Design and evaluation of a novel Transillumination SFDI system for quantitative assessment of tissue sections for rapid, label-free cancer margin detection

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Introduction

Spatial Frequency Domain Imaging (SFDI) is a non-invasive imaging technique that that employs optical measurements to generate quantitative images of biological tissues in terms of its function and structure [1]. This makes it a compelling platform for imaging sensitive tissues such as the skin or the eye [3].

Motivation

Using frozen section histology, Mohs surgery is a standard tissue conserving procedure for removing a skin cancer while maintaining margin control. However the procedure is labor-intensive and time consuming, as multiple histopathologic sections must be performed and interpreted while the patient waits [2].

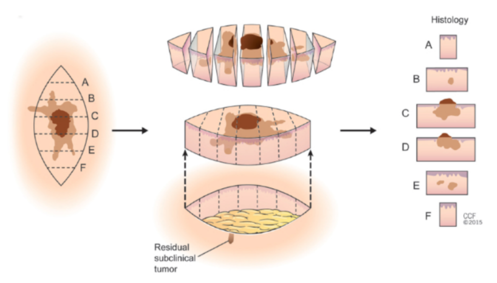

Figure 1:Thick tissue histology

A transmission-based SFDI system can potentially improve tissue-conserving surgeries by enabling direct analysis, at the point of care, of tissue properties. This system can provide rapid and accurate information about tissue characteristics without the need for histopathologic processing, allowing for more precise and efficient surgical procedures and better patient outcomes.

System Development and Design

A low-cost SFDI system is developed with a novel geometry, in which an LED-based projector and an RGB camera are positioned opposite to each other with the sample placed in between, see Fig 2. The LED-based projector illuminates the sample with sinusoidal light patterns while the RGB camera captures the transmitted light, allowing for the extraction of the sample's optical properties. This configuration offers several benefits, including improved flexibility in sample size and positioning.

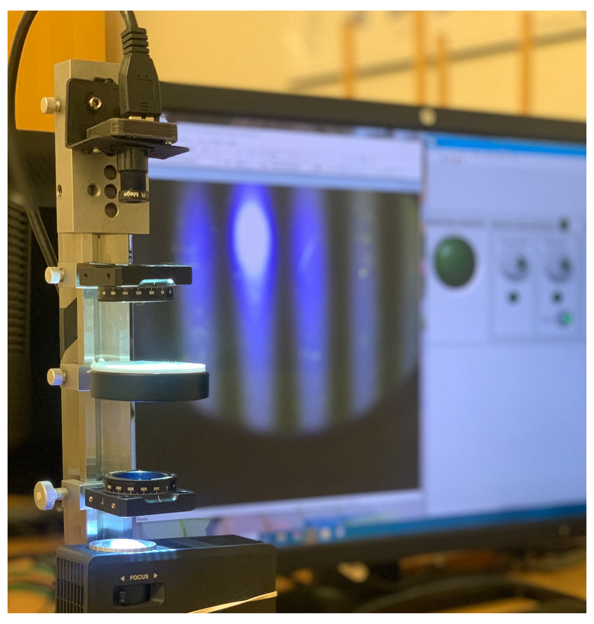

Figure 2:A transmission-based SFDI system in action, illuminating a tissue sample to extract its optical properties.

References

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[3] Z. Sun, D. Hu, Z. Wang, L. Xie, and Y. Ying. Spatial-frequency domain imaging: An emerging depth-varying and wide-field technique for optical property measurement of biological tissues. In *Photonics*, volume 8, page 162. MDPI, 2021.

Results

Characterizing the differentiated spatial frequency response to absorption and scattering

The amplitude of a sample varies with the spatial frequency of incident light, and this variation is dependent on the optical properties of the sample. A $4x4$ matrix, which can be seen in Fig 3, was constructed, consisting of samples that each possessed unique optical properties. Notably, despite some samples having similar coloration, the SFDI system proved capable of differentiating between samples with distinct optical properties, see Fig 4 and 5.

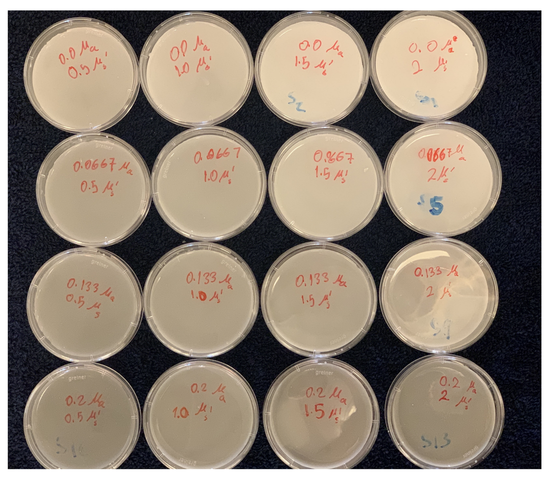

Figure 3:A 4x4 matrix of samples with distinct optical properties.

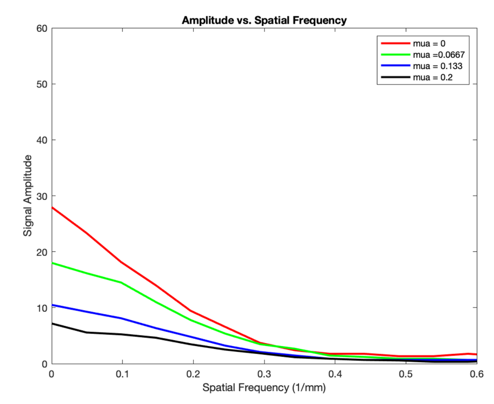

Figure 4:amplitude as a function of spatial frequency for 4 samples with uniform μ_s' and variable μ_a

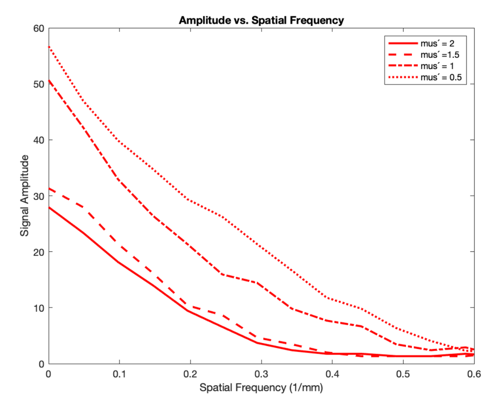

Figure 5:amplitude as a function of spatial frequency for samples with uniform μ_a' and variable μ_s'.

Strategy for determining optical properties of an unknown sample: an empirical LookUp Table approach

The response curves from the 4x4 matrix are interpolated across both absorption and scattering value dimensions. This generates a 3D mesh of response curves spanning ranges of 0-.2/mm μ_a and 0.5-2/mm μ_s'. The response curve from an unknown sample is then compared to the values generated in this Look-Up-Table. A minimization algorithm determines with reference curve best fits the unknown sample response and those reference optical properties can then be assigned to the unknown sample, See Fig 6.

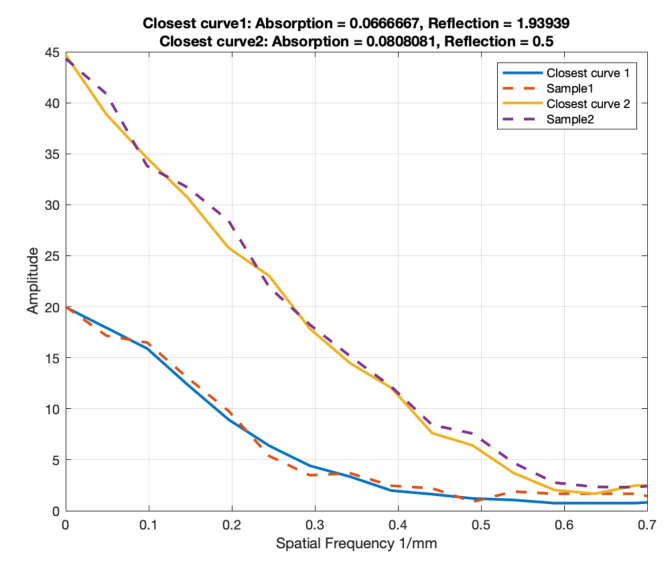

Figure 6:Using a Lookup Table approach and an algorithm, the system fits each given sample and identifies its optical properties.

Conclusion and Future Work

In conclusion, the SFDI-system developed in this study is able to differentiate absorption and scattering up to a spatial frequency of $0.6mm^{-}1$ using fixed thickness samples of $2mm$. As a direction for future work, it would be worthwhile to further investigate the range of tissue thickness and optical properties that can be imaged with residual spatial frequency patterns, and to determine the accuracy with which the system can distinguish between scattering and absorption properties of healthy and injured/unhealthy tissues.

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