Automatic Segmentation of the Prostate On CT Images Using a Bi-Directional Convolutional LSTM U-Net with Novel Loss Function

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JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING

EASTERN TIME [GMT-4]

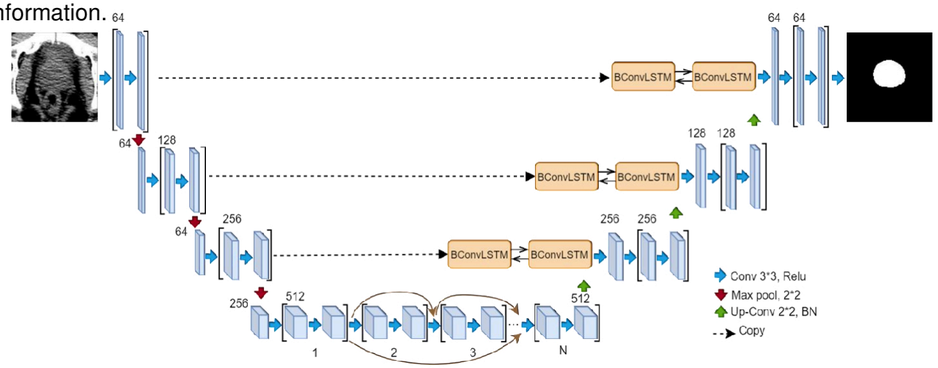
INTRODUCTION

Deep learning-based networks have achieved practical performance in the field of medical image segmentation. Here we introduce a deep neural network with an enhanced U-net architecture trained using a novel loss function to perform automatic segmentation of the prostate gland on pre-treatment planning CT images of patients with prostate cancer.

METHOD

The proposed methods incorporate two major innovative aspects:

1. An enhanced U-net architecture benefiting from bi-directional convolutional long short-term-memory (BConvLSTM) with densely connected convolutions (BCDU-Net), as an improved version of the U-Net. The advantages of proposed enhancement network can be summarized as follows: (a). It enables learning of a diverse set of feature maps instead of redundant features. (b). It improves the network's representational power by permitting information flow through the network and reutilization of feature information.

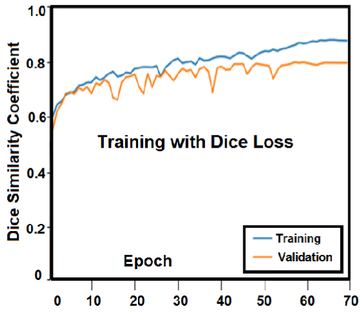


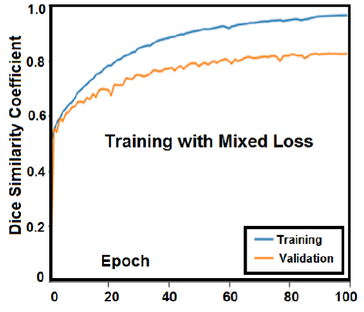
2. Training with two region-based loss functions (Focal Tversky Loss [1], FTL and Dice Loss, DSC), which are combined using weighted sum to minimize the mismatch and maximize the overlapping regions between the ground-truth and the predicted segmentation. The FTL function is especially useful in dealing with extreme foreground-background class imbalance, as is the case with segmentation of the prostate gland vs. the surrounding background due to: (a). It is flexibility in balancing false positive (FP) and false negative (FN) detections. (b). It can reduce the loss assigned to well classified example during the training while focus on hard cases with low probabilities.

Dataset: Planning-CT datasets for 100 prostate cancer patients were retrospectively evaluated as part of an IRB-approved protocol. Physician-delineated images constituted the ground-truth. Patient dataset was split into cohorts of train (55%), validate (15%) and test (30%). All images were linearly interpolated/resampled to a spatial resolution of 1×1×1.5mm. Image regions containing the cross-section of the prostate gland ($128\times128mm^2$) were used for experiments.

RESULTS

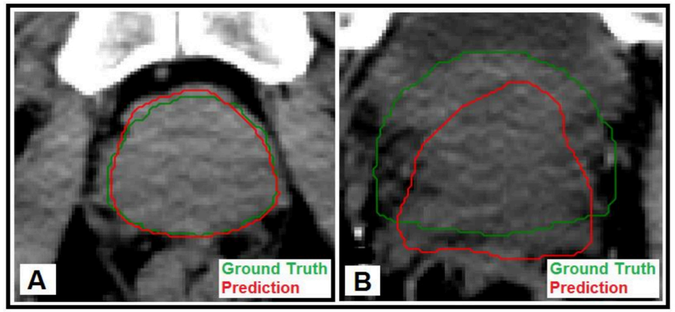
Compared to the Dice loss, our weighted combined (mixed) loss function successfully avoids potential overfitting by improving the attention and stability during the training and validation phases.





The following results support and confirm the generalizability and robustness of the proposed network for automatic segmentation of the prostate gland on CT images: Results comparing the optimal BCDU-Net (FTL+DL) and physician-generated contours for the test data were: DSC (Dice)=0.84, Area-under-receiver-operator-characteristic-curve (AUC=0.98), Area-under-precision-recall-curve (AUPRC=0.98), JSC (Jaccard)=0.98, Sensitivity=0.82, Specificity=0.99, Accuracy=0.99, and Precision=0.85.

The following figure illustrates two exemplary predicted prostate segmentations with high (DSC=0.954) and low performances (DSC=0.670) respectively.



DISCUSSION & CONCLUSIONS

Limited training set size, noisy ground truth and the weighting factors for the two loss functions (in the mixed loss) not being optimal could be the main reasons for the inferior performance of the network (segmentation with DSC=0.670). Dice loss, which is the most commonly used segmentation evaluation metric, directly optimizes the Dice coefficient and assigns equal weights to false negative (FN) and false positive (FP) incidents while the focal Tversky loss, sets different weights to FN and FP to emphasize on hard cases with low probabilities. To improve the network performance, its generalization error, and to circumvent contour variability problem, our research group is currently working on the optimization of the weights for the mixed loss model along with training and refining of the network using a much larger cohort of patients (~1000 cases) contoured by a panel of physicians. The agreement between the proposed BCDU-Net segmentations and physician contours was comparable to the agreements reported in our previous studies and the literature. Despite the small sample size BCDU-Net-based model utilizing a combined loss function combining dice and focal Tversky loss functions showed promise for robust segmentation of the prostate gland on smaller planning CT image datasets. Further investigation is warranted.

REFERENCES

[1] Abraham, Nabila, and Naimul Mefraz Khan. "A novel focal tversky loss function with improved attention u-net for lesion segmentation." *2019 IEEE 16th International Symposium on Biomedical Imaging (ISBI 2019). IEEE,2019*

ACKNOWLEDGEMENTS

This work is supported in part by a grant from Varian Medical Systems (Palo Alto, CA)

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