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University of Southampton

Spatial orientation of microstructural features from 3D images of biological soft tissues

Aim

To develop an algorithm for determination of fiber orientations from 3D image datasets and present orientation data as a 3D vector field (in Mathematica)

Motivation

- Collagen fiber orientation provides an indication of the functionality and performance of the tissue. For example – skin wrinkling with age can be predicted using changes in the fiber density and orientations.
- A potential biomarker for diagnosing diseased tissues, assessing response to treatments, localizing injuries or monitoring engineered tissue development. For example – Osteoarthritis can be identified in early stages by detecting damage in collagen network.

Background

Orientation of fibers in 2D images are well studied and successful methods have been developed. Usually, these involve Fourier transforms, Hough transforms or Gradient filters.

3D orientation determination is a comparatively new area and not so well studied. Some of the existing methods include:

- Gaussian Orientation Space filters
- Fourier Transform of SHG images (Filter Bank method)
- Principal Component Analysis (Structure tensor, moment of inertia tensor)
- Weighted Vector Summation

Weighted vector summation is one of the latest methods (2015) and outperforms most other methods according to its author. This is used as the comparison point.

Overview of process

Image acquisition → Image Pre-processing → Binarization → Orientation algorithm → Output: 3D Vector Field

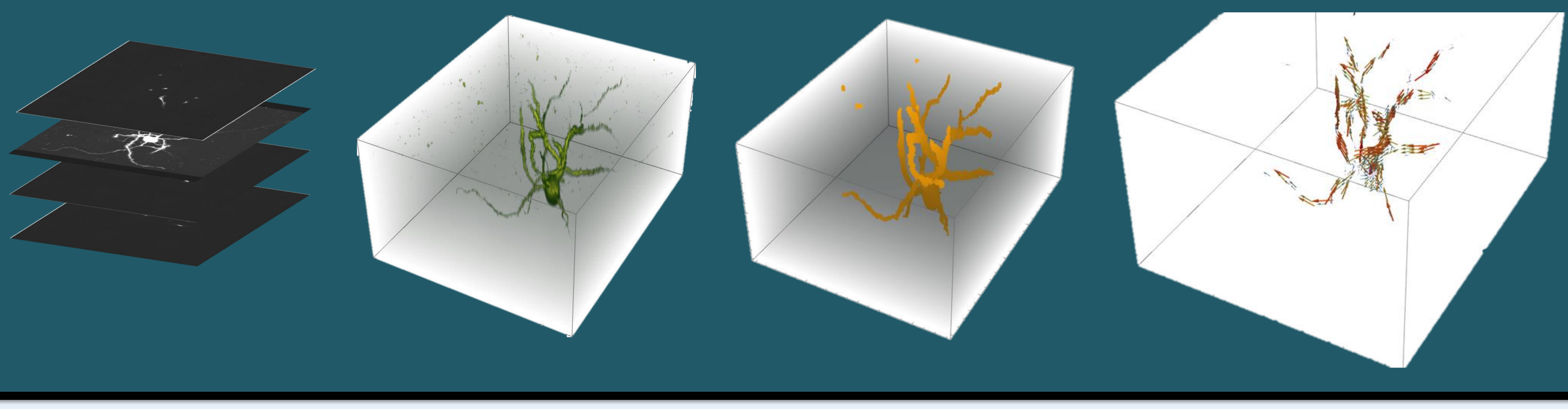
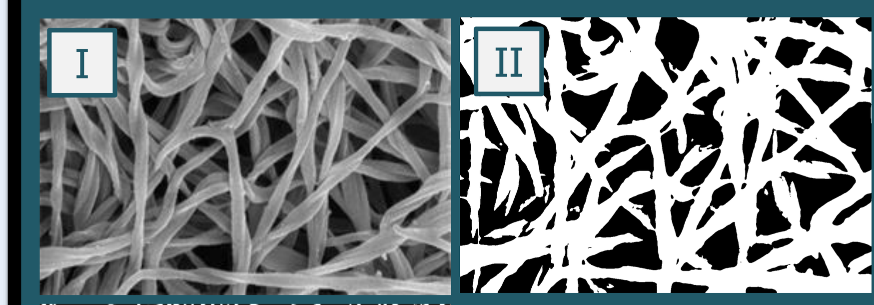


Image processing

- Noise filtering
- 3D Image construction
- Edge Detection: Canny, Sobel filters
- Binarization : Otsu's Global Thresholding, Hysteresis



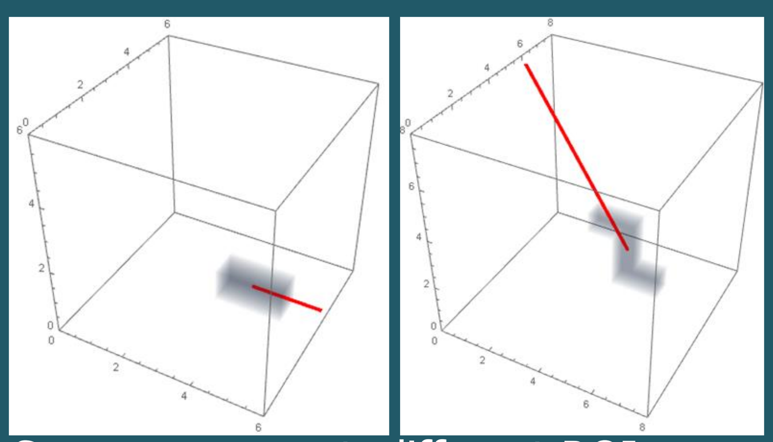
I: Original image
II: Hysteresis, Otsu's
III: Canny edge detection

Proposed Algorithm

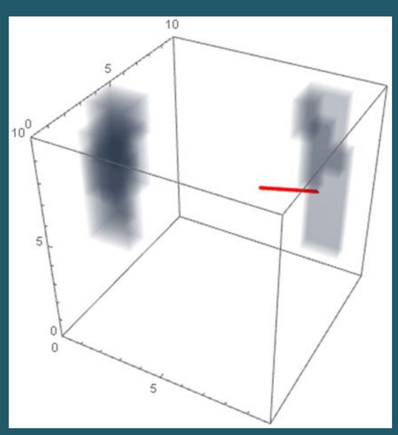
- Based on Principal Component analysis of Moment of Inertia Tensor
- Binarized image divided into smaller sub volumes (Regions of Interests - ROIs) and orientation found within each ROI

Features :

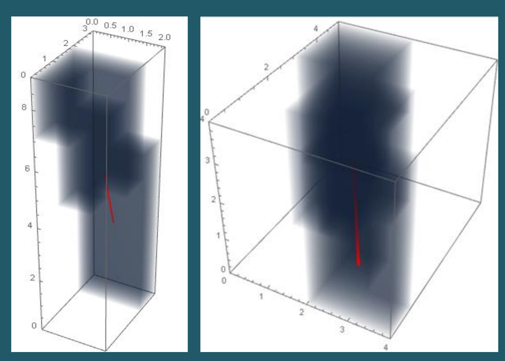
- Averages vector fields obtained from different ROI sizes (multiple passes)
- Checks for disconnected components and divides ROI further if needed
- Ignores fully white and fully black ROIs and perfectly cubic components in ROIs
- Does not iterate through all pixels. Assigns same vector to white pixels in a ROI
- Applies Mean or Gaussian filter (with small radius) to smoothen the vector field



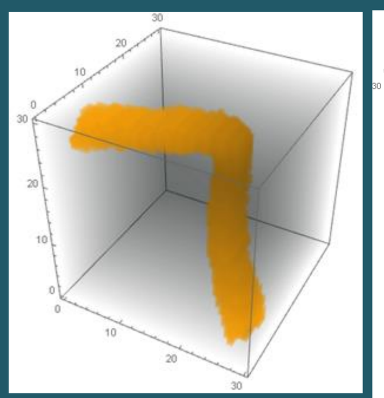
Same component, different ROI windows



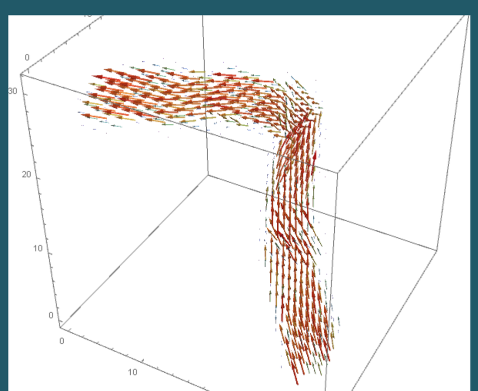
Disconnected components in ROI



Further dividing ROI

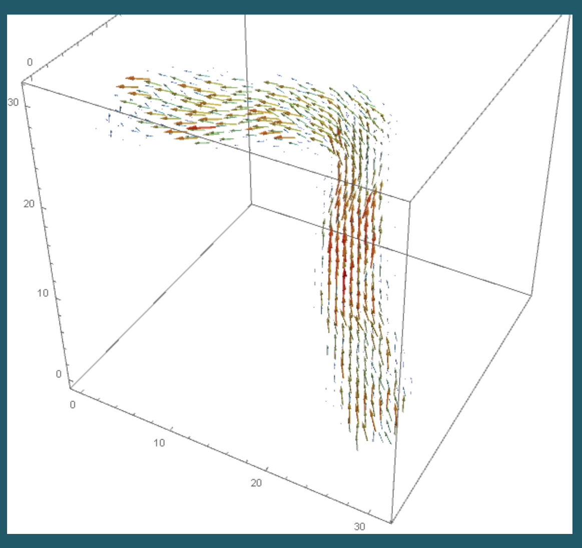


Original image



Single ROI size 6x6x6

Average of multiple ROI sizes and mean filtered



Conclusion

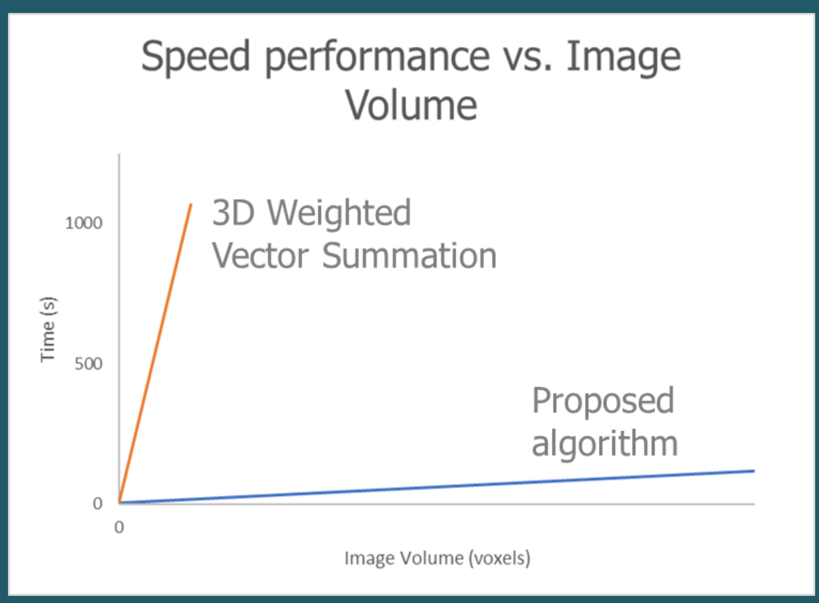
- The proposed algorithm outperformed weighted vector summation both in terms of speed performance and accuracy *

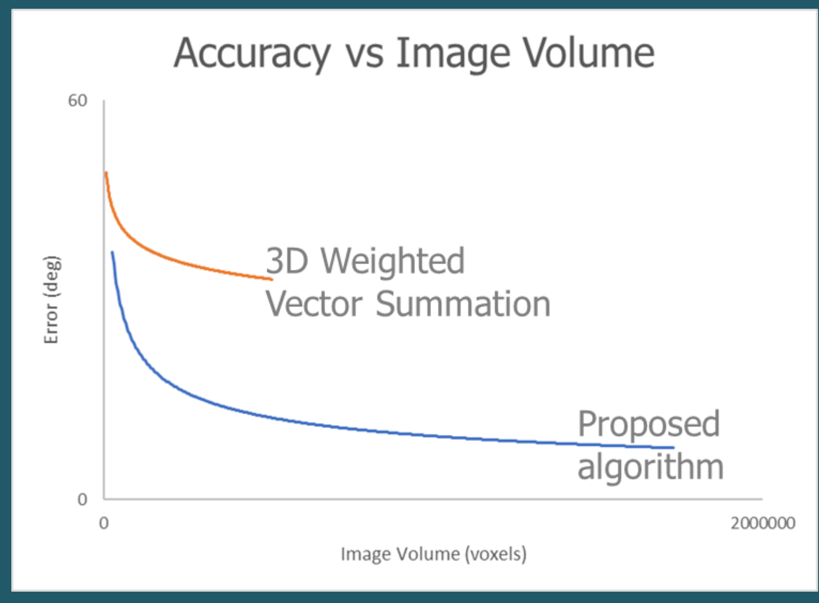
Further research/improvement opportunities:

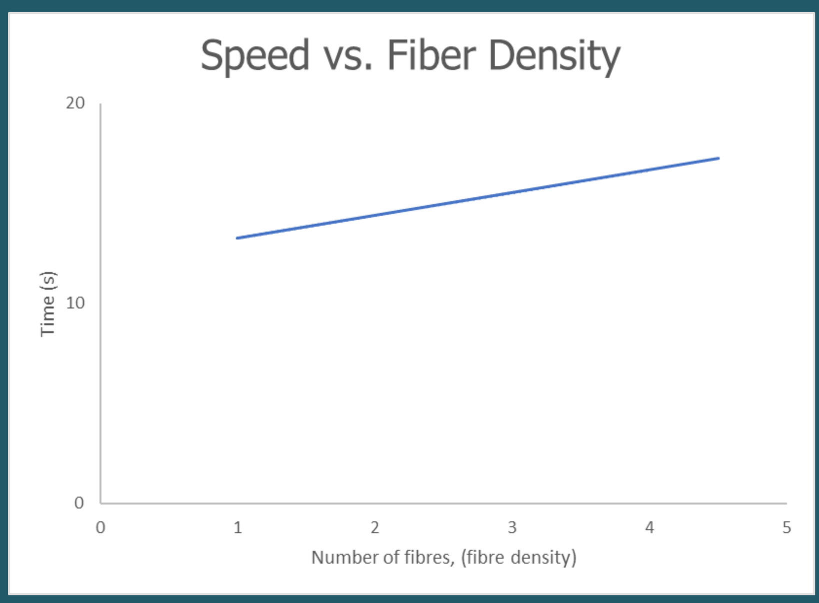
- Resultant 3D vector field could be used in a FEA study to fully appreciate a use case and refine algorithm.
- Optimizing current implementation for performance through parallelization
- Application of algorithm on larger datasets (compare with known orientations)
- Integration with other software systems for improved workflow.

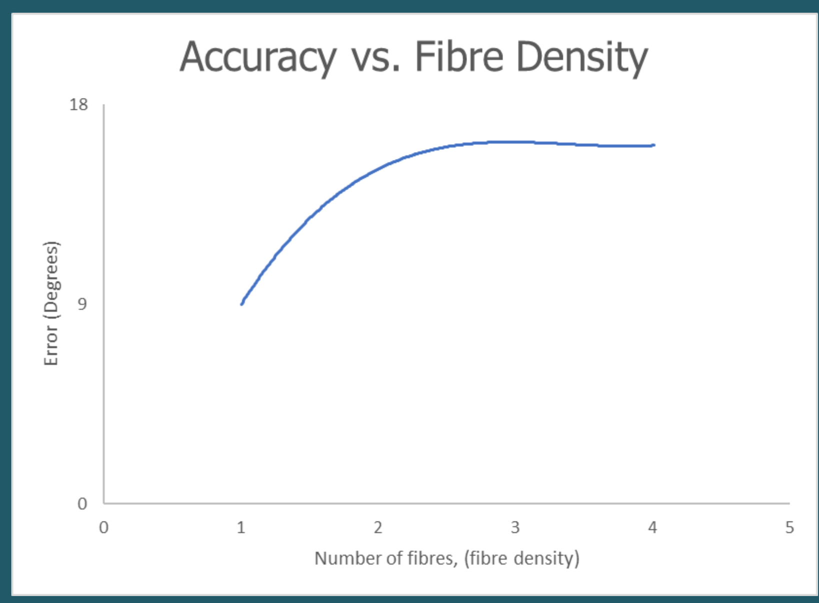
* The implementation of vector summation method in this study did not use parallelization (as intended by its author) and hence its speed performance can be improved drastically

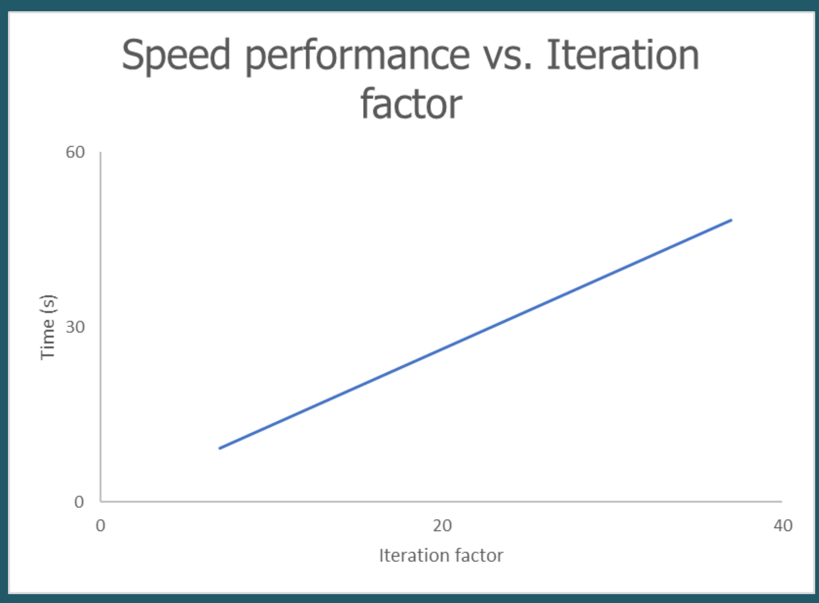
Analysis/Results

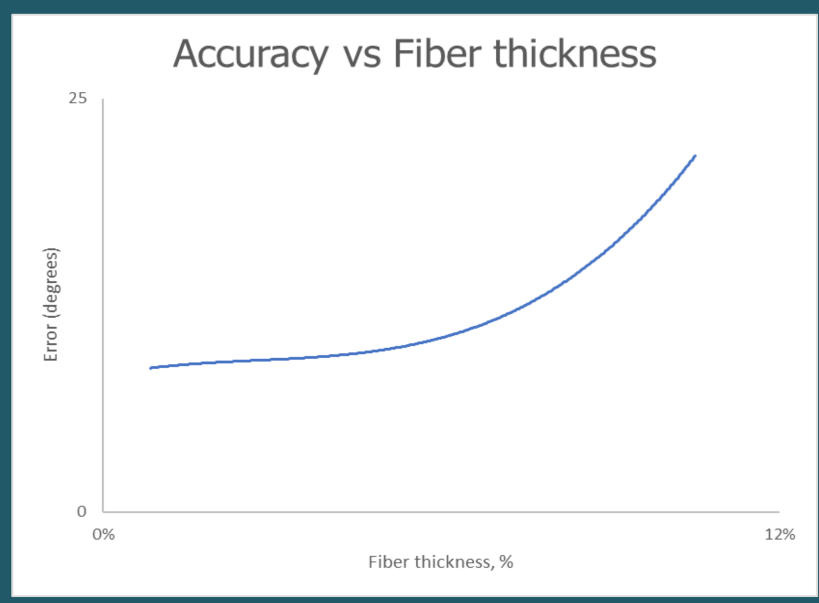




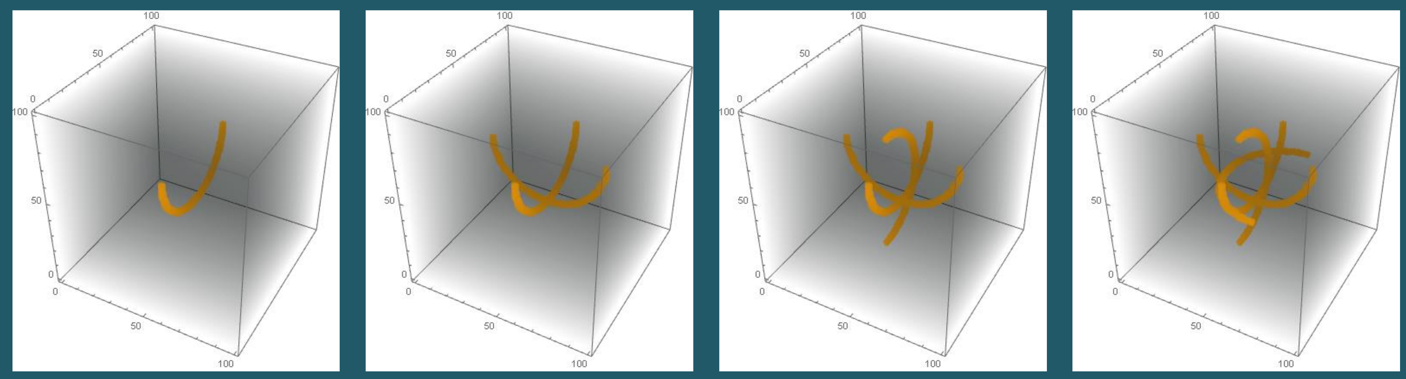








Example computer generated images used for analysis



Ankur Sharma, 27566137, Supervisor : Dr. Georges Limbert, 2018

Key References: **[1]:** M. P. B. Petrou, Image Processing: The Fundamentals, Chichester: John Wiley & Sons Ltd, 1999, pp. 1-323, **[2]:** Z. Liu et al, "Rapid three-dimensional quantification of voxel- wise collagen fiber orientation," J. Biol. Chem. Science Acad. Sci. U.S.A. J. Miner. Met. Mater. Soc. Biomech, vol. 277, no. 3910, pp. 4223-4231, 2002., **[3]:** M. Martone and E. Bushong, Mouse BIRN test data, Cell Image Library, 2001. **[4]**: X. Bi et al, "A novel method for determination of collagen orientation in cartilage by Fourier transform infrared imaging spectroscopy (FT-IRIS)," OsteoArthritis and Cartilage, vol. 13, pp. 1050-1058, 2005. **[5]:** A. Miettinen, "Characterization of three-dimensional microstructure of composite materials by X-ray tomography X-Ray computed micro-and nano-tomography of metamorphic fabric analysis View project," 2016.