Registration using wavelet coefficients in spectral domain

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Abstract

This paper focuses on the development of an efficient registration method of Optical Coherence Tomography (OCT) images. The proposed technique is based on the use of a wavelet representation of the OCT images in the registration process. The validation tests show that beside non-stationary and highly inhomogeneous OCT images, the wavelet-based registration demonstrates very interesting results.

1 Introduction

A biopsy is a medical intervention usually performed by a clinician who takes, from the body, a sample of a suspect tissue for an *ex-situ* examination [1]. The latter is performed using usually a microscope to detect signs of damage or disease. Biopsies can be performed on all parts of the human body even in the brain. Thus, there are various types of biopsy processes: needle biopsy, endoscopic biopsy, surgical biopsy, etc. Most of these methods are invasive procedures even minimally and generally follow four essential steps: sampling, transfer, histological analysis, and then diagnostic. This takes time, requires a short hospitalization of the patient, a general or local anesthesia, and especially can cause infections in the tissue collection [2].

Furthermore, a biopsy may be performed in another way using specific medical imaging systems. This is usually known as *optical biopsy* and consists of an in-situ and real-time optical analysis of the suspect tissue without any removal. To perform an optical biopsy, it requires miniature and high resolution imaging systems as an optical endomicroscopic device. Doubtless, the two most popular techniques used in optical biopsy are confocal microscopy [3] and OCT [4]. Over the past two decades, OCT has emerged as the most suitable technique for carrying optical biopsies. This is mainly due to a better compromise between resolution and depth of penetration of tissues compared to the confocal microscopy technique.

This paper deals with the use of OCT images as a means for an *in-situ* chronological monitoring diagnosis of suspect tissues by tacking several optical biopsies of the same tissues at different time intervals. To be able to compare the different optical biopsies and detect the evolution of the suspect tissue, it is necessary to represent all the biopsies in the same reference. This amounts to perform a registration between successive OCT images [5]. To ensure an accurate registration of the high resolution OCT images, we provide a novel method based on wavelet representation in the spectral domain of the OCT signals.

2 Wavelet Transform

The wavelet transform allows to represent a 1D or 2D indeed 3D signal by orthonormal series [6]. The wavelet is widely used for the study of non-stationary and highly inhomogeneous signals in both time and frequency domains. It decomposes the signal into a set of elementary waveforms called *wavelets* defined by the wavelet coefficients (1).

$$\mathbf{WI}(b, a, \theta) \simeq \int_{-\infty}^{+\infty} \mathbf{I}(\mathbf{x}) \overline{\psi\left(\frac{\mathbf{r}_{-\theta}\left(\mathbf{x}-\mathbf{b}\right)}{a}\right)} d^2\mathbf{x}, \tag{1}$$

where $\mathbf{WI}$ are the wavelet coefficients, ψ is the mother wavelet, $\mathbf{I}(\mathbf{x}) \in \mathbb{R}^2$ is an image, $a \in \mathbb{R}_*^+$ is the scale parameter of the wavelet, $\mathbf{b} \in \mathbb{R}^2$ translation parameters along x and y, respectively, and $\mathbf{r}$ is the 3×3 rotation matrix carried by the angle θ. Thereby, $\mathbf{r}$ is given by

$$\mathbf{r} = \begin{pmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{2}$$

In order to maintain the continuity of the signal $\mathbf{I}$, we choose ψ as the mother complex oriented *Morlet wavelet* [7] defined in the spatial domain by considering the correction exponential term $e^{-\frac{1}{2}k_\psi^2}$ as follows:

$$\psi(x,y) = \left(e^{ik_\psi x} - e^{-\frac{1}{2}k_\psi^2}\right) e^{-\frac{1}{2}(x^2+y^2)} \tag{3}$$

where k_ψ is the wavenumber associate to the *Morlet wavelet*.

3 Wavelet-based Registration

The registration defined as the process to align current image $\mathbf{I}_c$ with reference image $\mathbf{I}_r$. This returns to find the minimum of the cost-function defined by:

$$\widehat{\mathbf{T}} = arg\min[\mathbf{WI}_r, \mathbf{WI}_c] \tag{4}$$

where $\widehat{\mathbf{T}} \in (SE(2) \times SO(1))$ is the estimated rigid transformation and $\mathbf{WI}_r$ and $\mathbf{WI}_c$ are the wavelet coefficients of $\mathbf{I}_r$ and $\mathbf{I}_c$ respectively.

Therefore, using a *log-polar* phase correlation method [8] it is possible to represent the cost-function between two images to be registered by the convex shape curve shown in Figure 1. Note the minimum of this cost-function is well defined and can be easily computed by a simple gradient-based optimization algorithm.

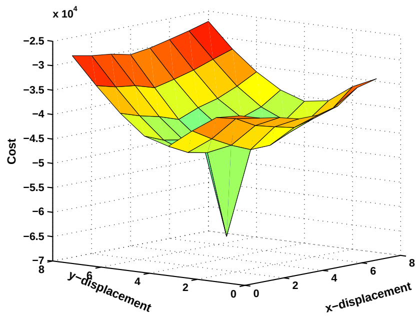

Figure 1: Illustration of the cost-function used in the developed registration method.

The developed wavelet-based registration method can be summarized by the algorithm given in Figure 2.

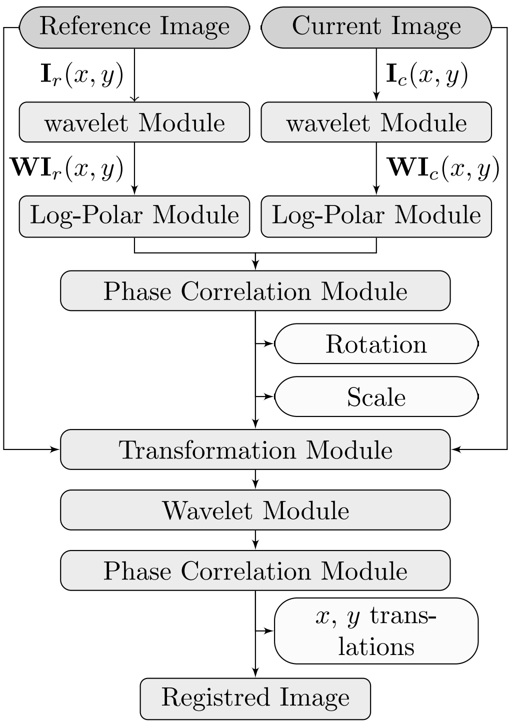

Figure 2: Overview of the registration algorithm.

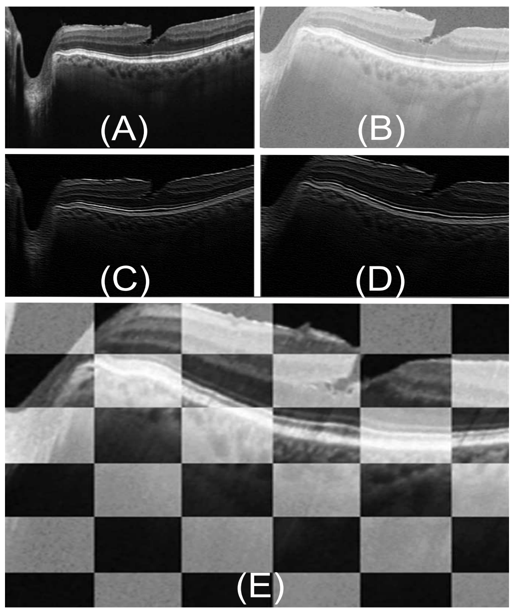

Figure 3: Registration results: (A) OCT reference image, (B) OCT image to be registered, (C) and (D) the corresponding wavelet coefficients, respectively, and (E) the result of the registration process.

4 Experimental Validation

Having not yet experimental set-up for a physical registration, we opted for a 4 dof (x, y, z, and θ) numerical registration. To ensure this, we consider a first OCT image $\mathbf{I}_r$ (reference image shown in Figure 3(A)) taken under nominal conditions and a second image $\mathbf{I}_c$ (image to register shown in Figure 3(B)) taken using another point of view and under extreme conditions of saturation. Figure 3(C) and (D) represent the corresponding wavelet coefficients of $\mathbf{I}_r$ and $\mathbf{I}_c$, respectively. The registration result is illustrated in Figure 3.(E) which is the combination "$\oplus$" of both images $\mathbf{I}_r$ and $\mathbf{I}_c$ after transformation. By analyzing the image result, it can be highlighted the high accuracy of the proposed registration method despite the high difference between $\mathbf{I}_r$ and $\mathbf{I}_c$. The registration process takes only 130 milliseconds for 256×256 pixels images, this using a 3.5 GHz PC.

5 Conclusion

In this paper, it was shown using a wavelet-based registration method in the case of OCT images. Despite of the large difference between the OCT images to be registered (i.e., nominal acquisition conditions *vs.* saturation acquisition conditions), the proposed method was illustrated that the wavelet-based registration algorithm remains efficient with high level of accuracy of convergence.

The next stages of this work will involve to implementation of the developed method in an experimental set-up (including a multiple degrees of freedom) in order to achieve a physical registration during repetitive optical biopsies.

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