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MEASUREMENT OF NORMALIZED SPECTRAL RESPONSE OF DIGITAL IMAGING SENSORS USING A LED-BASED TUNABLE UNIFORM SOURCE

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Abstract: A setup for the calibration of the normalized spectral response of digital imaging sensors/cameras has been developed. In this work, we report on the experimental procedure and results of the normalized spectral response measurement for a digital imaging sensor by using LED-based tunable uniform monochromatic source. Measurement accuracy is verified by evaluating the measurement uncertainty and systematic error sources for the case of normalized spectral response.

Keywords: Digital imaging sensor, spectral response.

1. INTRODUCTION

Recently, digital imaging systems based on CCD or CMOS sensors are widely used in several fields, particularly in the field of scientific imaging, due to its high resolution, high quantum efficiency, wide spectral response, acceptable signal-to-noise ratio, linearity, geometric fidelity, fast response, small size and durability [1,2]. To calibrate two-dimensional imaging sensors and imaging systems such as cameras, one needs a uniform source with calibrated irradiance or radiance [3, 4]. The spectral response measurement of imaging sensors and cameras, in particular, requires a monochromatic uniform source tunable in a wide wavelength range. We developed such a tunable source by using light-emitting diodes (LEDs), where LEDs are compact, cost-effective, efficient, and commercially available at different wavelengths covering from UV to NIR for radiometric applications, which has been presented elsewhere [5].

A well-calibrated two dimensional imaging sensor with low measurement uncertainty would open up new facilities in many applications since it would offer increased ability to analyze recorded information. For digital sensors, however, the overall gain can be easily adjusted and manipulated so that only the normalized values of spectral response are of interest.

2. EXPERIMENTAL SETUP

Figure 1 schematically shows our experimental setup. The description of the setup, and the characteristics of the developed tunable monochromatic uniform source, which is part of the setup has been presented elsewhere [5]. Irradiance level between 1 nW/cm^2 and 100 nW/cm^2, with corresponding radiance level between 0.5 nW/cm^2.sr and 50 nW/cm^2.sr could be achieved at the measurement plane. The radiation field uniformity at the measurement plane was measured and it was concluded that the emission could be assumed as the emission of a quasi-lambertian source.

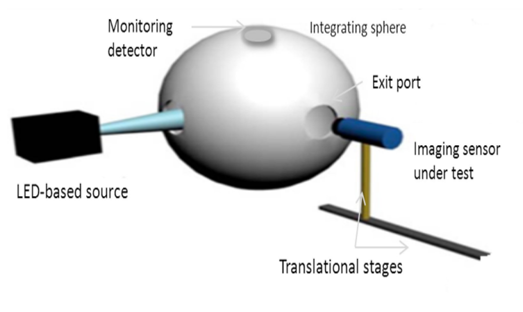

Fig 1. Schematic diagram of the setup.

3. CALIBRATION PROCEDURE AND ERROR SOURCES

The measurement system of the normalized spectral response of digital imaging sensors which was described in section 2 is calibrated by evaluating the spectral response of the sphere monitoring detector, $S_{REF}(\lambda)$, in the wavelength region of interest, which is defined as [6, 7]

$$S_{REF}(\lambda) = y_{REF} / E \quad (1)$$

y_{REF} is the output signal of the sphere monitoring detector (REF), and E is the radiometric quantity (radiant power, radiance, or irradiance) at the measurement plane as measured by the standard photodiode which has been calibrated against KRISS (Korea Research Institute for Standards and Science) spectral responsivity scale. This step is to calibrate the sphere monitoring detector (REF) against the standard photodiode to use these calibration data in the following step.

Using this value of the spectral response of the REF at the set wavelength, we can determine the spectral response of the device under test (DUT) by recording the readings of both the REF and the DUT simultaneously (i.e. recording the REF output then recording the DUT at the same wavelength and same measurement conditions). Now, by using equation (1), we can produce the following equation for determining the spectral response of the DUT by substituting the value of E from equation (1) into the following equation

$$S_{DUT}(\lambda) = y_{DUT} / E$$

We can get the following equation

$$S_{DUT}(\lambda) = (y_{DUT}/y_{REF}).\, S_{REF}(\lambda) = Ratio.S_{REF}(\lambda) \qquad (2)$$

Where, y_{DUT} represents the output digital counts of the imaging sensor under test, Ratio represents the ratio between the DUT and REF readings. Using this equation we measured the normalized spectral response of the sensor under test using the data of calibration of the REF, which has been calibrated against the standard photodiode in the first step. Referring to equation (2), we could study all the sources of both random and systematic errors with using the suitable algorithms for correcting these systematic errors, if possible, during the measurement process.

As standard photodiode we employed a silicon photodiode of proven linearity with an aperture. This standard used in the calibration of the setup has been calibrated against the spectral responsivity scale of Korean Research Institute for Standards and Science (KRISS). The uncertainty associated with the calculation of the normalized spectral response value has been calculated by applying the partial derivative rule to equation (2) while assuming that the different variables are not correlated. Following this approach, the total relative uncertainty estimated to be less than 1% (k=2), except at few points in the wavelength range of interest, where the associated uncertainty is wavelength dependent. It was evaluated by propagating the random and systematic error sources, as error arises from the effect of the reflectance from the DUT surface upon the REF signal recording process, wavelength set error of the monochromator [8], Non-uniformity of the field at the measurement plane, the used standard photodiode's associated uncertainty, and the procedure reproducibility uncertainty. The uncertainty associated with the calibration process itself can be derived from the reproducibility of the procedure, which is computed from three separate measurements that were registered for each wavelength, this reproducibility uncertainty in the whole range of interest is shown in figure 2 which has been shown to be varying with changing the wavelength and it is proved to be less than 0.3 % all over the whole range.

In our setup as we previously discussed we use the REF to monitor the signal and to transfer the calibration of the standard photodiode. One of the sources of error in this process is the back reflected radiation from the surface of the DUT, especially if the DUT is set at closer distance to the port. Here in our case we selected to position the DUT as close as possible to the port to have higher Signal-to-Noise ratio (SNR) of the DUT for having more resolution of the measured data. However, such an influence by the back reflection from the DUT should be corrected or minimized. For a correction, the sphere design should be modified by adding baffles to the sphere to prevent the back reflected radiation from being reached the REF photodiode, which complicates the setup and interrupt the sphere uniformity, where as described the sphere has small diameter (2 inch).

4. RESULTS AND CONCLUSION

Figure 3 shows the curve of the measured spectral response of the REF. These data has been used, as described in section 3, to measure the value of the normalized spectral response of the imaging sensor under test.

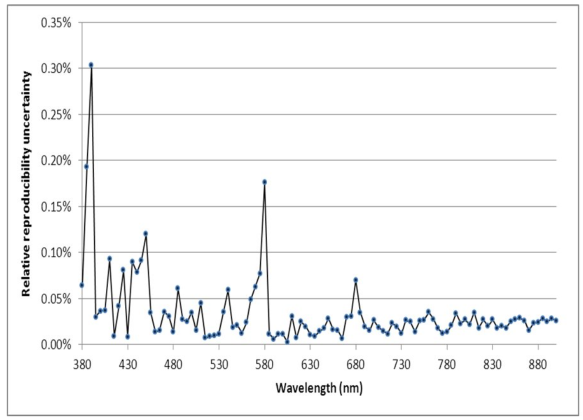

Fig 2. Relative reproducibility uncertainty as a function of wavelength.

The normalized spectral response of CCD sample monochrome sensor (Sony: ICX205AL with 1280×1024 pixels, with pixel size of 4.65µm ×4.65 µm integrated in a camera equipped with a 8-bit A/D converter) has been measured to test the method. The measurements were carried out by placing the DUT centered on the optical axis by using an alignment software algorithm in which we move the DUT in both X and Y directions until we reach the point where the relative standard deviation of the counts data in the Area-of-Interest (AOI) is minimum.

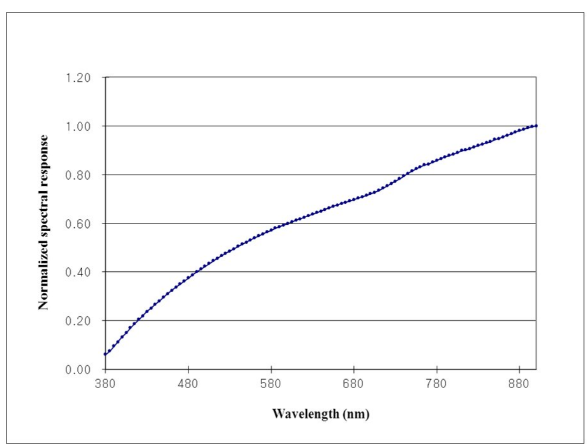

Fig 3. Spectral responsivity of the reference detector.

The distance between the output port and the DUT has been optimized to minimize the effect of the back reflected radiation upon the REF recorded signal, and the plane of the sensor was parallel to the plane of the output port (normal incidence). We have analyzed in detail and quoted the uncertainty sources that contribute to the total uncertainty. The final results of the measured normalized spectral response which is the average of all the pixels in the central AOI (20×20 pixels) at 20 mm distance of the sample imaging sensor has been shown in figure 4 with the associated expanded uncertainty represented by error bars.

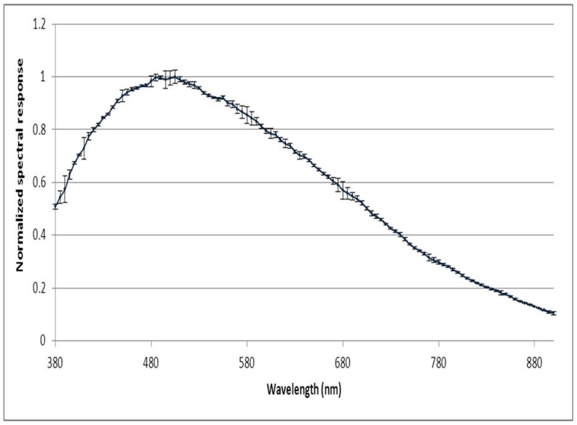

Fig 4. Normalized spectral response of the CCD sensor under test with error bars represents the associated expanded uncertainty at each wavelength.

We applied the same method on another sample DUT, which is, a tri-chromatic CMOS based camera from HVS (Model: HVR-2300CA), with a matrix of 2048×1536 pixels with pixel size 3.2×3.2 µm, with a 8-bit A/D converter. Figure 5 represents the normalized spectral response of the three channels (Red, Green, and Blue) of the pixels (in average) in the central AOI (20×20 pixels). The three channels' responses are normalized and presented together in the same scale to be more visible and comparable.

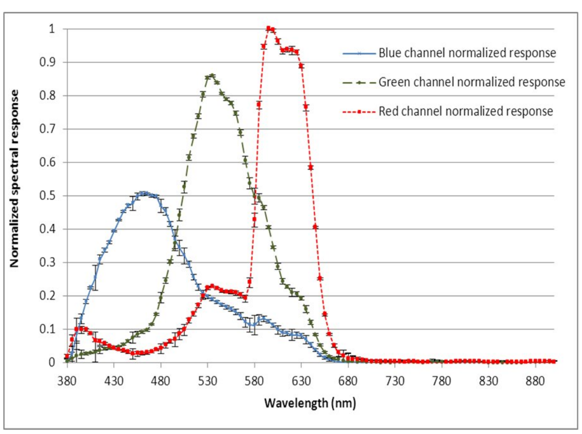

Fig 5. Normalized spectral response of Red, Green, and Blue channels of the CMOS color sensor under test with error bars represents the associated expanded uncertainty at each wavelength.

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