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Novel 3D Approximate Entropy parameter for Quality Assessment of CT/CBCT Images

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Purpose

To investigate Approximate Entropy (ApEn) as a single parameter describing the degree of structural information in noisy IGRT data sources such as cone-beam CT (CBCT). ApEn is a regularity statistic previously applied to 1D time series data, and capable of distinguishing degrees of regularity versus randomness [1]. It overcomes the limitations of traditional, variability-based statistics and has proved useful in monitoring individuals and identifying group characteristics for heart rate variability and speech perturbation after cancer treatment [2].

In this work we present a new extension of the ApEn concept to three dimensions ($ApEn_{3D}$), allowing ApEn to be calculated for an ROI centred on each voxel in a 3D image dataset. It is hypothesized that $ApEn_{3D}$ may prove useful in measuring image quality of medical images by mapping the spatial variation of regularity vs. randomness (i.e. the prominence of useful image information such as edges or regular textures).

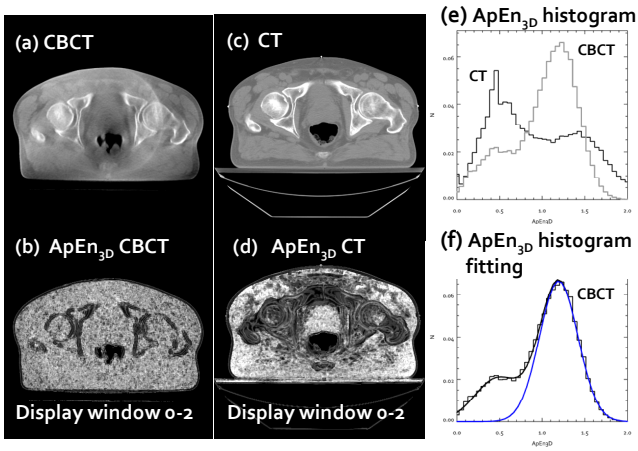

Figure-1: Pelvis CBCT and CT before and after $ApEn_{3D}$ processing.

Methods

In 1D, ApEn can be described as the likelihood that runs of data that are similar over a certain comparison length, and remain similar when the comparison length is increased. In 3D we interpret "runs of data" centred on a specific voxel as expanding outwards from the central voxel, rather than being defined in a particular vector direction through the data. The second element of a run is then comprised of the 26 surrounding voxels (first rim), the third element consists of the 98 voxels in the second rim, and so on. Runs are compared by considering the mean of the absolute differences between the corresponding voxels of each element. $ApEn_{3D}$ processing was applied to CT & CBCT images for pelvis and head & neck sites. This produces an $ApEn_{3D}$ value at each voxel of the image, which reflects the degree of regularity in the image data around that point. Areas dominated by noise have high $ApEn_{3D}$ values, while areas with simple structure (e.g. edges, regular texture) have low values. The distribution of $ApEn_{3D}$ values was compared for CT vs. CBCT images and for CBCT images acquired at different dose levels.

Results

Figure-1a-d shows $ApEn_{3D}$ processed CBCT & CT images. A histogram of their $ApEn_{3D}$ content divides into a high value peak (where noise dominates) and a low value tail (Figure-1 e). The proportion of voxels falling outside the noise peak (i.e. where structure dominates) was investigated as a quality parameter for clinical utility (figure-1f illustrates value separation for CT images). For a particular site this proportion was found to be consistently higher for CT than CBCT. In pelvic images 0.54±0.04 vs. 0.29±0.09 respectively based on 10 images from each modality. Additionally, head & neck CBCT of the same patient acquired at high vs. low dose (5.6 vs. 1.4 mGy) show a higher value for higher dose scan (0.41 vs. 0.30), see figure 2.

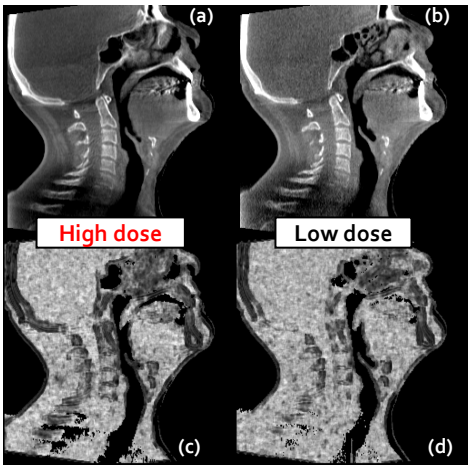

Figure 2: Head & Neck CBCT

(a) High dose
(b) Low dose.
(c/d) $ApEn_{3D}$ processed resp.
(e) Histograms of $ApEn_{3D}$

Conclusion

$ApEn_{3D}$ shows potential as a single parameter metric of clinical image quality for real-world medical image data such as those frequently encountered in IGRT. Initial results suggest modality and dose based differential capability.

References

[1] SM Pincus, "Approximate Entropy as a measure of system complexity," *Proc Natl Acad Sci USA*, 88, pp. 2297-2301, 1991.

[2] CJ Moore, K Manickam and N Slevin, "Collective spectral pattern complexity analysis of voicing in normal males and larynx cancer patients following radiotherapy," *Biomedical Signal Processing and Control*, 1 (2) pp. 113-119, 2006.

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