Integral Geometry Descriptors for Characterizing Emphysema and Lung Fibrosis in HRCT Images

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Abstract

Integral geometry descriptors (**Minkowski functionals**) are used to characterize local textural properties of lung parenchyma from HRCT images. They describe the **morphology** & **topology** of 2D and 3D binary structures, and have been shown to be effective in describing properties of complex and disordered media.

We propose their use for detecting and grading emphysema and fibrosis in HRCT images. We present some illustrative results and make proposals for their use in a larger validation study.

Minkowski Functionals: Definition

Defined on sets in 3D space. They are proportional to [4]:

- **Volume** V
- **Surface Area** S
- **Mean Breadth** B: a measure of average width
- **Euler-Poincaré Characteristic** χ: Connectivity number = # connected components −# tunnels +# cavities

Minkowski Functionals: Properties

Fundamental role over certain functions of **binary images**

- **All** Real-valued, additive, isometry invariant, continuous functions on a compact 3D binary image A are of form

$$\sum_{i=0}^{3} \alpha_i W_i(A)$$

  where the α_i are **constants** and the W_i are the **Minkowski functionals**.
- Are themselves **additive**: for K_1, K_2 compact parts of a 3D image

$$W_i(K_1 \cup K_2) = W_i(K_1) + W_i(K_2) - W_i(K_1 \cap K_2). \quad (1)$$

- Are themselves **isometry invariant**: do not change their value under rotation or translation.
- Can be extended to the **interior** of compact set K by

$$W_i(K^\circ) = (-1)^{3+i+\dim K}(W_i) \quad (2)$$

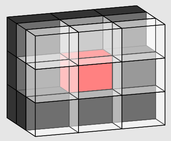
Finding Functionals

Finding functionals reduces to **counting** cells, faces, edges and vertices of image seen as collection of cubic voxels.

- The Minkowski functionals for a cube, rectangle, line and vertex all **known analytically**.
- $\Longrightarrow$ can use (1) and (2) repeatedly to find:

$V = n_3$	n_3: # voxels
$S = -6n_3 + 2n_2$	n_2: # faces
$B = 3n_3/2 - n_2 + n_1/2$	n_1: # edges
$\chi = -n_3 + n_2 - n_1 + n_0$	n_0: # vertices

- To find n_i We use the **Algorithm of Equations** [1], where the faces, edges and vertices of the voxel (light red) counted assuming the 13 adjacent voxels (black) already counted.

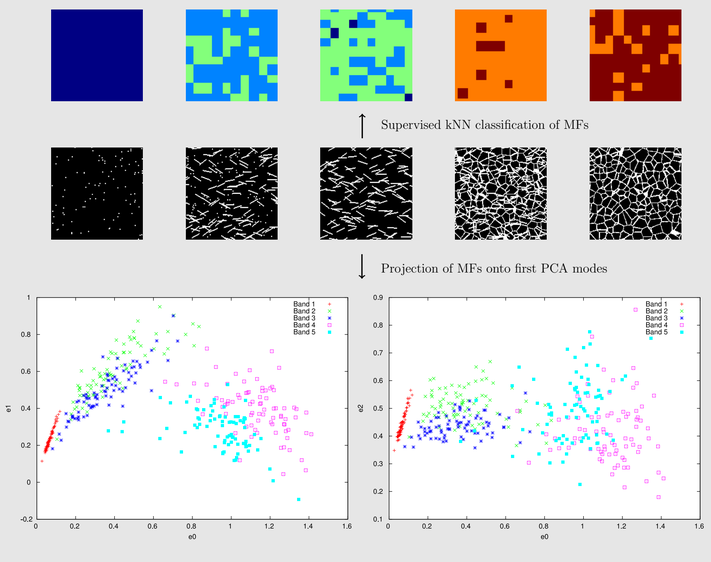


- To describe **heterogeneity** functionals are found on **windows** of fixed size over the 3D image

Results: Synthetic Model

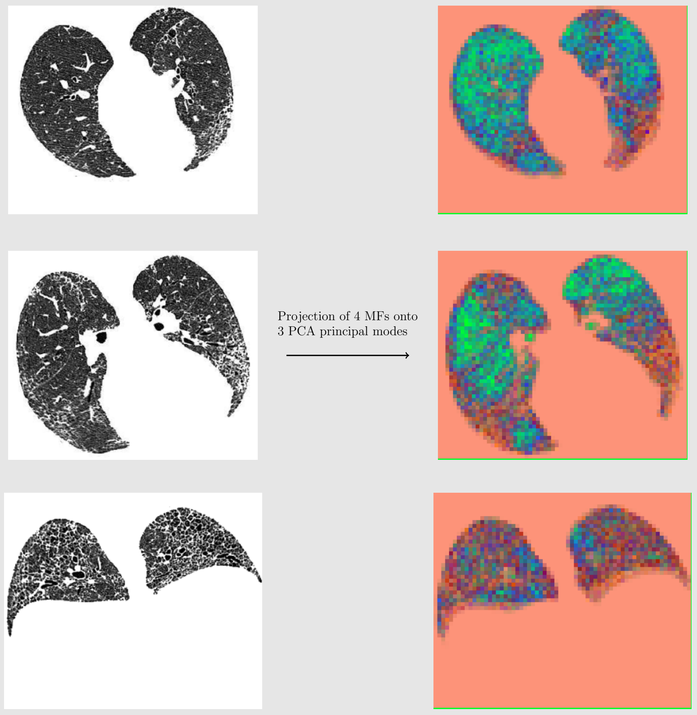
Models, left-to-right: healthy, fibrotic and honeycomb.

- Based on **Boolean model** and **Voronoi tessellation**. [4]



Results: Lung Data

Functionals found on **thresholded in-vivo** lung HRCT scan.



Conclusion

Promising results: Minkowski functionals do appear to **separate tissue types**.

- Larger validation study required.
- More advanced probabilistic model development needed.
- Work concurrent to, but independent from, Boehm et al. [2, 3].

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