Multiple hypothesis tracking based extraction of airway trees from CT data
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Using statistical ranking of template-matched hypotheses

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Abstract
Segmentation of airway tree from CT scans of lungs has important clinical applications, in relation to the diagnosis of chronic obstructive pulmonary disease (COPD). Here we present a method based on multiple hypothesis tracking (MHT) and template matching, originally devised for vessel segmentation, to extract airway trees. Localized tubular templates are constructed and ranked using scores assigned based on the image data. Several such regularly spaced hypotheses are used in constructing a hypothesis tree, which is then traversed to obtain improved segmentation results.

Introduction
COPD is a leading cause of mortality worldwide, characterised by:
- Distortion of the lung tissue (emphysema)
- Morphological changes to the airways

Objective: Develop segmentation methods, with improved specificity and sensitivity, to study morphological changes of airway trees from CT.

Existing methods:
- Airway tree segmentation is a challenging problem
- Most methods try to strike a balance between specificity and sensitivity.
- Room for improvement on both fronts
- Single hypothesis / greedy algorithms
  - Inconsistent decisions
  - Only the best hypothesis is propagated
  - Sensitive to noise
  - Highly local solutions

MHT-based methods

Idea: Defend decision at current step to a future step. Meanwhile, maintain all hypotheses.

Multiple hypothesis tracking (MHT)

Philosophy: Delay decisions. Use more data. Benefit from hindsight.

- Widely used in multi-target tracking [5]
- Deferred decision based on more data
- Several hypotheses are maintained
- Search depth controls the size of tree
- Trade-off between optimality, tractability

A tracking perspective to segmentation
- Prediction by regularly spaced guesses
- Image data is used to update the guesses

Template matching-based MHT
Method based on [1], proposed for tracking small vessels.
- Designed to track small tubular structures
- Uses a scale-dependent score threshold
- Semi-automatic

Model
- Probability images obtained from trained KNN classifiers (k = 21), airways (p = 1)
- Method in [1] is modified, while retaining the image model:

\[
\text{image} \propto \text{contrast*template + mean + noise}, \quad \text{or} \quad \hat{v} = \{\text{contrast} \cdot \langle \text{template} \rangle + \langle \text{mean} \rangle + \langle \text{noise} \rangle \}\]  

- Template function (T) used to map probability variations to a profile function (p)

\[
T(x, x_0; \hat{v}) = \frac{1}{(\sqrt{2\pi} \sigma)^{d^2/2}} \exp\left(-\frac{1}{2} \frac{d(x, x_0; \hat{v})^2}{\sigma^2}ight)
\]

\[
d^2 = \text{minimum squared distance between } x \text{ and line along } \hat{v} \text{ through } x_0, \quad \gamma = 8
\]

Constructing the hypothesis tree
- Fixed number of guesses are generated
- Guesses are 3D templates based on parameters from previous step.
- Corresponds to the “prediction” step.
- Predictions are “updated” by solving the weighted minimization problem:

\[
\min_{\hat{v}} \left( W(x, x_0; \hat{v}) + 
\frac{1}{2} \sum_{j=1}^{c} \left| \frac{1}{C_{\text{op}/j}} - \frac{1}{C_{\text{rg-int}/j}} \right| \right)
\]

W is the weighting matrix.

Handling branching
- Spectral clustering is performed
- If two clear clusters are observed, best hypothesis within each is propagated as a new branch.

MHT allows for improved tracking decisions, as tracking solutions are not local.

Method in [1] has been modified to extract airway trees.

Results
Data & Experiments
- Single seed point automatically placed at the origin of trachea; thus fully automatic
- Set of 32 images split into training, test sets
- Danish Lung Cancer Screening Trial data used [2]
- Probability images from KNN classifier

Centers of segmentation results are compared with reference segmentations, to quantify estimation error:

\[
E_n = \sum_{i=1}^{n} \min_{j=1}^{c} \left| \frac{1}{C_{\text{op}/j}} - \frac{1}{C_{\text{rg-int}/j}} \right|, \quad d_{\text{op}} = \text{Euclidean distance}
\]

Conclusions
- MHT improves tracking decisions, as tracking solutions are not local.
- Method in [1] has been modified to extract airway trees.
- Ranking based scheme is more suitable for extracting airways, where structures of varying dimensions are observed.

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References