]. The aim of this research work is to compare between tools for the monochromator calibrations. Using two different high precision techniques, calibration using emission spectra of Hg(Ar) and Xe pencil lamps and the absorption peaks of Holmium glass.

II. MATERIAL AND METHOD

A. Spectral Monochromator Calibration by Pencil Lamp

A Mercury Argon pencil lamp from Newport cooperation model 6035 and Xenon lamp model 6035 were used as one of the techniques for verifying the wavelength positions of CCD UV-VIS spectrometer from [HAMAMATSU model C10082CAH with spectral response in the range of 200-800nm]. The system setup is illustrated in Fig. 2.

In the setup, the radiation from spectral calibration lamps produces narrow and intense lines from the excitation of Argon gas and Mercury vapour Hg(Ar) or Xenon lamp. This radiation is introduced into an integrating sphere to build a uniform and nearly lambertian source. The Optical fibre was connected at the output of the integrating sphere. The output radiation from the integrating sphere is used to calibrate the mini spectrometer from HAMAMATZU at the spectral range of 200 to beyond 800nm. The output signal scan obtained directly through software provided by the spectrometer as a function of wavelength verses count. For the experiments described here, eight usable lines from Hg (Ar) and Xe lamps. Using the characteristic standard spectrum table of the lamps and the position of the peaks appears in the run scan we determine the error in wavelengths.

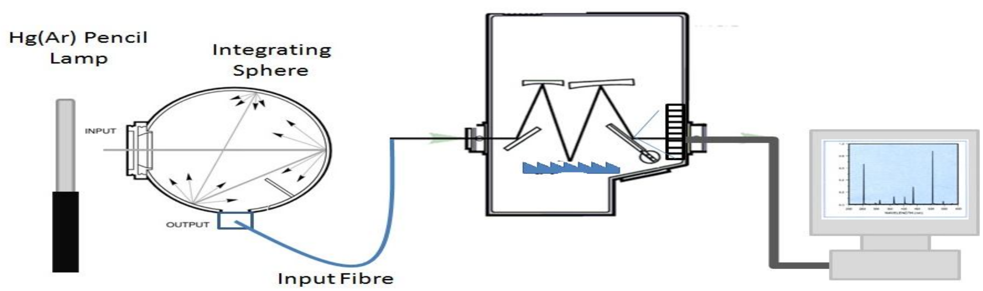

Fig. 2 System setup for monochromator calibration by pencil lamp.

B. Spectral Monochromator Calibration by Holmium or Didymium Glass

The other setup technique used consisted of Holmium glass and Didymium glass calibration filters from UQG optics models CFH-3010 and CFD-3010 and 2mm thickness. The illuminating lamp used in this technique was 30 Watt Deuterium lamp from Newport cooperation as an ultraviolet to the visible source (Fig. 3).

The Holmium or Didymium glass was placed at the optical axis between the source and optical fibre. The absorbance spectrum of a selected glass filter was recorded. According to a definite characteristic of the standard wavelength positions of the Holmium or Didymium glass, the shift in peaks that appeared on the run scan was determined and the error in wave length was obtained.

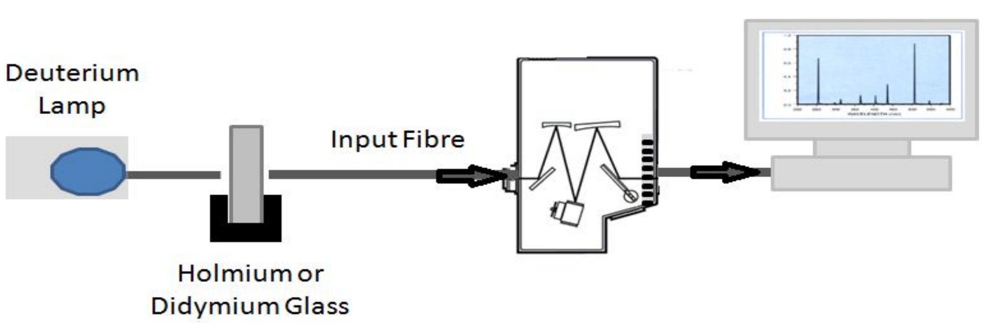

Fig. 3 System setup for monochromator calibration by Holmium or Didymium glass.

III. RESULTS AND DISCUSSION

The mini-spectrometer detecting range is from 200nm to nearly 800nm and Table I and Table II shows the Hg(Ar) and Xe output spectra presented by mini-spectrometer respectively. The wavelength shift values resulting from the mini-spectrometer were between 0.02nm at 435.84nm and 0.39nm at 253.65nm compared to those wavelengths characterized by Hg(Ar). On the other hand the shift values, compared to those wavelengths characterized by Xe resulted from mini-spectrometer were between 0.02nm at 547.2nm and 0.16nm at 840.9nm (Table II)

On the other hand, the results in Table III and Table IV show the positions of the output peaks detected by the CCD mini-spectrometer using Holmium and Didymium filters respectively. The error values that resulted from the mini-spectrometer were between 0.06nm at 360.8nm and 0.67nm at 445.9nm compared to those characterized wavelength peaks of the Holmium glass filter. While the shift values, compared to those characterized wavelength peaks of Didymium glass filter, that resulted from mini-spectrometer were between 0.03nm at 585.2nm and 1.38nm at 740.5nm (Table IV).

The wavelength errors for the two techniques is illustrated in Fig. 4 and Fig. 5. As noticed, the percentage error in the UV region was 0.01 - 0.18 for lamps, 0.02 - 0.06 for filters, while in the visible region the error % was 0.02 - 0.05 for lamps, 0.01 - 0.19 for filters. On the other hand the error % in NIR region was 0.01 - 0.02 for Xe lamp and 0.13 for Didymium filter. The wavelength error between measured and certified glass filters in visible and infrared regions are higher than the error in wavelengths between measured and certified pencil lamps in the same regions.

TABLE I

COMPARISON OF KNOWN HG LAMP' WAVELENGTHS AND WAVELENGTHS OBTAINED BY THE SPECTROMETER WITH THE CCD ARRAY.

The Wavelength of Hg(Ar) lamp (measured)	The Wavelength of Hg(Ar) lamp (known)	Absolute Error
253.26	253.65	0.39
313.12	312.57	0.55
365.04	365.02	0.02
435.64	435.84	0.20
545.97	546.07	0.10
614.7	615.0	0.3

TABLE II

COMPARISON OF KNOWN XE LAMP' WAVELENGTHS AND WAVELENGTHS OBTAINED BY THE SPECTROMETER WITH THE CCD ARRAY.

The Wavelength of Xe pencil lamp (measured)	The Wavelength of Xe pencil lamp (known)	Absolute Error
547.19	547.2	0.02
609.7	609.8	0.1
680.4	680.5	0.1
823.29	823.2	0.09
827.91	828.0	0.09
841.06	840.9	0.16

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TABLE III

ABSORBANCE PEAKS OF HOLMIUM GLASS OBTAINED BY MINI SPECTROMETER.

Peak Wavelength of Holmium filter (Measured)	Peak Wavelength of Holmium filter (Knwon)	Absolute Error
360.86	360.8	0.06
445.23	445.9	0.67
536.15	536.6	0.45

TABLE IV

ABSORBANCE PEAKS OF DIDYMIUM GLASS OBTAINED BY MINI SPECTROMETER.

Peak Wavelength of Didymium filter (Measured)	Peak Wavelength of Didymium filter (Certified)	Absolute Error
358.62	358.4	0.22
480.37	480.6	0.23
529.38	528.9	0.48
585.17	585.2	0.03
739.12	740.5	1.38
806.25	805.2	1.05

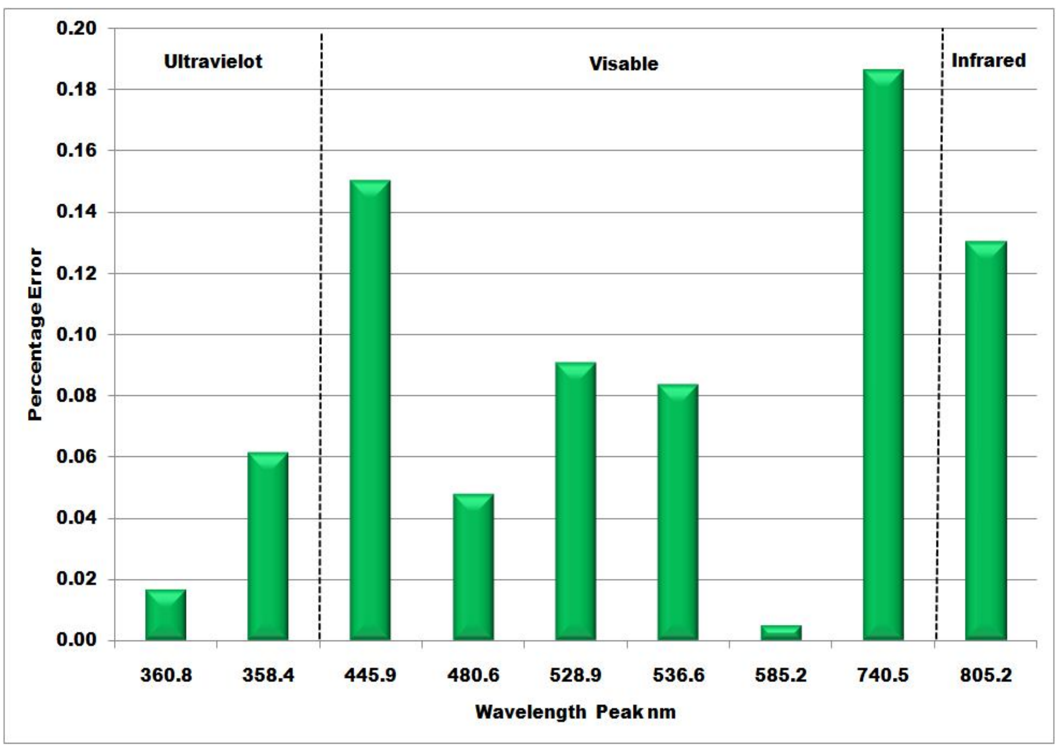

Fig. 4 Wavelength errors due to the use of filters in the calibration of CCD-spectrometer.

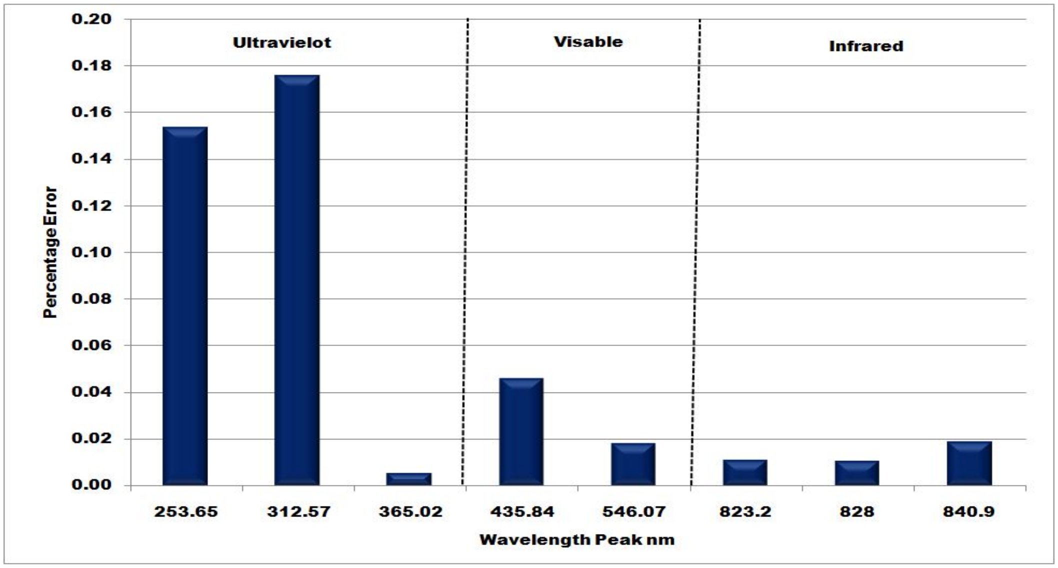

Fig. 5 Wavelength errors due to the use of spectral lamps in the calibration of CCD-spectrometer.

IV. CONCLUSION

In this work two calibration techniques are used. Wavelength verification and recalibration can be performed using the deuterium lamp source in conjugation with rare earth glass filters (Holmium and Didymium). The other technique was based on detecting the emission spectra of Xe, and Hg pencil lamps. The reference wavelengths of the Hg and Xe lines as well as the absorption peaks of the Holmium and Didymium glass were compared to the measured wavelengths.

The results show that the errors due to using lamps at the UV range are more than that obtained using filters. On the other hand the error in the visible region is smaller than that of filters. As a conclusion, we can use spectral lamps for calibration of this mentioned model of CCD spectrometer at the range of visible to infrared, and use glass filters at the range of Ultraviolet. Depending on the different resolutions of each CCD detector.These results are based on the specific design of the tested instrument and may not be the same for another CCD spectrometer. A special study is necessary for each model of CDD spectrometer.

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