The Significance of Heterogeneity in Multi-Modal Medical Imaging

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ABSTRACT

Heterogeneous features have been observed in clinical PET-CT and PET-MRI imaging of tumors. The biological significance of this heterogeneity is not well understood but may have prognostic value for clinicians. To advance understanding of this parameter, an investigation of the inherent heterogeneities of PET imaging will be performed using known homogeneous subjects. Once the inherent heterogeneities of the imaging processes are characterized, further investigation will introduce known heterogeneous features to determine their imaging characteristics. It is anticipated that the results of this work will be used to characterize heterogeneous tumors imaged in human patients.

RESULTS

In the original paper, PET images consisted of 48 shades of gray. However, most machines output 12 or 16-bit images, corresponding to 4096 or 65536 shades of gray, respectively. To account for this large magnitude difference, a simple normalization is required.

In the equation:

\[ \zeta' = \frac{\zeta}{2^{\text{Bit Depth}}} \]

This metric was also cited as size-invariant, yet an obvious size dependence emerged, chiefly due to the magnitude difference. Illustrated below, the phantom in figure 3 was scanned on both PET-CT and PET-MRI and, in both cases, an increase in ROI size was followed by an increase in heterogeneity, regardless of attenuation correction. To further illustrate this phenomenon, a simulation of circular phantoms with set levels of noise and varying radii were measured for heterogeneity, with results showing the same trend.

DISCUSSION

This metric for quantifying heterogeneity was intended to be size-invariant and to correspond strongly with qualitative assessment from experienced radiologists and physicians. While the size-invariance proved to not be the case with current imaging technology, these methods match very well with observational assessment. In every test, images with higher degrees of randomness, both in pixel-intensity and shape, showed higher heterogeneity.

Between PET images from PET-CT and PET-MRI, the largest functional difference lies in the attenuation correction. Data taken using the same phantom on both machines shows large variation, especially for smaller ROI. However, not enough data has been gathered to delineate a discernable trend.

METHODS

A simple iterative technique has been developed to quantitatively define heterogeneity.[1]

This method involves isolating the region of interest and performing a calculation of average inter-pixel intensities across the entire ROI. These values are grouped by length and integrated, and resulting value is the heterogeneity factor.

\[ I_{\text{ROI}} = I_w + \frac{L-I_w}{L-I_{\text{ROI}}}, \quad \Delta r = \frac{1}{L} \sum |I(r_{\text{ROI}}) - I_w| \]

\[ \zeta = \frac{\Delta r}{L} = \frac{1}{L} \sum \frac{|I(r_{\text{ROI}}) - I_w|}{L} \]

This metric was tested on known homogeneous and known heterogeneous images, either from phantoms or simulated data, and the results were assessed for validity.

INTRODUCTION

Tumor heterogeneity has always been a large roadblock for medical treatment due to its effects on metabolic activity, tumor structure, and general unpredictability. Due to the random nature of cancer growth, tissues with vastly different properties can exist within the same lesion, resulting in an overall heterogeneous image. In addition to this biological heterogeneity, a large number of intrinsic inhomogeneities can be imparted onto an image from the machine itself.

Previously, image heterogeneity has largely been described qualitatively. The goal of this project is to establish a meaningful quantitative metric for measuring heterogeneity.

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REFERENCES