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Therapy Educational Course - PET Imaging for Radiation Treatment Planning and Therapy Response Assessment

PET Image Segmentation for Radiation Therapy

Handout
(images available upon request)

Assen S Kirov, Ph.D
Department of Medical Physics
Memorial Sloan-Kettering Cancer Center
New York

PET auto-segmentation

I. Types of PET segmentation tasks
- Treatment planning: a) segmentation ; b) dose painting
- Treatment Assessment
- New PET tracer Evaluation

II. Classifications and examples

III. Limitations: PET image specifics, inaccuracy and uncertainties

IV. Challenges for contour evaluation

Image segmentation is a two stage process

- Recognition
  - a high level process
- Delineation
  - a low-ER level process

Udupa *et al,* A framework for evaluation of image segmentation algorithms, Computerized Medical Imaging and Graphics, 30, (2006) 75-87

Deficiencies of manual PET Segmentation

- Large intra and inter- observer variation
- Image windowing
- Time consuming

Classifications of PET auto-segmentation methods

Classification of Zaidi & El Naqa, EJNM 2010
- Thresholding:
  - fixed and variable threshold
- Variational:
  - region growing, level sets, gradient, active contours
- Learning: supervised (classif.) or unsupervised (clustering)
  - K-means, fuzzy C-means
- Stochastic:
  - Expectation maximization (EM); EM + spatial dependence
- Other: - "Quantitative analysis In Nuc. Med. Imaging", Ed. Zaidi, H, Springer, 2006;
  - J. Lee, Radiotherapy & Oncology, 96, p.302, 2010

1. Fixed threshold

- 40 % of Peak Activity (or 36 to 44 %), *Erdi et al, 1997*
- 50% Mah *et al*, IJROBP 2002,
- 40% Bradley *et al, IJROBP 2004*
- SUV = 2.5 , Paulino *et al, IJROBP, 2005*
- ..

Biehl et al 2006 (J. Nuc. Med. 47, 1808) : "No single threshold … provides accurate volume definition.."

2. Adaptive threshold methods

- *Black et al, IJROBP 60(4), p 1272, 2004 :*

T_{SUV} = 0.307 x (mean target SUV) + 0.588

optimized for their scanner and procedures !

- *Nestle et al, J N M, 46 (8) p. 1342, 2005 :*

$I_{threshold} = (0.15 \times I_{mean}) + I_{background}$

optimized for their scanner and procedures !

…

- *Nehmeh et al, Med. Phys. 36, p.4803,2009 :*
  - Iteratively find a point on the correlation between threshold and volume

optimized for their scanner and procedures !

….

Such methods may need re- adaptation and adjustment if used on a different scanner or protocol !

3. Advanced methods: customization also required, more or less

- Gradient based:
  - Geets *et al, 2007*; … ,SNM 2010: Nelson et al, abstract # 24 , Yang C, abstract # 28
  - Region growing: Li *et al*, *2008;* Day *et al*, *2009, …*
- Statistical:
  - K- Means clustering
  - Markov Models, Montgomery *et al, 2007,* Hatt *et al, 2007*, …
  - Stochastic, Hatt *et al*, *2008,* Dewalle-Vignion *et al, 2011…*
  - Textural, Yu *et al, 2009; … ,* Maroy *et al,* SNM 2010, abstract # 23
  - …
- Combination: artifact correction + segmentation
  - De Bernardi *et al, Med. Phys. 2009,*
  - Bhatt *et al,* SNM 2010, abstract # 1290

Factors affecting PET Accuracy

- Biological - glucose level, inflammation, patient comfort (stress), motion..
- Physical - positron annihilation physics, detector limitations, reconstruction,
- Technical - activity specification, administration, time of injection, …

Boellaard R, J Nucl Med, 2009, 50, p. 11S-20S

Effect of the main physical PET artifacts on segmentation accuracy

Factor	Effect on segmentation
PET Resolution	Smearing; threshold depends on object size
Attenuation	Shifts and artifacts => relative voxel intensities
Photon Scatter	Local intensities after attenuation correction
Reconstruction	OSEM: Ringing artifacts; iteration number; filters
Registration and motion	Attenuation artifacts, and scatter artifacts

Evaluation criteria for segmentation algorithms

- Accuracy (validity)
- Precision (reliability)
- Efficiency (viability)

Udupa *et al,* A framework for evaluation of image segmentation algorithms, Computerized Medical Imaging and Graphics, 30, (2006) 75-87

- Robustness

Hatt *et al,* 2011, 'PET functional volume delineation: a robustness and repeatability study', *Eur J Nucl Med Mol Imaging*, vol. 38, no. 4, pp. 663-72.

Challenges in contour evaluation TG211:

- Experimental images
  - Simple phantoms - unrealistic
  - Realistic phantoms - expensive
  - Patients - ground truth
- Simulated images
  - Monte Carlo simulated - expensive
  - Analytically simulated - approximate

Selection of evaluation criteria
TG211:

- Unknown ground truth
  - Dice similarity index ~N(overlap) / N(mean)
- Known ground truth
  - Classification Error ~N(incorrect) / N(true)
  - Sensitivity ~N(correct) / N(true)
  - Positive Predictive Value ~N(correct) / N(predicted)
- The ground truth has associated uncertainty:
  - Reversed-AUC, Shepherd T *et al*, Segmentation challenge, Univ. of Turku, May 2011

Summary: PET image segmentation for RT

A. Auto - segmentation methods

- Potential use as an initial approximation for physicians

- Need robustness to non-uniform activity irregular shape tumors => advanced methods

- Imperative evaluation and validation for each PET scanner model and protocol

B. Both Manual and Auto – segmentation

- Depend on segmentation task

- Limited by the physical and biological uncertainties of the PET images

Mc. Manus *et al*, Letters to the Editor,
Int. J. Rad. Onc. Biol. and Physics, 60 (3) 2004:

- "We do not have answers to these questions but are wary of simple numerical class solutions that tend to simplify a very complex problem to a level where frequent exceptions could be made"

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AAPM TG 211

Caldwell, Curtis, Ph.D.
Das, Shiva, Ph.D.
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Geets, Xavier M.D.
Gregoire, Vincent, M.D.
Hatt, Mathieu Ph.D.
Jeraj, Robert, Ph.D.
Lee, John, Ph.D.
Lu, Wei, Ph.D.
Nelson, Arden, Ph.D.
Nestle, Ursula, M.D.
Schmidtlein, C. Ross Ph.D.
Schöder, Heiko M.D.
Shepherd, Tony, Ph.D.
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