

Multiplexed light source for flexible coupling into fan-out fiber bundles in biomedical optical imaging

Ömer Atmaca, Anton Zimmermann, Markus Großmann, Alois Herkommer
Institute of Applied Optics (ITO), University of Stuttgart, Germany
mailto:oemer.atmaca@ito.uni-stuttgart.de

This work presents two setups using incoherent and coherent sources for flexible light coupling into the individual cores of a fan-out fiber bundle. The setups use dichroic mirrors to unite the optical paths of each source and a rotatable mirror to control the coupling into each fiber core. The systems show negligible stray light coupling and fiber crosstalk, while providing adequate output powers.

1 Introduction

The trend in biomedical optics for diagnostics leads towards multimodal imaging as every modality is distinct in terms of spatial resolution, penetration depth and spectral sensitivity. However, different modalities pose partially shared and distinct illumination requirements. This can result in a multitude of different single light sources parallel to each other [1], which also need to be coupled into shared or distinct channels of optical fiber bundles in miniaturized imaging setups. Cost-effective options to couple many different light sources flexibly into every core at will are not readily available. This work therefore reports on a simple, yet flexible and extensible solution for multispectral coupling of light into every core of fan-out fiber bundles. All optical and electrical components are standard components purchased from conventional suppliers and selected for easy interchangeability in cases of changing requirements.

2 Optical setups

Two near-identical setups have been devised in this work, which operate under the same principle by combining the optical paths of a few single light sources with separate emission wavelengths into one using a beam combiner assembly with dichroic mirrors with according transmission spectra (see Fig. 1). The combined optical path is redirected into one of seven fiber optic collimators used in reverse for efficient coupling into individual cores of a 1-to-7 fan-out fiber bundle ($NA = 0.39$ & $\varnothing = 400 \mu\text{m}$) by using a rotatable mirror, which is mounted onto a stepper motor. The light source and stepper motor drivers can be controlled with a single microcontroller. The differences between both setups relate to the coherence of the single light sources and the type of beam shaping element.

2.1 System with incoherent sources

The setup with incoherent light sources consists of three collimated light-emitting diodes (LEDs) with blue (405 nm), green (530 nm), and red (660 nm)

peak wavelengths and a clear aperture diameter of 50 mm. An achromatic doublet in the combined optical path is used to focus the light into each fiber optic collimation package, which have an NA of 0.4. The collimation packages are arranged in a circular arc and the position of the beam combiner is adjusted so that the arc aligns best with the focus of the LED with the lowest output power, which is green.

2.2 System with coherent sources

The setup with coherent light sources consists of three laser diodes (LDs) with similar wavelengths (405 nm, 520 nm, and 660 nm) for cases of fluorescence excitation and possibly higher power requirements. The collimation packages have an NA of 0.25 and the LD drivers are manually power-limited due to laser safety. This setup uses custom-built electronics as the power requirements and pinouts of each LD renders the use of one universal LD driver challenging. Since the beam diameter of the collimated LDs are already small enough to be coupled freely into the collimation packages, no focusing element is needed in the combined optical path. Instead, a holographic diffuser with a 1° diffusing angle mounted onto a brushless DC (BLDC) motor is placed in front of the rotatable mirror to reduce the speckle formation at the fiber output. This creates a quasi-incoherent output, depending on the integration time of the camera and the rotational speed of the BLDC motor, for imaging modalities where the speckle pattern can be considered a noise signal.

3 Fiber output characterization

The output power for both systems was determined at the common end of the fan-out fiber bundle using a fiber-coupled power meter. The output power stays mostly constant over all positions (see Tab. 1). Any major deviation in the setup with LDs comes from a misaligned positioning of the stepper motor, which is corrected via microstepping in the setup with LEDs. Stray light coupling or crosstalk between the individual cores is negli-

gible after subtraction of the ambient background intensity, as shown in Figs. 2 & 3. The formation of speckles in the fiber output is largely dependent on the rotational speed of the BLDC motor and the exposure time of the camera (see Fig. 3).

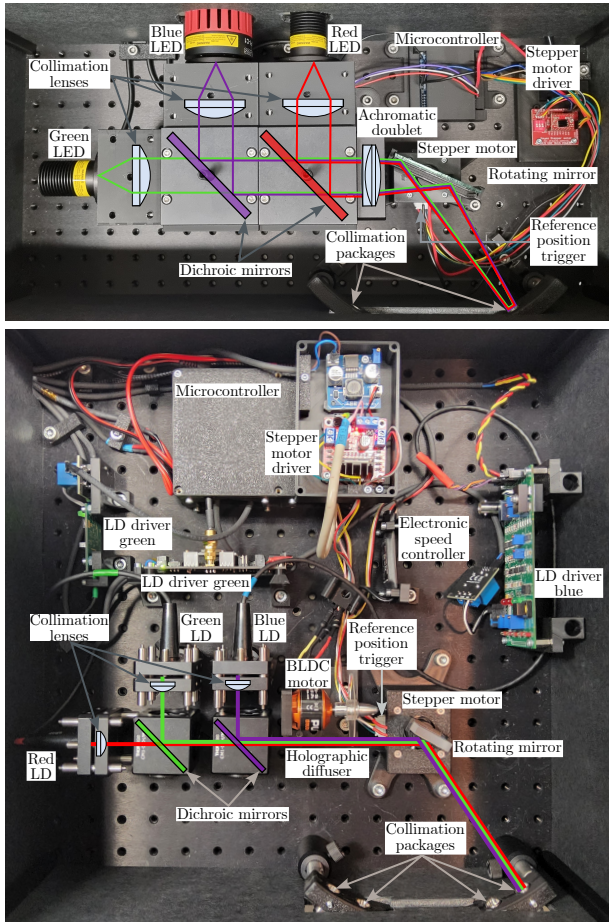


Fig. 1 Multiplexed light source systems with incoherent (top) and coherent (bottom) single sources.

4 Conclusion and outlook

This work demonstrates the effective implementation of a low-cost, flexible, and extensible platform for light coupling into a multi-fiber setup using standard components. Future work will focus on the deployment of these setups for different biomedical optical imaging modalities like fiber-based multispectral, spatial frequency domain, and fluorescence imaging.

Acknowledgements

The work described in this paper was conducted in the framework of the Graduate School 2543 "Intraoperative multi-sensor tissue differentiation in oncology" (Project ID 409474577) and the project "Miniaturized 3D printed platform for quantitative multispectral imaging of turbid media in the spatial frequency domain using elastically scattered light and fluorescence" (Project ID 537519988) funded by the German Research Foundation (DFG – Deutsche Forschungsgemeinschaft). The authors

thank Valerie Klockner for her assistance with Fig. 1.

Position	Output power in mW					
	Blue		Green		Red	
	LED	LD	LED	LD	LED	LD
-3	9.14	11.27	4.78	8.63	12.84	2.78
-2	10.94	4.61	5.03	5.65	13.68	1.84
-1	10.71	2.43	5.16	5.47	13.67	1.99
0	10.93	3.27	5.15	3.64	13.65	3.29
1	10.43	5.15	4.93	2.73	13.00	3.89
2	10.28	3.53	4.94	2.19	13.13	3.96
3	10.23	4.62	5.34	3.37	13.63	3.82

Tab. 1 Emitted power of each setup measured at the output of the fan-out fiber bundle.

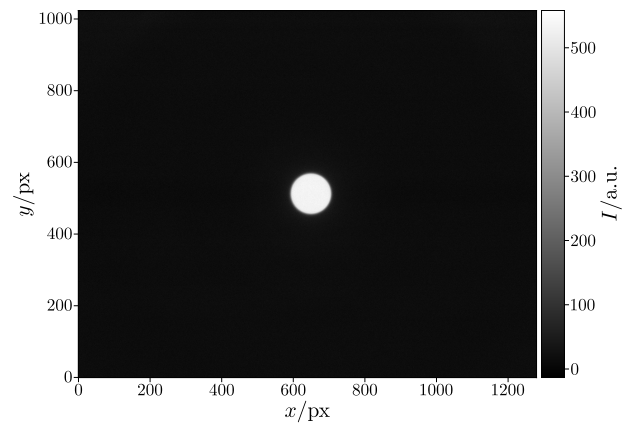


Fig. 2 Fan-out fiber facet with the illuminated center fiber at 530 nm after background subtraction.

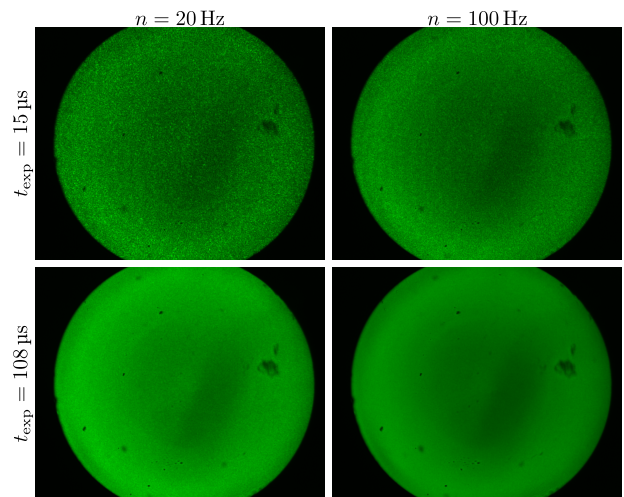


Fig. 3 Fiber output speckles on the camera image sensor for different camera exposure times t_{exp} and the rotational speed n of the BLDC motor.

References

- [1] K. Kandurova *et al.*, "Fiber-Optic System for Intraoperative Study of Abdominal Organs during Minimally Invasive Surgical Interventions," *Appl. Sci.-Basel* **9**(2), 217 (2019).