A multispectral snapshot camera method to analyze optical tissue characteristics *in vivo*

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Purpose: Pathological structures can develop between or in the direct proximity to important structures, e.g. nerves. To reach the operating area, the surgeon has to expose the nerves in this area without causing substantial damage. This structure exposition process is of high risk and difficult, as damage to healthy structures can cause a temporary or permanent paralysis of the affected region. Furthermore, in normal light condition, the different tissue types do not differ much from neighboring tissue, thus the surgeon’s tissue differentiation process is based on his experience and knowledge only.
In order to support the surgeon’s decision by detecting optical tissue characteristics not visible to human eyes, in this preliminary study we developed a multispectral in vivo tissue measurement setup based on a snapshot camera and analyzed several human tissue types relating to its optical behaviors.

Methods: We built an imaging setup including two multispectral snapshot camera featuring a 4x4 mosaic and a 5x5 mosaic pattern as recording device. A snapshot camera shows the advantage of acquiring the complete multispectral dataset in a single shot compared to a filter-wheel setup [1], while on the other hand the spatial resolution is reduced due to the larger filter array. The first camera holds a 4x4-filter array, resulting 16 bands between 460 nm to 630 nm. The second camera holds a 5x5-filter array, sensitive from 600 nm to 975 nm. To avoid off peak filter responses in some pixels of the 5x5-filter array, a 675 nm long-pass filter is placed in front of the camera, resulting in 25 HSI-bands between 675 nm to 975 nm. Each band has a specific response pattern containing primary or secondary peaks in the sensitive interval of the sensor. Therefore, the band response is not a correct spectral signature as the signal is a combination of the sensor level response and the system level components. To measure a correct spectral signature, it is required to calibrate the signal through spectral correction.
Both cameras hold a 75 mm f/2.8 lens and are aligned on a rack with a distance of 6 cm, focusing on the same point in a distance of approximately 25 cm. In the setup, two cameras are used to increase the number of spectral channels over the complete visual and near-IR range (465 nm to 975 nm) while preserving the spatial resolution. Two configurations are used for scene illumination, a xenon source, which exhibits an almost homogeneous spectrum in the spectral range of interest, and the surgical LED light.
In order to spatially align the images of the two cameras, we use normalized cross correlation as cost function to register local specified tissue areas to a multispectral data cube. This allows a spectral scanning of the surgical area and the investigated tissue. Using the measurements of the 41 bands of every tissue type, we are able to analyze the relating tissue properties in a multi-dimensional wavelength domain.
In this study, we analyze several different healthy tissue types of four patients in two different ENT surgery types, parotidectomy and neck dissection. For evaluation, interesting tissue structures are annotated in the images by the surgeon.

Results: We investigated artery, vein, bone, muscle, fat, skin, connective tissue, parotid gland, and different nerves as nervus facialis and nervus hypoglossus. To evaluate the tissue behavior and make the results of our spectral analyzer comparable to the literature, we calibrated the setup to transform the measurement data into the physical unit reflection using

$$I_{ref} = \frac{I_{raw} - I_{dark}}{I_{white} - I_{dark}},$$

where I_{dark} contains the dark reference image, I_{white} holds the white balance alignment and I_{raw} is the measured pixel information [2].

As a result, for each tissue type we achieve a reflection spectrum that shows individual behavior of the tissues in the wavelength domain. Figure 1 displays the spectra of two selected interesting tissue types, nervus facialis and neighboring parotid gland, of one measurement. Each curve represents the average tissue response of the corresponding tissue in one measurement of an individual patient, annotated by the surgeon. It is obvious that each curve has a different trend, which allows an explicit classification. Hence, using these 41 spectral bands allows a robust differentiation of the annotated tissue data because spectral tissue data can be better separated than in three-dimensional RGB color space.

Conclusion: These fundamental investigations give very promising results to develop a real-time system that allows multispectral tissue analysis with snapshot cameras for surgery. A mosaic snapshot camera, gives a low spatial resolution while acquiring the complete spectral data cube in one image. This is a big advantage compared to filter wheel setups [1]. In order to increase the spectral range while keeping a high spatial resolution, we used two snapshot cameras and spatially aligned the acquired data cubes using image registration.
Future work towards the development of a real-time system will address the following questions. Based on the analysis of a larger number of test data, a robust decision and classification system has to be developed. An online tracking system capturing the surgical field of interest will be needed. Further, a user friendly visualization approach will be developed that presents the additional information to the surgeon without concealing other important information in the surgical area but supporting treatment decisions.

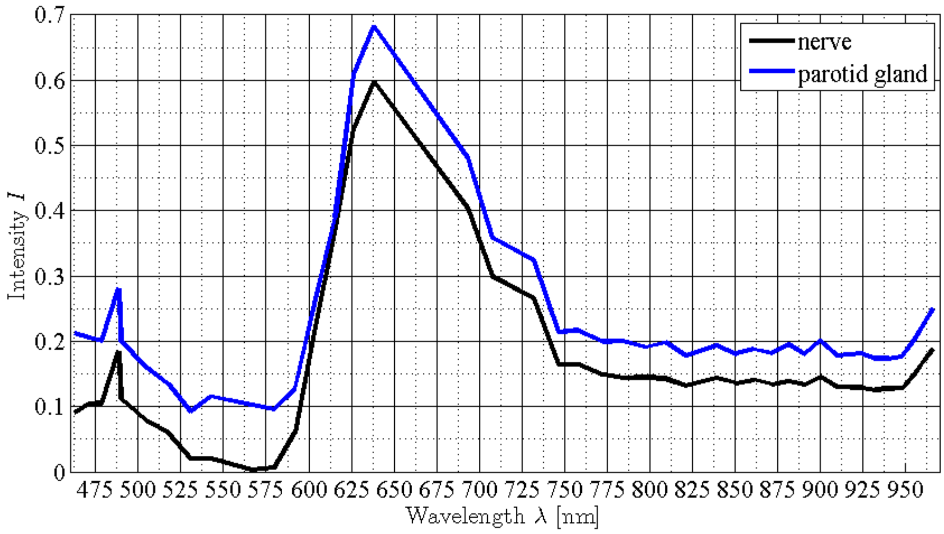

Figure 1: This plot shows the averaged intensities of the nervus facialis (black) and parotid gland (blue) in the analyzed spectral range. Both curves are achieved of the same patient data.

Keywords:
Image-guided surgery
Hyperspectral imaging
Multispectral image processing
Tissue analysis

References

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