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Marina Parker, Craig M. Browning, Thomas C. Rich, Silas J. Leavesley, "Optimization of light transmission through an excitation-scan hyperspectral mirror array system," Proc. SPIE 10881, Imaging, Manipulation, and Analysis of Biomolecules, Cells, and Tissues XVII, 108810O (4 March 2019); doi: 10.1117/12.2510555

SPIE.

Event: SPIE BiOS, 2019, San Francisco, California, United States

Optimization of Light Transmission through an Excitation-scan Hyperspectral Mirror Array System

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ABSTRACT

Hyperspectral imaging has numerous applications in a range of fields for target detection. While its original applications were in remote sensing, new uses include analyzing food quality, agriculture and medicine, Hyperspectral imaging has shown utility in fluorescence microscopy for detecting signatures from many fluorescent molecules, but acquisition speeds have been slow due to the need to acquire many spectral bands and the light losses associated with spectral filtering. Therefore, a novel confocal microscope, the 5-Dimensional Rapid Hyperspectral Imaging Platform (RHIP-5D) was designed and is undergoing testing to overcome acquisition speed and sensitivity limitations. The current design utilizes light-emitting diodes (LEDs) and a multifaceted mirror array to combine light sources into a liquid light guide. Initial tests demonstrated feasibility and we are now working on determining the ideal location of the liquid light guide, LEDs, lenses and mirror array to optimize optical transmission. A computational model was constructed using Monte Carlo optical ray tracing in TracePro software (Lambda Research Corp.). LED sources were simulated by importing irradiance properties from the manufacturers' specifications. Optical properties of lenses were modeled using lens files available from the manufacturer. Analysis of the model includes geometry and parametric optimization, assessing lens power, mirror angles and location of optical elements. Initial results show an increase of transmission is possible by up to 20%. Future work will involve evaluating the position of the liquid light guide as well as analyzing lens configurations to further increase optical transmission.

Keywords: Systems Design, LED, Tissue imaging, HSI, Spectroscopy, Microscopy, Transmission, Spectral, Fluorescence, Molecules, Cells

1. INTRODUCTION

Hyperspectral imaging technology has been applied to numerous fields from its beginning stages to today's applications, specifically in the medical field[1]. The use and need for HSI has grown greatly over the past decade. HSI has proven to be an effective tool for a range of fields to detect specific materials and targets. Many technologies were developed for the application of hyperspectral imaging, such as NASA's Landsat mission, launching the first Earth Resources Technology Satellite, which was devoted to monitoring and managing of earth's resources[2,3]. The remote imagery acquired from Landsat allowed for land classification, assessment of sea ice conditions, coastal water quality and water pollution monitoring, measuring snow line elevation and melting rate, as well as crop and soil classification. The data acquired with the multispectral scanner (MSS) allowed estimation of mineral content and vegetation mapping. While its original applications were in the field of earth remote sensing[4,5], HSI methods have been applied in a range of fields including food quality[6], agriculture[7], and historical documents authentication[8]. Hyperspectral imaging has shown great utility in fluorescence microscopy applications for separating signatures from many fluorescent molecules, but has unfortunately been slow due to the need to acquire signal in many spectral bands and the light losses associated with spectral filtering[9–13]. A primary goal in HSI medical applications is detection of cancerous cells and effectively identifying distinctive parts of tissue[14,15].

The purpose of this work is to investigate the feasibility of increasing speed and sensitivity of hyperspectral imaging microscopy applications through system design of excitation scanning. As hardware and technologies continue to advance, medical hyperspectral imaging and analysis methods will improve the

Imaging, Manipulation, and Analysis of Biomolecules, Cells, and Tissues XVII,
edited by Daniel L. Farkas, Attila Tarnok, James F. Leary, Proc. of SPIE Vol. 10881,
108810O · © 2019 SPIE · CCC code: 1605-7422/19/$18 · doi: 10.1117/12.2510555

accuracy of disease diagnosis. Addressing speed and sensitivity limitations allows for necessary advancement in improving the accuracy of identifying cancerous cells. Here, we report on a new HSI system for high-speed microscopy called RHIP-5D. The system has been designed to detect the entire fluorescence emission in a single channel, while simultaneously providing spectral discrimination by quickly scanning through a range of excitation wavelength bands. The system is expected to increase sensitivity by 25-100X, compared to currently available emission-filtering based systems[16].

2. METHODS AND RESULTS

The RHIP-5D system is currently being designed to utilize light-emitting diodes, a multifaceted mirror array, and lenses to focus all light sources into a liquid light guide. A computational model was constructed using Monte Carlo optical ray tracing in TracePro software (Lambda Research Corp.). Importing irradiance properties from the manufacturers' specifications simulated LED sources, while optical properties of lenses were modeled using lens files available from the manufacturer. A TracePro macro language was created to analyze transmission collected at a range of possible locations of the LED, liquid light guide (LLG), and lens with a fixed mirror angle and position. Figure 1 shows an example of the geometric model created in TracePro, while Figure 2 shows an example of ray trace analysis from LED to LLG. The design evaluated the effect of all possible combinations of LED, lens, and LLG parametric locations on the amount of transmission collected. Several lenses were considered to determine the optimal focal length (FL) for the system design. Each geometric element in the software model design was characterized based on its optical characteristics. Specific optical properties of the LED, lens, multifaceted mirror, and LLG geometry were specified in the software to match their experimental characteristics. For example, a surface on the LED was characterized as the 'source generator', which defined the starting location, power, and angular dispersion for all rays traced. Similarly, surfaces on the rest of the geometric elements in the design were specified to properly refract, reflect, or absorb light during the ray trace.

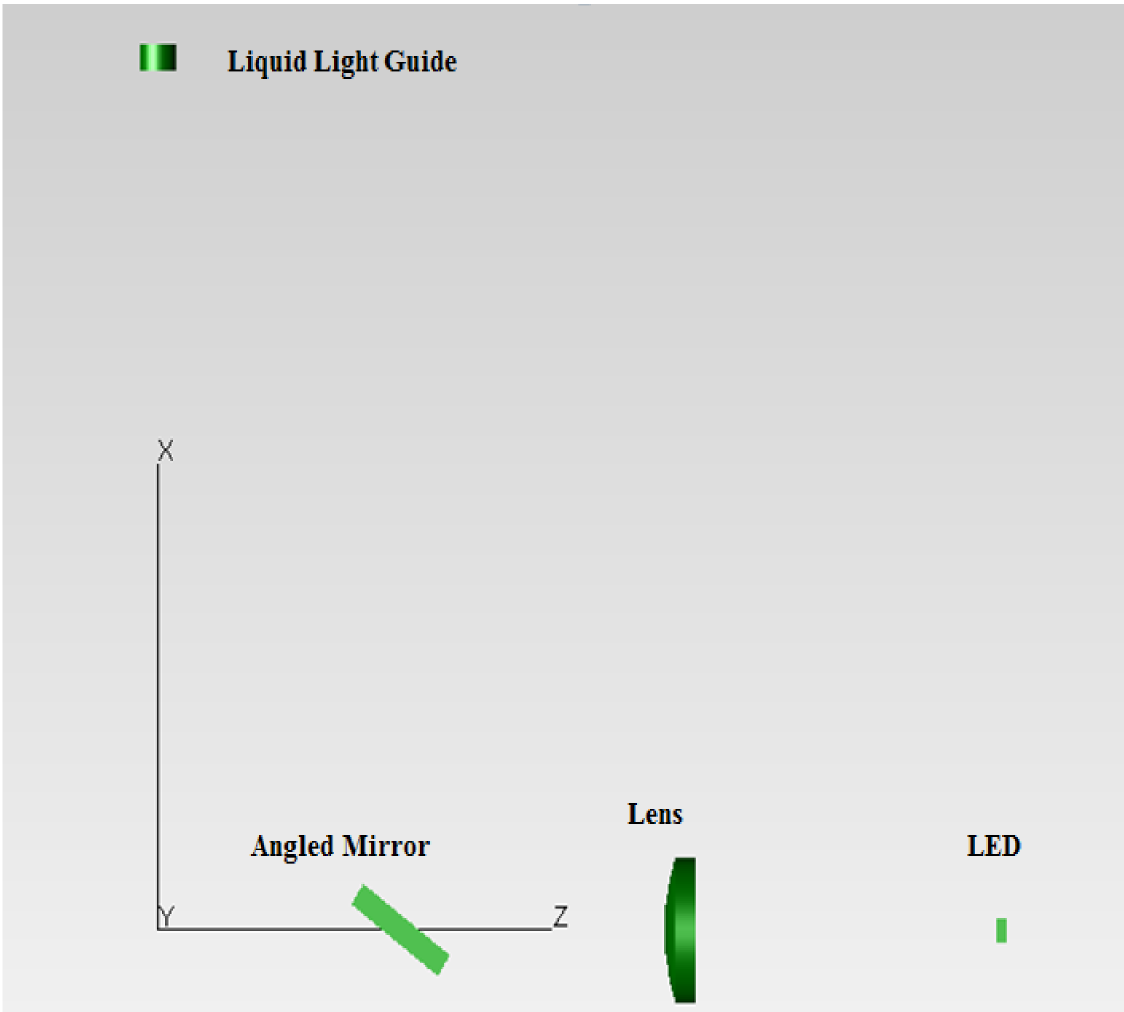

Figure 1: Geometric model created for light path and transmission collection analysis in TracePro. The angled mirror represents one face of the multifaceted mirror array for the system. It was set at a fixed ZX location of (23, 0) mm ensuring that it was centered to reflect light to the LLG entrance aperture. LED-to-lens minimum distance was determined based on the focal length of the lens used, which was 31.8 mm. Various lenses with different FL were considered to determine the most optimal lens. A range of possible combinations of LLG, LED, and Lens positions were analyzed to determine the best geometric locations for transmission collection. The surface of the LED facing the lens was set as a surface source, allowing the software to apply the imported irradiance properties of the LED to this surface. Similar methods were used to define lens and mirror surface properties. Finally, the LLG surface facing the mirror was defined as an interrogation plane, allowing for transmission collection analysis at the LLG entrance aperture.

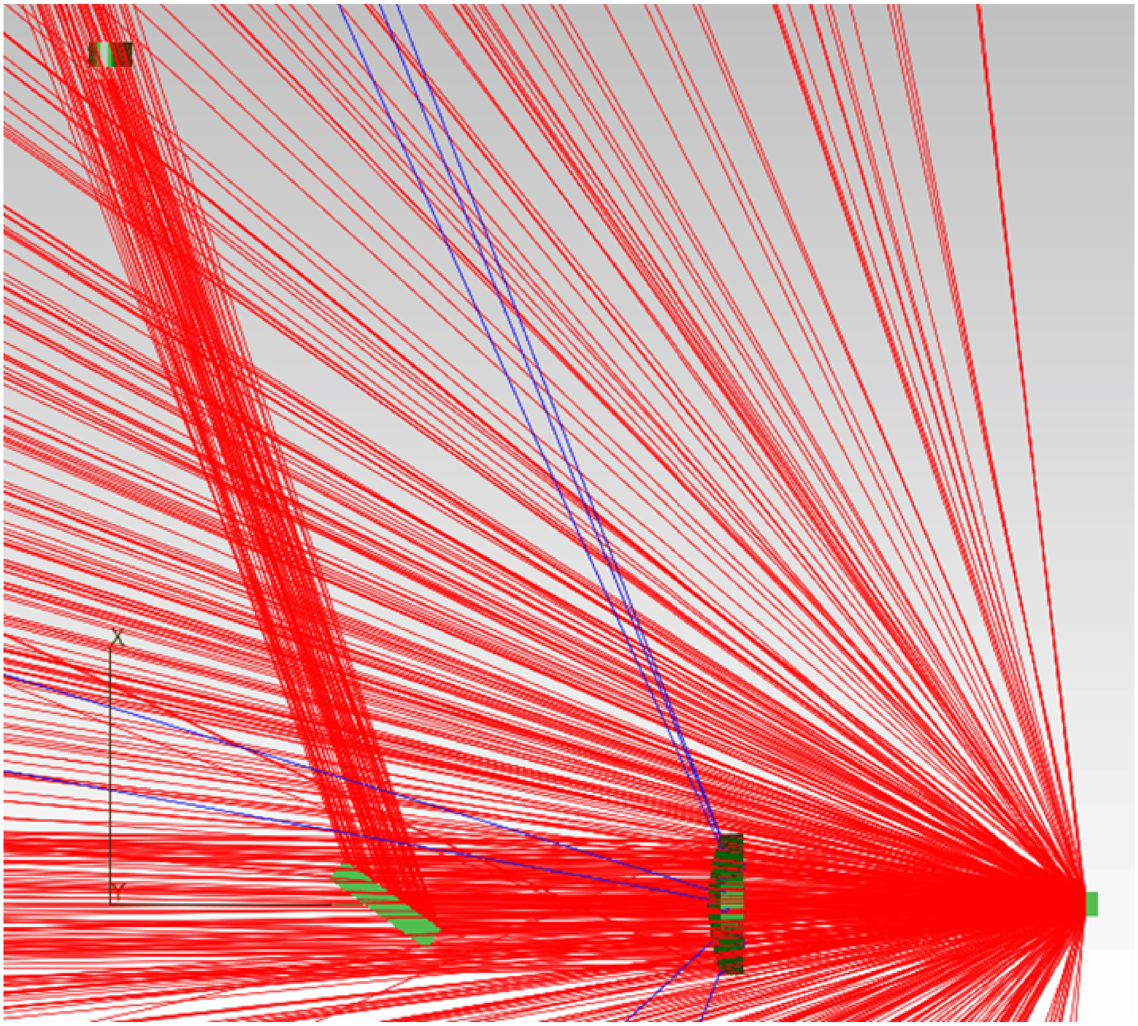

Figure 2: Light Path and Ray Trace Analysis in TracePro. Colors of rays represent the flux or the power of the rays. Red signifies rays at the initial, 100% optical flux value, while blue signifies that the flux has dropped below 33.3% of the initial value. As seen in the figure, light rays are emitted from the LED surface defined as a source generator, pass through the lens, and are reflected by the mirror to the LLG entrance aperture.

To evaluate transmission data, an irradiance map was generated. An irradiance map is the irradiance in watts per unit area or lux, incident or absorbed on the selected surface, which in this model it is the entrance aperture of the LLG. Highest flux percentages were plotted with their respective parametric locations (Figure 4).

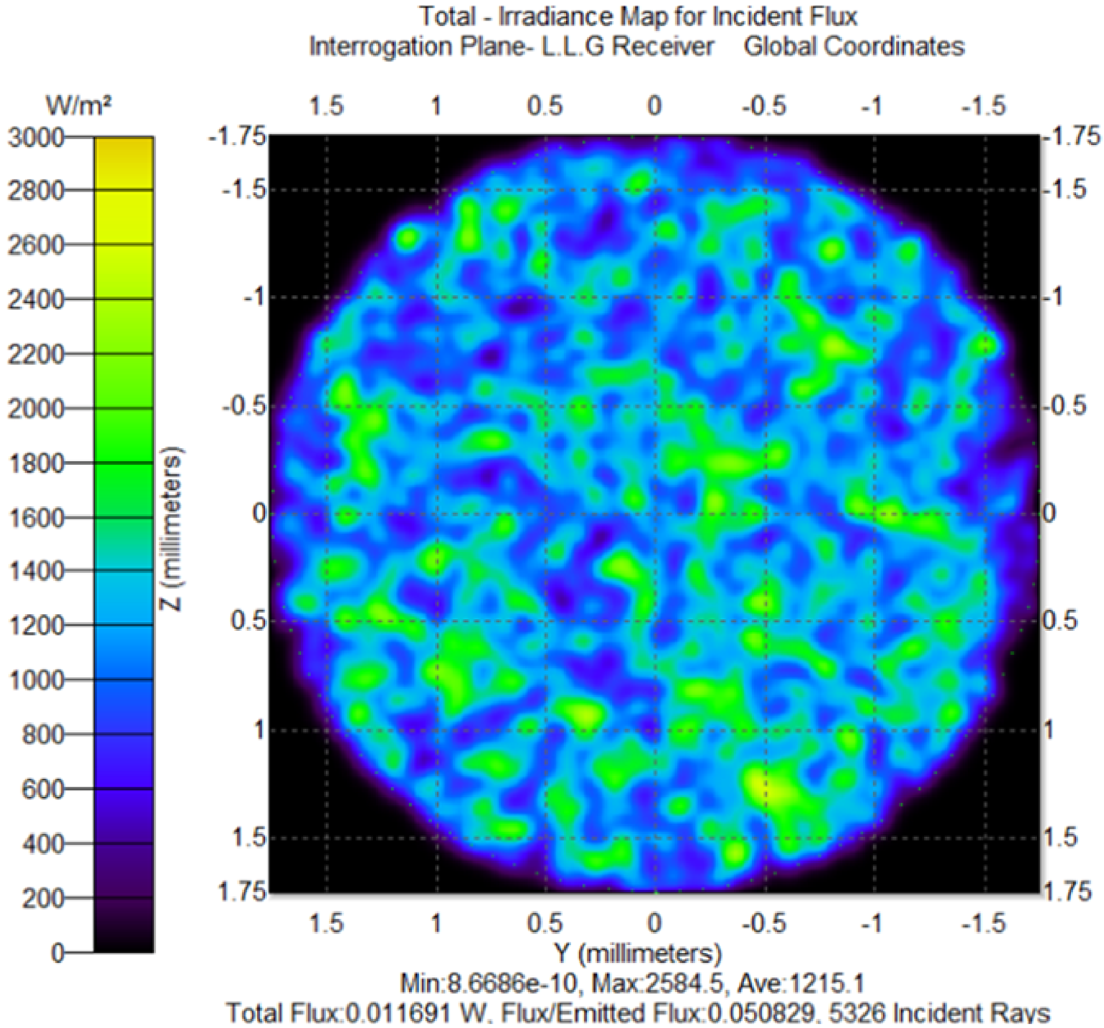

Figure 3: Irradiance map for incident flux at the interrogation plane of LLG. The irradiance map represents the illumination intensity as distributed over a measurement surface and it is attained by visualizing the distribution of all rays divided by total initial emitted power of LED. From the plot, a total transmission percentage was calculated using flux/emitted flux results. As shown above, the flux/emitted flux is 0.05083, resulting in a transmission percentage of 5.083%. The colorbar indicates the increase or decrease in optical flux (W/m^2) at a given area on the LLG entrance aperture.

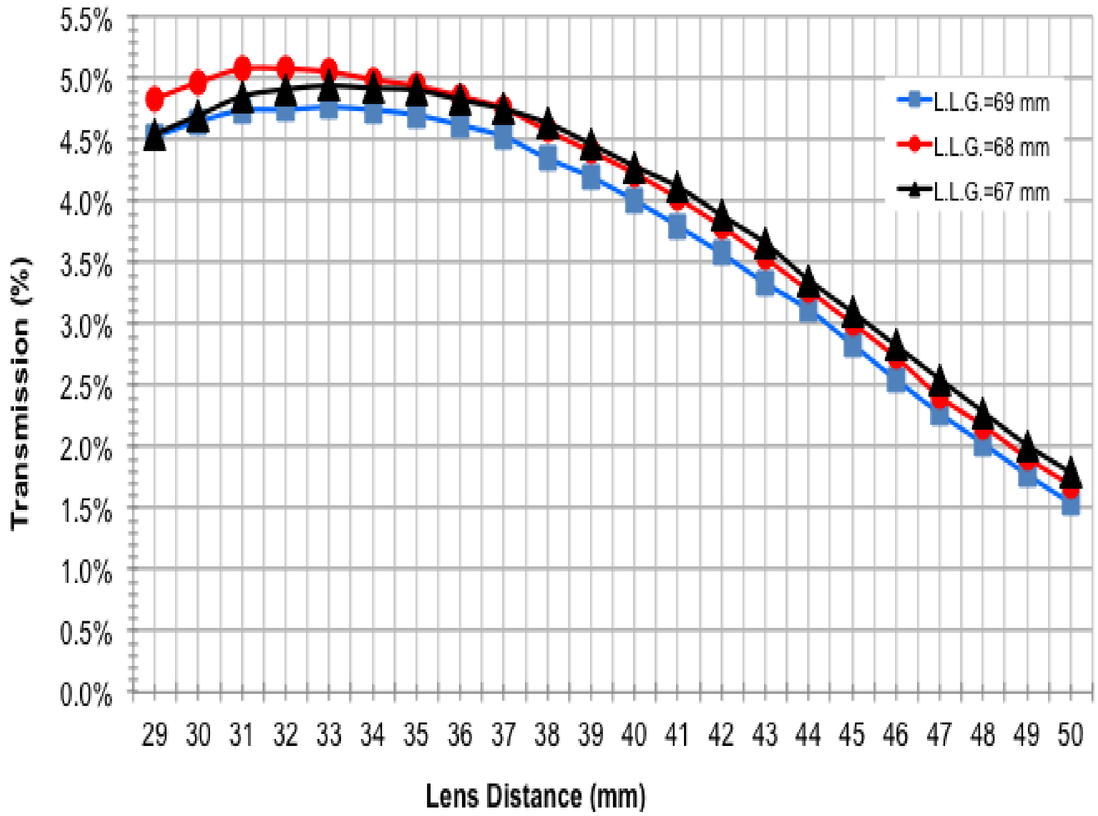

Figure 4: Percent transmission for a fixed LED position of (82,0). The highest three LLG distances were plotted and it was concluded that the maximum percent transmission achievable was 5.083%, with parametric constraints of (82,0) for LED position, a range of (0, 68-69) for LLG positions and a range of (29-50,0) for lens distances.

3. CONCLUSION AND FUTURE WORK

Hyperspectral imaging is a powerful tool for fluorescence microscopy applications for separating signatures from many fluorescent molecules. In this work, we have developed the first step in a full systems design of the planned RHIP-5D microscope – an initial software model for evaluating the theoretical feasibility of a high-speed HSI system using a multifaceted mirror array. Future work will focus on additional geometry optimization to further increase transmission collection. Geometry optimization includes investigating the addition of two or more lenses, two or more LEDs per channel, and mirror angle rotation. In addition, larger diameter liquid light guides will be implemented in the design to evaluate the impact on transmission collection in relation to diameter size. Preliminary design data suggest that the RHIP-5D system has potential for increasing the sensitivity and speed of HSI techniques when compared to current HSI approaches, which will be evaluated in future work by characterizing the sensitivity and speed of the system and comparing it to more traditional emission-scanning HSI systems.

4. ACKNOWLEDGEMENTS

The authors would like to acknowledge support from NIH grant P01 HL066299, NSF grant 1725937, and the Abraham Mitchell Cancer Research Fund. Drs. Leavesley and Rich disclose financial interest in a start-up company, SpectraCyte LLC, formed to commercialize spectral imaging technologies.

References

[1] Guolan, L., and Baowei, Fei, "Medical Hyperspectral imaging: a review," Journal of Biomedical Optics 19(1), 24 (2014).

[2] Fink, D.J., "Monitorng Earth's Resources from Space," Technology Review(June 1973), 10 (1973).

[3] "History of Remote Sensing, Satellite Imagery," <https://www.oneonta.edu/faculty/baumanpr/geosat2/RS%20History%20II/RS-History-Part-2.html> (24 May 2018).

[4] Harris, A.T., "Spectral mapping tools from the earth sciences applied to spectral microscopy data," Cytometry Part A 69A(8), 872–879 (2006).

[5] Goetz, A.F.H., Vane, G., Solomon, J.E., and Rock, B.N., "Imaging Spectrometry for Earth Remote Sensing," Science 228(4704), 1147–1153 (1985).

[6] Sun, D.-W., [Hyperspectral Imaging for Food Quality Analysis and Control] , Elsevier (2010).

[7] Adão, T., Hruška, J., Pádua, L., Bessa, J., Peres, E., Morais, R., and Sousa, J.J., "Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry," Remote Sensing 9(11), 1110 (2017).

[8] Goltz, D., Attas, M., Young, G., Cloutis, E., and Bedynski, M., "Assessing stains on historical documents using hyperspectral imaging," Journal of Cultural Heritage 11(1), 19–26 (2010).

[9] Leavesley, S.J., Annamdevula, N., Boni, J., Stocker, S., Grant, K., Troyanovsky, B., Rich, T.C., and Alvarez, D.F., "Hyperspectral imaging microscopy for identification and quantitative analysis of fluorescently-labeled cells in highly autofluorescent tissue," Journal of Biophotonics 5(1), 67–84 (2012).

[10] Leavesley, S.J., Deal, J., Martin, W.A., Lall, M., Lopez, C., Rich, T.C., Boudreaux, C.W., Rider, P.F., and Hill, S., "Colorectal cancer detection by hyperspectral imaging using fluorescence excitation scanning," in Opt. Biopsy XVI Real-Time Spectrosc. Imaging Diagn., R. R. Alfano and S. G. Demos, Eds., 19 (2018).

[11] Favreau, P.F., Hernandez, C., Heaster, T., Alvarez, D.F., Rich, T.C., Prabhat, P., and Leavesley, S.J., "Excitation-scanning hyperspectral imaging microscope," Journal of Biomedical Optics 19(4), 046010 (2014).

[12] Leavesley, S.J., L. Britain, A., Cichon, L.K., Nikolaev, V.O., and Rich, T.C., "Assessing FRET using spectral techniques: Spectral FRET Measurements," Cytometry Part An/a-n/a (2013).

[13] Favreau, P., Hernandez, C., Lindsey, A.S., Alvarez, D.F., Rich, T., Prabhat, P., and Leavesley, S.J., "Thin-film tunable filters for hyperspectral fluorescence microscopy," Journal of Biomedical Optics 19(1), 011017 (2013).

[14] Leavesley, S.J., Walters, M., Lopez, C., Baker, T., Favreau, P.F., Rich, T.C., Rider, P.F., and Boudreaux, C.W., "Hyperspectral imaging fluorescence excitation scanning for colon cancer detection," Journal of Biomedical Optics 21(10), 104003 (2016).

[15] Dontu, S., Miclos, S., Savastru, D., and Tautan, M., "Full Length Article: Combined spectral-domain optical coherence tomography and hyperspectral imaging applied for tissue analysis: Preliminary results," Applied Surface Science 417, 119–123 (2017).

[16] Leavesley, S.J., Sweat, B., Abbott, C., Favreau, P., and Rich, T.C., "A theoretical-experimental methodology for assessing the sensitivity of biomedical spectral imaging platforms, assays, and analysis methods," Journal of Biophotonics 11(1), e201600227 (2018).