Spatial-Frequency Approach to Fibrous Tissue Classification in Intracoronary Optical Images

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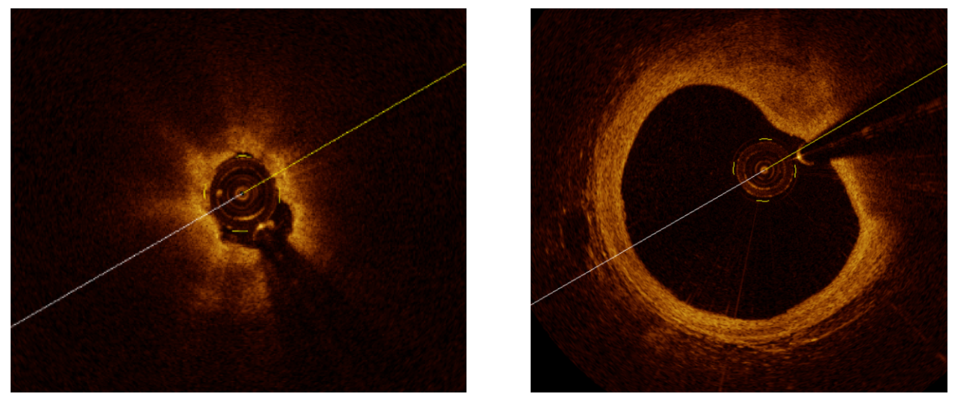
Contribution

Intravascular optical coherence tomography (IOCT) provides images with micrometer axial (10-15μm) and lateral resolution (40μm), resolution sufficient to characterize fibrous cap tissue and determine its thickness in vivo [1]. This work describes a fully automated method for identification and quantification of fibrous tissue in IOCT human coronary images based on spatial-frequency analysis using the Short-Time Fourier transform.

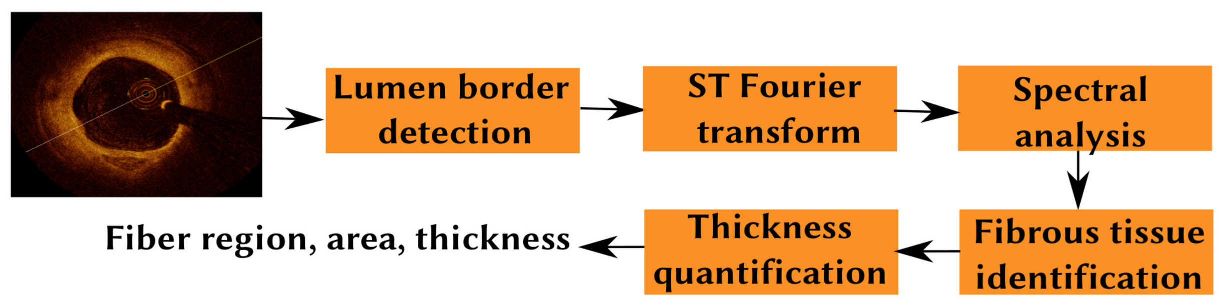
Image data

Images were acquired using a Fourier-Domain OCT (FD-OCT) system. The 2D input images to the proposed method were in DICOM format with dimensions 1024×1024 pixels and spatial resolution of 10×10 μm in Cartesian coordinates.



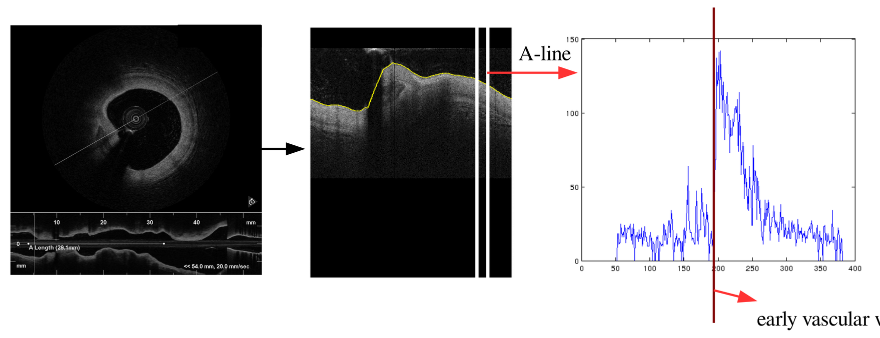
Method

Given an IOCT frame, the proposed method to identify and measure the thickness of the fibrous tissue consists of 5 steps, shown in the Figure below.



Lumen border detection

The lumen border indicates where the vessel wall starts, limiting the input signal.



Cartesian image, polar image and A-line intesity profile.

Short-time Fourier transform

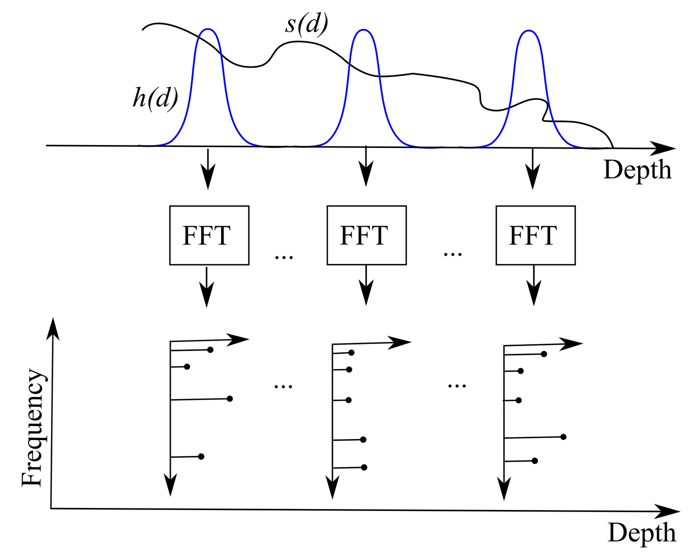
This method consists of multiplying a signal by a window function, h, with a given length, δ, in a specific depth, d, to produce a modified signal and perform the Fourier transform of this signal [2].

Method

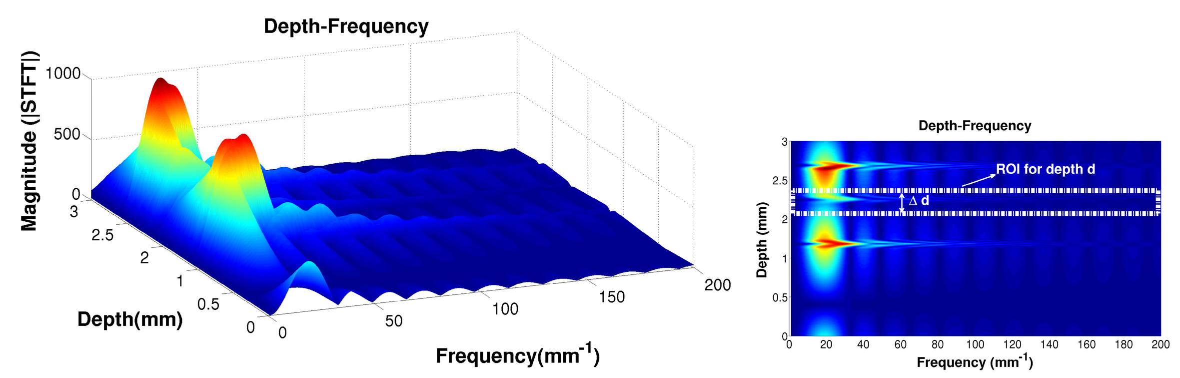
Short-time Fourier transform

$$STFT(\omega, d) = \int s(\delta)h(\delta - d)e^{-j\omega\delta}d\delta \qquad (1)$$

where ω is the angular frequency.



The intensity value in an IOCT A-line scan is presented as the function, $s(d)$, which is windowed by the function, $h(d)$.



3D surface plot showing variation of magnitude of the STFT with changing depth and frequency.

Spectral analysis

The best measures determined by **Forward Regression Orthogonalization Least Squares** (FROLS) [3] were:

- Maxmag (maximum magnitude):

$$Maxmag(d, \Omega) = max\{M(d, \Omega)\}$$

- $Fmag_{mean}$ (mean of freq. multiplied by magnitude):

$$Fmag_{mean}(d, \Omega) = \overline{\Omega * M(d, \Omega)}$$

- E (energy density spectrum):

$$E(d, \Omega) = \sum_{i=1}^{n} P(d, \omega_i)$$

where $\Omega = \{\omega_1, .., \omega_n\}$, $M(d, \Omega) = |STFT(\Delta d, \Omega)|$ and $P(d, \Omega) = |STFT(\Delta d, \Omega)|^2$.

Fibrous tissue identification

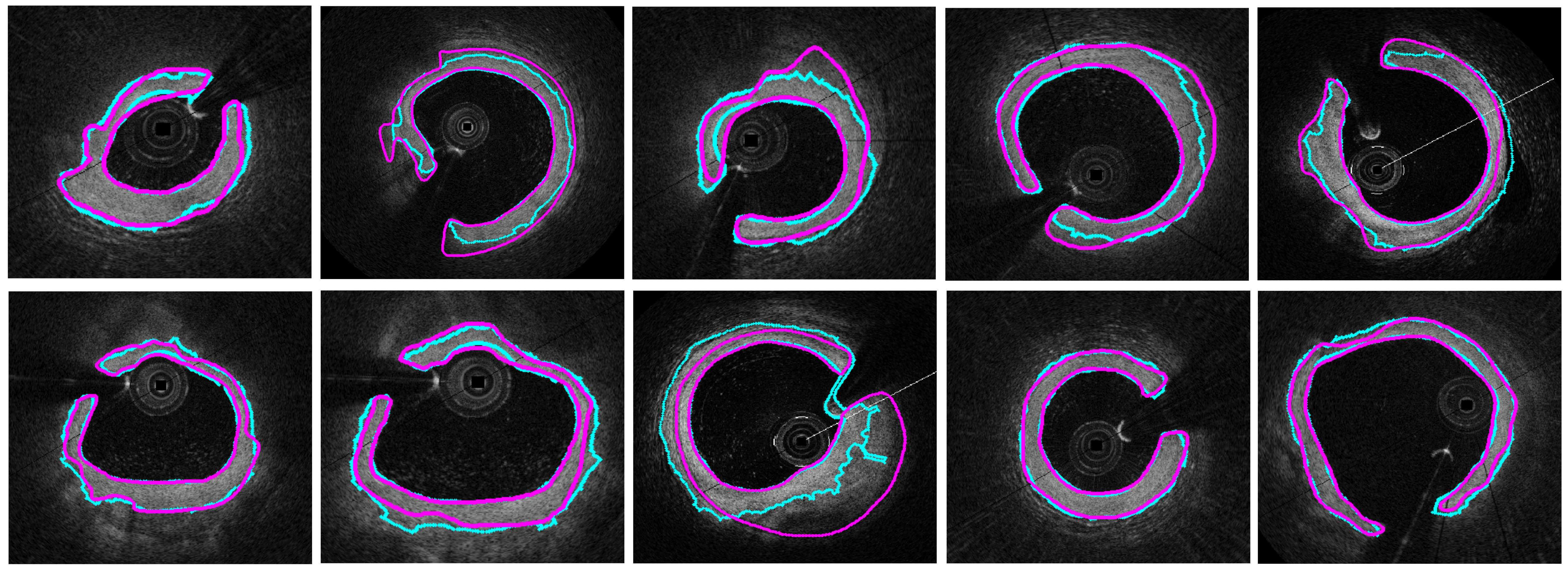
The optimization method FROLS finds a set of best features and their respective weights for a linear combination. If the linear combination has a value ≥ 0.5 for a given pixel, considering the range $[0, 1]$, it is labeled as fiber.

Results

In total, 40 2D images from 9 patients were used, 6 IOCT frames for the training phase and 34 for testing. The fibrous area was obtained without any user interaction. The Table below shows all evaluation metrics of the proposed automated method.

Evaluation of automated fibrous tissue identification for 34 frames.

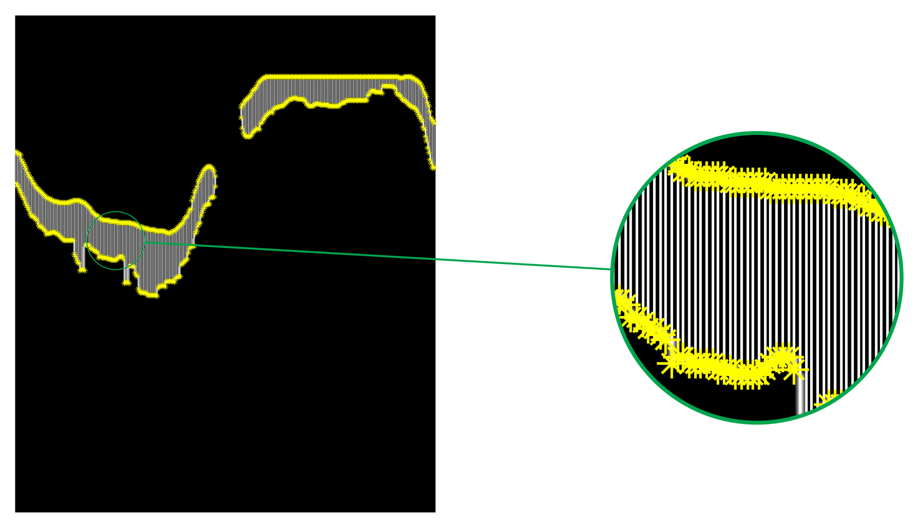
RMSSSD(mm)	DICE(%)	MADA (mm^2)	S (%)	SPE(%)	ACC (%)	H (mm)
0.13	76.3	1.1	79.9	98.6	97.4	0.40



Segmented IOCT images showing fibrous tissue area with automated method in cyan and the manual segmentation in magenta.

Quantification

In the IOCT images, the fibrous tissue thickness is defined as the distance from the internal border of the signal-rich layer, nearest the lumen, to the internal border of the signal-poor middle layer or to the internal border of the signal-poor region in the case of lipid pools or calcium plaques.



IOCT frame in polar coordinates showing automated identification of fibrous tissue (yellow) and distance between inner and outer contour (white).

Validation

The evaluation of the fibrous tissue segmentation method was based on manual segmentation by an expert. A set of seven metrics was used to measure the accuracy of the proposed automated method for fibrous tissue identification.

Discussion

A limitation of the frequency analysis in this study comes from choosing a small window to optimize spatial resolution and select pixels within a single region, which limits the number of frequency bins for the Fourier transform.

Ughi et al. [4] developed an automated tissue characterization reaching an accuracy of 89.5% for fibrous tissue, which is lower than our method (97.4%). But Athanasiou et al. [5] developed a method using K-means and achieved 87% and $0.09mm^2$ for sensitivity and MADA respectively, whereas we obtained 80% and 1.1mm^2 for these measures.

References

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[2] S. Qian Joint Time-frequency Analysis: Methods and Applications In *PTR Prentice Hall, 1996* isbn=0132543842

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[4] G. Ughi, T. Adriaenssens, P. Sinnaeve, W. Desmet, J. D'hooge. Automated tissue characterization of in vivo atherosclerotic plaques by intravascular optical coherence tomography images In *Biomedical Optics Express, 2013*

[5] LS. Athanasiou, et al. Methodology for fully automated segmentation and plaque characterization in intracoronary optical coherence tomography images In *Journal of Biomedical Optics, 2014*