Reconstruction of Transmitted Cherenkov Lights Spectra from the RGB Camera Image

Yoichi Watanabe, PhD[1]; N. Gopishankar[2]
[1]University of Minnesota, [2]All India Institute of Medical Sciences

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: To develop a computational method for the reconstruction of the spectra of the Cherenkov light transmitted through a fluorescent material from the RGB image data taken by digital color cameras.

Methods: The desired solution of the transmitted photon spectrum, X, can be obtained by solving the following minimization problem:
$\min\|X - X_0\|^2 \quad subject\ to\ QX = C$ (1)
Here, X_0 is the Cherenkov photon spectrum emitted by the MV photon. Q is the camera's sensitivity to RGB colors. C consists of the measured pixel values of three colors. The solution was achieved using the LSQLIN function in MATLAB.

For experimental tests of the algorithm, a water bath was irradiated with a 5 x 5 cm^2 10 MV FFF beam from the side. A cotton cloth with fluorescein dye was placed on the front wall of the bath. A Canon EOS 6D digital camera captured photos of the beam generated by the transmitted Cherenkov light.

Results: The original Cherenkov light spectrum peaked at 300 nm and decreased gradually with increasing wavelength. The reconstructed spectra showed that without the dye, the transmitted light intensity decreased in the range of 500 to 560 nm but increased in the range of 560 to 660 nm, due to the photon transmission characteristic of cotton, which strongly absorbs photons below 550 nm but effectively transmits those above 550 nm. Meanwhile, when the cloth contained the dye, there was a slight decrease in the photon intensity below 500 nm (blue), but an increase in the range of 500 to 550 nm (green). These changes were caused by fluorescence induced by the fluorescein dye, which absorbs blue light and emits green, fluorescent photons.

Conclusion: The proposed reconstruction method is simple and could successfully reproduce the spectrum of Cherenkov light transmitted through a thin cotton cloth containing a fluorescent dye.

CONTACT

Yoichi Watanabe, Ph.D.
[University of Minnesota
420 Delaware St. SE, MMC494,
Minneapolis, MN 55455, USA
watan016@umn.edu
(612) 626-67-0

INTRODUCTION

Cherenkov light generated by high-energy photons can be used for radiation dosimetry and patient setup checks. Images of the Cherenkov photon intensity distributions can be easily captured with a standard digital camera. If optical spectral information is available, more information can be obtained than with only photon-intensity data. We proposed a novel computational method to reconstruct the wave-frequency spectra of the transmitted Cherenkov light from three-color data acquired by a digital color camera.

METHODS AND MATERIALS

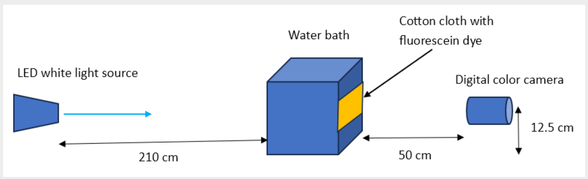
ALGORITHM: The desired solution of the transmitted photon spectrum, $\boldsymbol{X}$, can be obtained by solving the following minimization problem,

$$\min\|\boldsymbol{X} - \boldsymbol{X}_0\|^2 \quad subject\ to\ Q\boldsymbol{X} = \boldsymbol{C} \qquad (1)$$

Here, $\boldsymbol{X}_0$ is the source photon spectrum. Matrix Q represents the camera's sensitivity to RGB colors. $\boldsymbol{C}$ consists of the measured pixel values of three colors. The solution was achieved using the LSQLIN function in MATLAB.

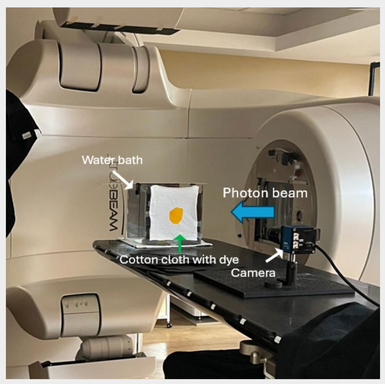
TEST 1: Figure 1 presents a diagram of the measurement setup in the lab setting. Instead of actual Cherenkov light, an LED flush light emitted white light that traveled through the water bath (25 x 25 x 25 cm^3 cube). A digital color camera was located 50 cm from the water bath. A cotton cloth with fluorescein dye was attached to the water bath on the camera side.

Figure 1. Experimental setup of Test 1.



TEST 2: To test with Cherenkov light, we took a picture of the cotton cloth containing fluorescein dye, placed on the wall of a water bath, using a digital color camera in a dark room. A 10 MV FFF photon beam, 5 cm x 5 cm field size, generated Cherenkov photons in the water. The measurement setup is shown in Fig. 2

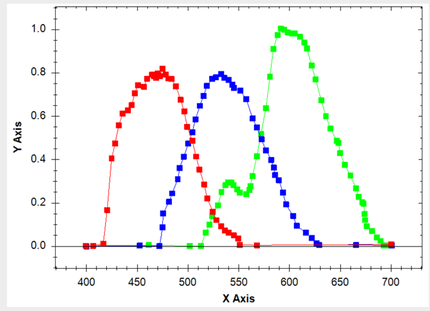
Figure 2. Experimental setup of Test 2.



RESULTS

DATA: The N x 3 matrix Q of the camera, Canon EOS 6D digital color camera, was generated from the quantum efficiency data found in the camera's specification sheet. Here, N is the number of points representing the continuous sensitivity curves for 3 color channels. Fig.3 plots the normalized sensitivities of the camera's Red, Blue, and Green channels. The data indicates three channels respond to photons of wavelength specific to each although the response curves overlap each other. Furthermore, it shows that the green channel is the most sensitive to light.

Figure 3. Sensitivity (Y-axis) vs. wavelength [nm] (X-axis) of the Canon camera.



TEST 1: Equation (1) was applied to the TEST 1 setup. The spectrum of the white light source $\boldsymbol{X}_0$ is shown in Fig.4 (a). The integrated intensities of R, G, B colors, $\boldsymbol{C}$, for various contents of fluorescein dye in the cotton cloth were measured on the photos. The reconstructed photon spectra obtained by applying Eq.(1) are plotted in Fig.4 (b). The red curve is the source photon spectrum. The dark blue curve is the photon spectrum transmitted through raw cotton, showing the overall intensity decrease due to the attenuation. Especially, a decrease of the 450 nm peak and a significant decrease in the photon at longer wavelength at around 550 nm (or red) are notable. As the dye concentration increased from 0 to 0.04g, then 0.12 g, the 450 nm peak height increased, but the increase at 550 nm was the maximum for the 0.12 g. As the concentration further increase, however, both peaks decreased. The raw fluorescein dye (or "no dilution) spectrum indicated a negligivle 450 nm peak and only slight increase of the 550 nm peak compared with the background.

Figure 4. Photon spectra of Test 1.
(a) The source photon spectrum. (b) Reconstructed spectra of transmitted photons through various fluorescein dye concentrations.

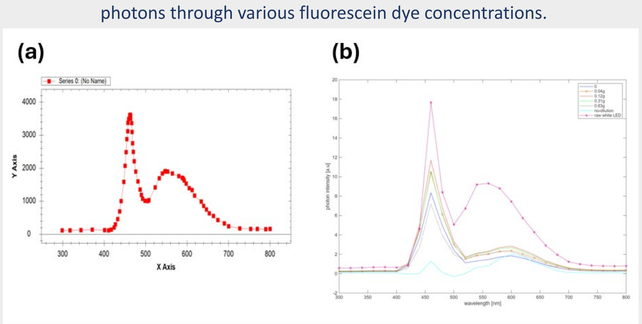
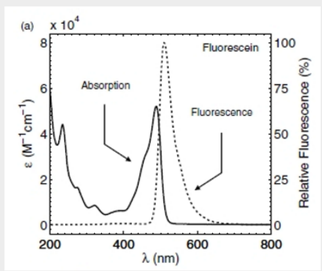


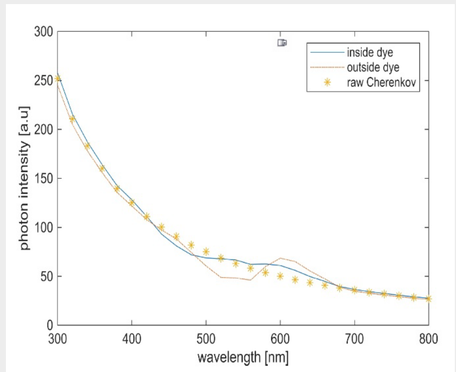
Figure 5. Absorption and fluorescence spectra of Fluorescein [2]



RESULTS (con't)

TEST 2: The reconstructed spectra in the two regions of an acquired beam image are shown in Fig. 6. The blue solid and yellow dotted lines represent the spectra for the areas with and without dye, respectively. Note that the incident Cherenkov light spectrum, indicated by a yellow line with star symbols, was the largest at 300 nm and decreased with increasing wavelength from the intensity of 250 to 25 in the arbitrary unit (a.u.). Without the dye on the cotton, the intensity decreased in the range of 500 to 560 nm but increased in the range of 560 to 660 nm. This was caused by the photon transmission characteristics of cotton, which strongly absorbs photons below 550 nm, but effectively transmits the photons above 550 nm wavelength [1]. Meanwhile, when there was dye, there was a slight decrease in the intensity of photons below 500 nm (blue), but an increase in the range of 500 to 550 nm (green).

Figure 6. Reconstructed spectra of Cherenkov light transmitted through cotton cloth with and without fluorescein dye.



DISCUSSION

The spectral changes observed in Tests 1 and 2 can be explained by fluorescence from the fluorescein dye, which absorbs blue light and emits photons in the green range, as shown in the absorption and emission data in Fig. 5 [2]. Fluorescein absorbs photons at shorter wavelengths, with a peak at 480 nm, and emits fluorescence photons at longer wavelengths, with a peak at 520 nm. Fluorescein has a rather narrow Stokes shift. Other materials such as quinine sulfate and quantum dots (CdSe/ZnS) possess much wider Stokes shifts, and those can be more useful to take advantage of fluorescence effects in many applications.

CONCLUSIONS

The proposed reconstruction method is simple and could successfully reproduce the spectrum of Cherenkov light transmitted through a thin cotton cloth containing a fluorescent dye.

REFERENCES

1. Wang, S., et al., Optical properties and Monte Carlo simulation of cotton fibers with different micronaire values. Industrial Crops and Products, 2025. 223: p. 120254.
2. Glaser, A.K., et al., Projection imaging of photon beams using Cerenkov-excited fluorescence. Phys Med Biol, 2013. 58(3): p. 601-19.

ACKNOWLEDGEMENT

This second author was sponsored by ICMR-DHR fellowship Project ID No 2024-00188 (2024-2025)