Automatic 3D Segmentation of Hydrogel Scaffolds Based on PBI-µCT

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Introduction

Hydrogel scaffolds are a promising biomaterial used in tissue engineering and regenerative medicine. Scaffolds can be constructed using 3D bioprinting techniques which allow for intricate architectures at the site of injury [1]. However, 3D segmentation of hydrogel scaffolds remains a challenge due to the low-density of hydrogels exhibiting poor image contrast. One promising method is to use synchrotron radiation (SR) propagation-based imaging (PBI) microcomputed tomography (µCT). This method shows the phase shift of X-rays between sample and detector with strong edge enhancement. Quantitatively, this phase shift can be calculated using phase retrieval (PR) algorithm which converts the edge enhancement into area where the X-ray propagated through the sample [2] but will reduce sharpness between across boundaries. Alternatively, image denoising, e.g., Noise2Inverse (N2I) [3], can be used to maximize the edge enhancement but does not represent the area. Thus, SR-PBI-µCT data can be processed in complementary ways. A convolutional neural network (CNN) can be trained to learn the complementary area and edge information which allow for more accurately represented result than either method alone. This provides efficient 3D segmentation without manual input or pre-existing reference.

Materials and methods

The 3D printed hydrogel scaffolds were composed of 3% w/v alginate. Scaffolds were scanned *in vitro* using SR-PBI-µCT performed at the 05ID-2 beamline at the Canadian Light Source (CLS). The X-ray energy was 30 keV, the sample-to-detector distance was 1.5 m, and the effective pixel size was 13 µm. Combining the area information from PR and edge information from N2I was accomplished by training a CNN in a U-Net architecture. The combined output was automatically segmented by applying a grey value threshold. This result was compared to a popular semi-automatic segmentation method, Biomedisa, as well as a fully manual segmentation considered to be ground truth by calculating the Dice similarity coefficient.

Results and discussion

A typical hydrogel scaffold is shown in Figure 1 which has been processed using phase retrieval, noise2inverse, and the proposed combined method. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated for each image as a quantitative measure of image quality with a greater value more advantageous for segmentation. Not only does the combined method offer the greatest image contrast, but the lost edge from PR has been recovered which allows for segmentation shown in a representative slice. The proposed method demonstrates a 6% increase in Dice coefficient to the ground truth over Biomedisa. The pink/green regions represent the over/under estimations, respectively, by each method.

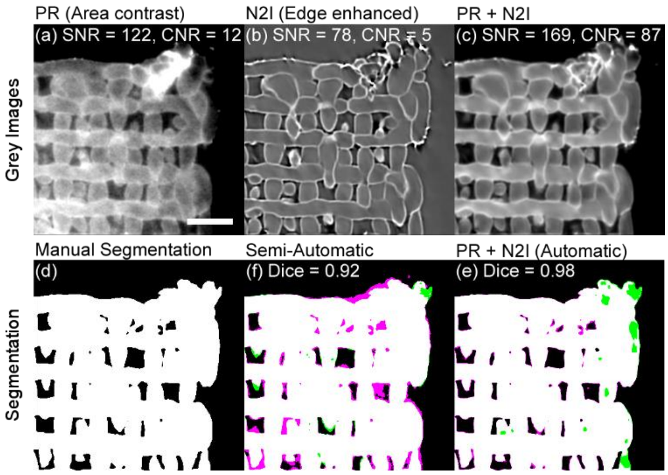

Figure 1. SR-PBI-µCT data processed using (a) phase retrieval, (b) noise2inverse, and (c) the proposed combined method. The scale bar represents 1 mm. Manual (d), semi-automatic (e), and automatic (f) segmentations with Dice coefficients.

Conclusions

The proposed segmentation method yields comparatively accurate results to existing methods without the time and attention required for manual input.

References

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