Abstract

High $b$-value diffusion-weighted imaging is a promising approach for diagnosing and localizing cancer in the prostate gland. Due to hardware limitations, an alternative approach is computed diffusion-weighted imaging, which allows for estimation of ultra-high $b$-value images from a set of diffusion-weighted acquisitions with different magnetic gradient strengths. This paper presents a quantitative investigative analysis of the improvement in tumour separability using ultra-high $b$-value computed diffusion-weighted imaging.

Introduction

- There were 913,000 new diagnoses of prostate cancer globally in 2008
- Localization of prostate cancer is particularly important for treatment using minimally-invasive focal therapy technologies

Problem

- Diffusion-weighted imaging (DWI) can be used to differentiate between healthy and cancerous tissues in the prostate gland using a diffusion gradient (with specific $b$-value)
- Prostate tumour identifiable in diffusion weighted images with a high $b$-value
- Due to hardware limitations, difficult to achieve high $b$-value at a high signal-to-noise ratio

Objective

To investigate and quantify the benefits of ultra-high $b$-value computed diffusion imaging for prostate cancer detection.

Computed Diffusion-Weighted Image Methodology

- ADC value ($A$) for a particular voxel is estimated using a set of diffusion-weighted images measured with different $b$-values ($b_i$ and $b_\alpha$)
  
  \[ S_i = S_\alpha e^{-(b_i-b_\alpha)A} \]

- If a collection of DWI images ($S$) is used, the ADC estimate is formulated as a Bayesian estimation problem
  
  \[ \hat{A} = \arg \max_A P(S|A) \]

  where $P(S|A) \sim N(S_\alpha e^{-(b_i-b_\alpha)A}, \sigma^2)$

- The ADC estimate $\hat{A}$ can be used to compute diffusion-weighted images $S_i$ at any desired $b$-value $b_i$
  
  \[ S_i = S_\alpha e^{-(b_i-b_\alpha)\hat{A}} \]

Experimental Results

Expected Probability of Error

Fig. 1: The expected probability of error curves suggest improvements for a wide range of $b$-values past 1500, with an optimal choice in the neighbourhood of 3000.

Example Patient Case

- Fig. 2: Patient case showing observed diffusion-weighted images for lower $b$-values and computed diffusion-weighted images for higher $b$-values
  
  Computed $b=3000$  Computed $b=4000$

Fig. 3: Receiver Operator Characteristic curve for the patient case showing good classification for higher $b$-value computed diffusion-weighted images

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