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A customized scope head for OCT-guided laser stimulation of the vagus nerve

Hanife GOKKAN[a,b] and Serhat TOZBURUN*[a,b,c]
[a]Izmir Biomedicine and Genome Center, Balcova, Turkey
[b]Izmir International Biomedicine and Genome Institute, Dokuz Eylul University, Balcova, Turkey
[c]Department of Biophysics, Faculty of Medicine, Dokuz Eylul University, Balcova, Turkey

ABSTRACT

In our laboratory, we are currently developing laser nerve stimulation using 1500 nm laser radiation, specifically as a potential alternative to electrical stimulation of the vagus nerve. The newly emerging stimulation method may have significant advantages over conventional electrical nerve stimulation for scientific studies and clinical applications: (1) non-contact delivery of external stimulus signals at mm scaled distance in air, (2) enhanced spatial selectivity, and (3) electrical artifact-free measurements. However, one of the issues limiting these advantages is that the tissue temperature is trapped in a narrow window (41 °C – 48 °C) for a successful and safe laser nerve stimulation. Another limitation is that only instantaneous surface temperature measurement is possible. This report presents to design a scope head that delivers a 1290 nm OCT beam for immediate backscatter coefficient feedback, a 1500 nm laser beam for laser nerve stimulation, and provides real-time imaging. The preliminary test of the scope head is described as fictitious.

Keywords: Optical coherence tomography, optical nerve stimulation, 3D printing, surface scanning

1. INTRODUCTION

The vagus nerve originates from the spinal cord in the central nervous system and is a long cranial nerve that reaches the neck, rib cage, abdomen, and colon [1,2]. It is critical as it provides two-way communication between the brain and internal organs. There are several advantages that the Laser Nerve Stimulation (LNS) technique offers compared to the traditional electrical nerve stimulation (ENS) technique [3]: (1) Non-invasive nerve stimulation method; (2) Improved spatial selectivity. (3) Artifacts-free measurements. Therefore, the advantages of LNS may offer new approaches where vagus nerve stimulation can eliminate or limit some side effects such as cardiac arrhythmia (heart rhythm disorder) [4].

However, one of the issues limiting these advantages is that the tissue temperature is trapped in a narrow window (41 °C – 48 °C) for a successful and safe LNS [5-7]. Another limitation is that only instantaneous surface temperature measurement is possible. For these reasons, there is a need for new thermal damage control approaches to successfully carry the LNS technique to clinical applications and especially vagus nerve stimulation applications.

At this very point, the report presents a 3D printable scope head design and ray optics simulation results. The scope head can deliver the 1290-nm optical coherence tomography (OCT) beam for depth-resolved thermal tissue damage detection and the 1500-nm laser beam for LNS and provide real-time white-light imaging via CMOS camera.

2. DESIGN AND SIMULATION RESULTS

Figure 1 shows a 3D CAD drawing of the scope head design. The design consists of variously shaped holders for the free space and 1-inch optical components. Also, the design includes two laser inputs and camera output. The dimensions of the scope head are 250 mm in length, 179-mm in width, and 44-mm in height. The following parameters can be based on the 3D printing of the scope head. Filament type: PLA; layer height: 0.2 mm; infill density: %30; printing temperature: 200 °C; build plate temperature: 60°C; print speed: 30 mm/s (infill speed: 30 mm/s, wall speed: 15mm/s); infill pattern: triangles.

The optical components are listed as follows: four achromatic lenses, two dichromatic mirrors, two convex lenses, a scanning lens, and a Galvo scanner. The galvo scanning mirror is used to scan the OCT laser beam on the sample's surface. One of the dichromatic mirrors aligns the 1500 nm laser beam for the LNS and the 1290 nm laser beam for the

* serhat.tozburun@ibg.edu.tr; phone 90 232 299-5100; fax 90 232 277-6353; tozburunlab.com

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OCT into the same optical path. The visible wavelength rays, collected by the scanning lens, are reflected onto the CMOS camera, while the other dichromatic mirror transmits the near-infrared rays.

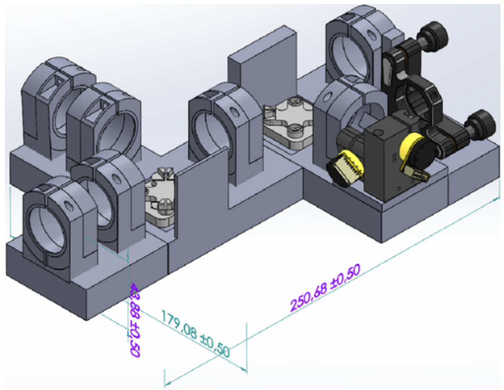

Figure 1. SolidWorks CAD drawing of 3D printable reticle head.

Figure 2 presents the ray optics simulation results. Computer simulations using basic and complex ray tracing were performed on a commercially available simulation package (free version 3DOptix, Israel). The yellow-colored rays mark the visible wavelength, the orange-colored rays mark the 1500-nm wavelength, and the red-colored rays mark the 1290-nm wavelength. According to the simulation, the optical insertion loss is estimated to be ~12% at the visible and ~15% at the near infrared range.

The technical specifications of the optical components are such that they are commercially available. For example, the focal length of the achromatic lens (AL1), which focuses the collimated 1500-nm laser beam onto the dichromatic mirror (D1, 1800 nm cut-off), is 40 mm. The collimated 1290-nm OCT beam reflected from the galvo scanner is focused on the dichromatic mirror (D1) with a 30-mm focal length achromatic lens (AL2). A bi-convex lens (CL) with a 25-mm focal length is used for an intermediate optical relay between two dichromatic mirrors (D1&D2). Another achromatic lens (AL3, f = 45 mm) collects the visible rays coming into the CMOS camera, while the other achromatic lens (AL4, f = 35 mm) directs the near-infrared rays to the scanning lens and focuses the backscattered rays onto the di-chromatic mirror (D2, 650 nm cut-on). The surface is scanned in a single axis, at a frame rate of 1k Hz (Galvo scanner, GM), over 4 mm, based on a focal length of 36 mm (scanning lens, SL).

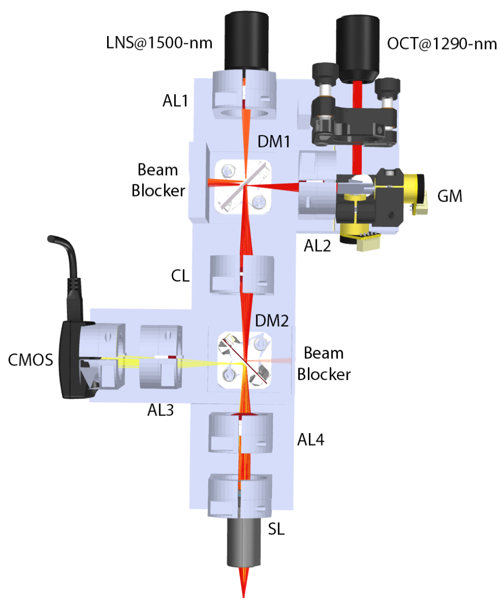

Figure 2. Ray optics simulation results. AL: achromatic lens. DM: dichromatic mirror. CL: bi-convex lens. GM: Galvo scanner. SL: scanning lens.

3. CONCLUSIONS

The objective of this study is twofold: 1) to roughly describe the design of a scope head capable of delivering a 1290-nm optical coherence tomography (OCT) beam for instant backscattering coefficient feedback and the 1500-nm laser beam for laser nerve stimulation; and 2) to present the preliminary simulation results.

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