SPECTRAL AND TEMPORAL MODULATION OF PULSOXYMETRY PROBE LIGHT SIGNALS – IMPROVED RECOMBINATION OF SPECTRALLY DECOMPOSED LIGHT

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Abstract: An optoelectronic system for the calibration of pulse oxymeter probes is described, based on the direct spectral and temporal modulation of the probe’s light signals with a spectroscopic setup combined with a micromirror array. An experimental setup to improve the recombination of the spectrally decomposed light is presented, which incorporates a diffractive optical element to reverse the spectral decomposition. The results are compared with a setup without any diffractive optical elements. It is shown, that the recollected spectral range and the overall recollected power can be significantly improved with the presented approach.

Keywords: pulse oxymetry, calibration, spectral modulation

Introduction

Pulse oximetry (PO) is one of the standard monitoring systems in emergency care, during surgery, intensive and postoperative care and is generally required as part of the basic monitoring during anesthesia [1, 2]. PO probes are calibrated by means of controlled hypoxemia studies (CHS) with volunteers [3]. CHS always imply invasive drawing of arterial blood samples and pose a certain risk for the volunteers. We propose a system for the temporally resolved acquisition of optical tissue transmission spectra (acquisition system), and a second system (playback system) to directly modulate the light signals of pulse oxymetry probes spectrally and temporally based on the afore recorded data [4]. This would reduce the amount of CHS needed and could potentially be used for the calibration of mult wavelength-parameter systems and for regular metrological controls [5].

The playback system decomposes the light emitted by the PO probe by a spectroscopic setup and images the optical spectrum onto the surface of a micromirror array (MMA). Each single mirror of the MMA can be tilted by either +12° or -12°, reflecting the incident light into two different directions (referred to as ON and OFF). Fig. 1 shows the playback system schematically.

![Figure 1: Concept of the playback system](image)

**Figure 1:** Concept of the playback system

The reflection pattern of the MMA can be changed with a maximum frequency of f = 22,727 Hz [6]. This allows to control the reflected intensity for each wavelength of the spectrum fast enough to reproduce a photoplethysmogram.

The light reflected into the ON direction has to be spectrally and spatially recombined to be guided back to the PO probe’s detector element. This work presents a spectral and spatial recombination approach based on a diffractive optical element in order to improve the recollection efficiency and thus the total optical throughput of the playback system.

Materials and Methods

**Principle of the 4f-stretcher**

Since the direct PO probe light modulation requires a spectral decomposition, it is necessary to recombine the spectrum after reflection from the MMA. This can be achieved by a second diffractive optical element. The 4f-stretcher principle uses a first grating for the spectral decomposition of the collimated incident light and a lens to form the spectral image. After passage of the image plane the whole beam path is basically reversed, i.e. a second lens re-collimates the light (rays of same wavelength are parallel) and a second grating combines the light to a common optical axis for all wavelengths. The elements are located in the focal lengths of the lenses, therefore the name 4f-stretcher. This concept is shown in Fig. 2.
Figure 2: Schematic of a 4f-stretcher

The collimated light emerging from the second grating is finally focused into a fiber. Transmission gratings from Wasatch Photonics, USA with g = 600 lines/mm, λ_{peak} = 900 nm and maximum diffraction efficiency of ca. 90% were used. For imaging the spectrum on the one side and recollimation on the other side two plano-convex lenses (f = 38.1 mm, Ø = 24.4 mm, VIS-NIR AR coated) were implemented. A plane reflection mirror was used instead of the MMA for the presented proof of concept experiments.

Comparison of different experimental setups

The spectral range that was possible to collect with a fiber (Ø = 1 mm) with the 4f-stretcher setup was compared with the results of a setup without any grating but only one single focusing lens. For all experiments an incandescent tungsten halogen lamp (Avalight HAL, Avantes, The Netherlands) was used for illumination and a spectrometer (Shamrock SR303i, Andor Technology, USA, TE cooled Si-CCD-detector, grating with g = 150 lines/mm and λ_{blaze} = 800 nm) for spectral signal acquisition.

Results

Figure 3 shows the recollected spectra (normalized by the reference spectrum emitted by the lamp and scaled to maximum of the spectrum detected with the 4f-stretcher).

Using only a focusing lens to recollect the light, only small portions (Δλ ≈ 120 nm) of the complete spectrum can be recollected by the fiber (dashed curves). By moving the fiber laterally this portion could be selected. Each of the dashed curves represents a different fiber position.

With the 4f-stretcher setup (solid curve) the spectral range increases dramatically from approximately 500 nm to over 1,000 nm and the overall intensity is significantly higher, at the maximum almost twice.

Discussion

It was shown, that the spectral range and the overall recollection efficiency can be improved with the 4f-stretcher concept compared to the approach with a focusing lens only. Since the latter only produces an image of the spectrum in the plane of the fiber end, the finite width of the fiber can only collect a certain portion of the spectrum.

The spectral range collected with the 4f-stretcher is limited by the diffraction properties of the grating and the total imaging qualities of the complete setup. In this work two gratings with their maximum diffraction efficiency at 900 nm were used, which might explain the high intensity in the recollected spectrum at 870 nm. Different grating diffraction efficiency curves for the incident and the emerging path might enhance the spectral range and the recollected optical power, especially regarding lower wavelengths.

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References

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