Thermal Characterization of Fiber-Coupled Spectrographs

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Accurate spectral radiometry utilizing spectrographs requires thorough instrument characterization. The performance of spectrographs with silicon photo-diode or CCD arrays demands increased scrutiny as applications continue to push for lower uncertainties and incandescent lamp sources are being replaced by non-Planckian radiators. In this work we characterized the sensitivity of the wavelength registration and the system radiometric responsivity of five commercial spectrographs to ambient temperature using a lamp illuminated integrating sphere source, emission line lamps, and an environmental chamber. The temperature was varied between 6°C and 45°C. We developed correction functions for the two effects and validated them with test data.

INTRODUCTION

Several projects in the Sensor Science Division at the National Institute of Standards and Technology (NIST) require accurate radiometric measurements during field work, where the ambient temperatures differ from the laboratories at NIST. In the future, solid-state sources such as LEDs may supplement or replace incandescent lamps in radiometric sources. As the latter are proxies for primary standards via Planck's Law, while the former are not, performance requirements on spectroradiometers will become more stringent, and sensitivity to temperature will be a critical aspect of instrument characterization.

Three different field projects were involved in this study, one where a source and spectroradiometer system are required to be stable over intervals of 6 months to 1 year, during which time the system is transported by a cargo ship inside a shipping container [1], a second where a spectroradiometer is calibrated in an unairconditioned aircraft hangar and then flown on a National Aeronautics and Space Administration (NASA) ER-2 aircraft [2], and a third where the spectroradiometer is calibrated and operated at high altitude (Mt. Hopkins or Mauna Loa) under conditions of varying ambient temperature [3]. For all three projects, insensitivity to temperature changes is mandatory.

In this work we report the sensitivity to ambient temperature for five fiber-coupled CCD spectrographs, see Table 1.

Table 1. Description of the spectroradiometers (BF = bare fiber, CC = cosine collector).

Name	Spectral Coverage, nm	Foreoptic
MOBY	298 to 1103	BF
UV	200 to 876	BF
LUSI	299 to 1104	CC
STARS	380 to 1050	BF
XSTARS	379 to 1040	CC

EXPERIMENTAL SETUP

The spectrographs (devices) under test (DUTs) were operated inside an environmental chamber with the relative humidity allowed to vary while the temperature was controlled at various set points. Two ports, one for electrical cables and one for the optical fibers, allowed for remote control of the DUTs, incorporation of additional temperature sensors, and simultaneous illumination of the DUTs using a lamp-illuminated integrating sphere source (ISS). The ISS and a fiber-coupled monitor spectrograph (MS) were outside the environmental chamber, where the temperature was 24.3°C±0.3°C. The stability of the ISS was recorded by the MS with occasional manual readings of the ISS' internal photopic monitor photodiode. When the chamber temperature was stable at the set point, the ISS measurements were interrupted for a sequence of wavelength stability tests using HgNe or Ne emission pen lamps.

Multiple, independent records of chamber and laboratory ambient temperature and relative humidity were recorded utilizing the chamber sensors, a two-channel digital thermometer-hygrometer, and a 10 kΩ thermistor. The thermistor was mounted on one of the DUTs. Temperature profiles were operated daily, always beginning and ending near ambient, with durations of 90 min or 120 min. The MOBY, UV, LUSI, and STARS were operated over 11 days in the fall of 2018; XSTARS was operated on a single day in April 2019. The set temperature varied between 5°C and 40°C, which was deliberately outside the stated operating range for the two of the DUT in order to replicate collects on prior field experiments.

ANALYSIS

The experiment generated 24,618 data files, as much of the data logging was on a 10 s, 30 s, or 60 s cadence (wavelength calibrations were the exception), so the processing was designed to be automated.

For both the wavelength and system response dependence on ambient temperature, the thermistor serves as the reference. The observed emission lines were fit to a Gaussian. The results were independent of which lamp (HgNe or Ne) as well as wavelength. The temperature-induced wavelength shifts were modelled by a quadratic and the sensitivity factors determined from the derivative, see Fig. 1.

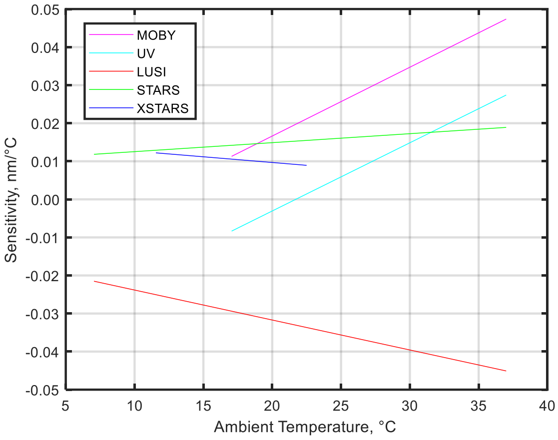

Figure 1. Sensitivity of wavelength shift to ambient temperature for the five DUTs.

After correcting for the wavelength dependence on temperature, the observations of the ISS were corrected for known effects (e.g. stray light, changes in alignment of the optical heads viewing the ISS, and drift in the ISS output over the 92 h burn time). DUT files acquired for 10 min to 20 min when the thermistor reading had stabilized were averaged, see Fig. 2 for MOBY. These results are for all 43 temperature plateaus, normalized to 24°C. Interpolation in these data results in a responsivity correction factor as a function of ambient temperature and wavelength. At 600 nm, these preliminary results correspond to a responsivity temperature sensitivity for MOBY of about 0.1%/°/C.

Results to date have modelled the sphere drift in terms of a Planckian distribution fit for CCT using the MS data. Correlation studies between the MS and the DUTs support the hypothesis that the responsivity of the MS was invariant, and it was the ISS that drifted.

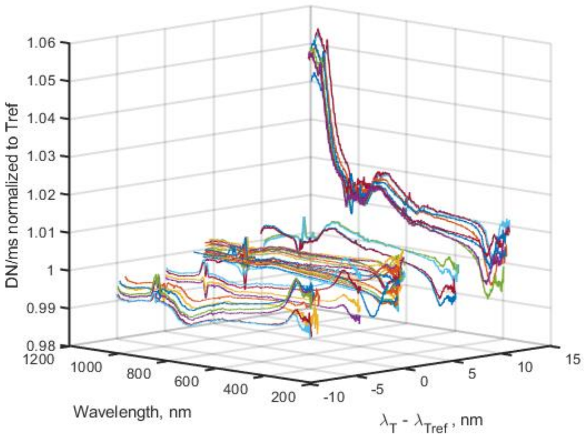

Figure 2. Normalized MOBY output as a function of wavelength and difference from the reference temperature.

DISCUSSION AND CONCLUSIONS

The five DUTs were all from the same manufacturer and the same general model number, manufactured between 2005 and 2015. The wavelength sensitivity with ambient temperature differed for each, indicating individual characterization is required. The system response demonstrated increased sensitivity to temperature for wavelengths greater than about 900 nm and ambient temperatures above 32°C. For all DUTs, the responsivity sensitivity depends on wavelength.

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