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Abstract: We present a Monte-Carlo study for the identification of the hyperspectral camera' spectral bands for intraoperative hemodynamic and metabolic brain mapping. We also show that a RGB camera is suitable for hemodynamic brain mapping.

1. Introduction

Non invasive functional brain mapping is an imaging technique used to localize the functional areas of the patient brain. This technique is used during brain tumor resection surgery to indicate to the neurosurgeon the cortical tissues which should not be removed without cognitive impairment. Optical imaging provides an ideal solution for intraoperative functional brain mapping because the analysis of the light absorption allows to monitor the brain activity with quantification of the concentration changes in oxy- (ΔC_{HbO_2}) and deoxygenated hemoglobin (ΔC_{Hb}) in brain cortex [1]. The acquisition of the intrinsic signal in the near infrared range using hyperspectral cameras offers the potential to monitor the brain metabolism with the quantification of the concentration changes of the oxidative state of cytochrome-c-oxidase (ΔC_{oxCCO}) [2].

The commercial hyperspectral cameras have a limited choice of spectral bands that do not correspond to the ideal configuration identified by *Bale et al* [2]. Moreover, the more spectral bands are used, the more time is needed to compute functional brain maps. Since time is the key factor in intraoperative imaging, the smallest number of spectral bands must be acquired while ensuring minimal quantification errors.

In this study, we propose a method (explained in detail in Ref [3]) based on Monte Carlo simulations to define the optimal spectral combinations of a commercial hyperspectral camera for intraoperative hemodynamic and metabolic brain mapping. This method could be used with any hyperspectral or standard RGB camera to evaluate its ability to compute accurate hemodynamic and/or metabolic brain maps following neuronal activation. All spectral combinations of the hyperspectral camera are tested to evaluate the optimal spectral configuration that minimize the quantification errors in ΔC_{HbO_2}, ΔC_{Hb} and ΔC_{oxCCO}. Finally, we compare standard RGB imaging and hyperspectral imaging for hemodynamic and metabolic brain mapping and show that RGB imaging is a low cost solution that is relevant to identify the functional areas in a patient brain based on the analysis of the cortical hemodynamics. Hyperspectral imaging is mandatory for an accurate computation of hemodynamic and metabolic brain maps.

2. Material and methods

We simulated the acquisition of the intrinsic reflection spectra of a patient exposed cortex using hyperspectral imaging to determine the optimal spectral configuration for the computation of hemodynamic and/or metabolic brain maps. We also simulated the acquisition of the intrinsic reflection spectra based on standard RGB imaging to evaluate the potential benefit of using hyperspectral imaging.

2.1. Simulated Setup

In this study, the imaging system represented in Fig. 1 was simulated. This setup was used in our previous study [1] for the identification of functional areas based on RGB imaging. The simulated wide field optical device

employed in this study is described in Refs [1,3]. This device is composed of a RGB camera (*BASLER acA2000-165uc*), a snapshot hyperspectral camera (*XIMEA MQ022HG-IM-SM5X5-NIR*) that acquires 25 spectral bands and a continuous wave white light source.

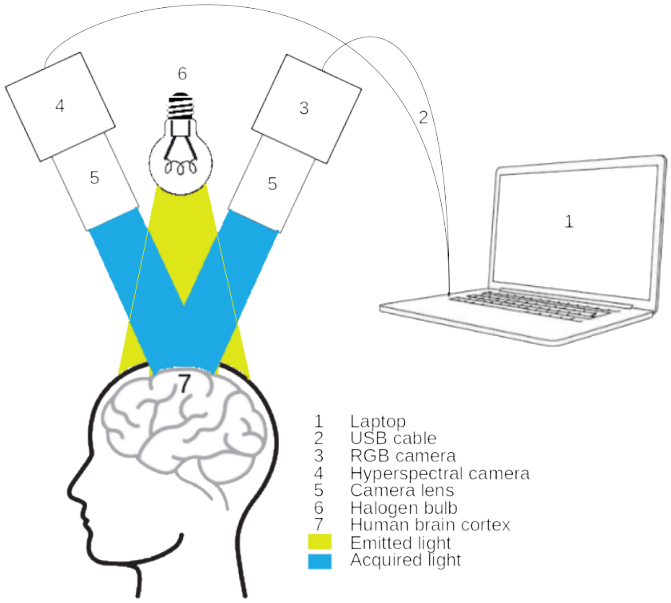

Fig. 1. Schematic of the simulated imaging system.

2.2. *Simulation of the Patient Cortical Activation*

A homogeneous volume of grey matter has been modeled and we simulated the acquisition of the reflection spectra at its surface with the RGB and hyperspectral cameras using Monte Carlo simulations [4]. In this grey matter model, we incorporated the hemodynamic and metabolic changes following a 20s neuronal stimulation. The objective is to study the capacity of both cameras to monitor brain hemodynamics and metabolics.

2.3. *Determination of the Optimal Spectral Configuration of the Hyperspectral Camera*

The modified Beer-Lambert law is then used to convert the simulated intrinsic reflection spectra into HbO_2, Hb and $oxCCO$ concentration changes. In order to evaluate the robustness of the chromophores' quantification, zero mean Gaussian noises (experimentally measured) were added to the simulated reflection spectra. The computation of the chromophores' concentration changes was repeated 10^3 times to get the mean and standard deviation values of the quantification errors (relative quantification errors with respect to modeled concentration changes). Finally, the optimal spectral combination of a hyperspectral camera was identified by minimizing the quantification errors in ΔC_{HbO_2}, ΔC_{Hb} and ΔC_{oxCCO}.

3. Results and discussion

In Fig. 2, the hemodynamic monitoring following neuronal activation computed with the RGB camera (left plot) and the hemodynamic and metabolic monitoring following neuronal activation computed with the optimal spectral combination of the hyperspectral camera (right plot) are represented. The results indicate that the optimal spectral combination of a hyperspectral camera (22 spectral bands) aims to accurately quantify the HbO_2 (0.5% error), Hb (4.4% error), and $oxCCO$ (15% error) responses in the brain following neuronal activation. We also show that RGB imaging is a low cost and accurate solution to compute Hb maps (4% error), but not accurate to compute HbO_2 maps (48% error). The optimal spectral combination of the hyperspectral camera could be however reduced from 10 to 12 spectral bands while keeping fairly constant performances.

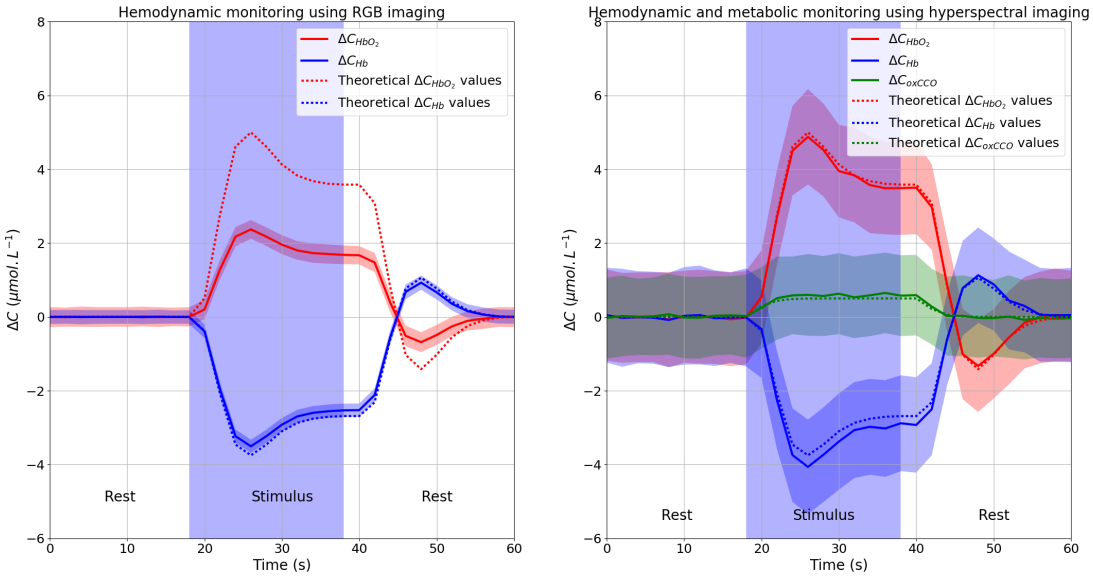

Fig. 2. Hemodynamic monitoring following neuronal activation computed with RGB imaging (left plot) and hemodynamic and metabolic monitoring following neuronal activation computed with hyperspectral imaging (right plot). The dashed lines represent the theoretical hemodynamic and metabolic responses following the neuronal stimulation. The dispersion ranges of the measurements are represented by colored areas. The concentration changes averaged over 10^3 noisy measurements are represented in solid lines.

4. Conclusion

In this work, we present a method for the identification of the optimal spectral bands of a commercial camera for the intraoperative monitoring of the brain hemodynamic and metabolic responses following neuronal activation. This method is based on Monte Carlo simulations of the light propagation in a volume of grey matter and incorporates a realistic modeling of the camera acquisition with the addition of Gaussian noises (experimentally measured with the cameras). We identified that an optimal spectral combination of our hyperspectral camera composed of 21 to 22 spectral bands can be used to compute hemodynamic and metabolic brain maps. This configuration could be however reduced from 10 to 12 spectral bands while keeping fairly constant performances, which is consistent with the spectral configurations proposed in the literature. We also showed that RGB imaging is not a suitable technique to compute metabolic brain maps, but is very accurate to compute hemodynamic maps with the quantification of deoxygenated hemoglobin concentration changes. Our Monte Carlo framework needs to be improved, namely with the consideration of the perfusion of grey matter by blood capillaries.

Acknowledgments

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