Toward complete colorectal tumor resection using intraoperative ultrasound and ensemble learning

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Editors: Under Review for MIDL 2022

Abstract

Cancer surgery is characterized by a delicate balance between radical tumor resection and sparing healthy tissue and critical anatomical structures. The trouble of recognizing tissue structures during surgery may either lead to resection too close to the tumor resulting in tumor-positive resection margins or too wide resection around the tumor with potential damage to vital anatomical structures. Ultrasound is a widely available and non-invasive imaging technique which can be used for surgical guidance by continuous real-time tissue recognition during surgery, however interpretation of US images requires training and experience. One of the notorious challenges in medical image analysis is the scarcity of labeled data. To address this issue, we introduce a deep ensemble learning framework for colorectal tumor detection in ultrasound images using models which are pre-trained for tumor segmentation in breast ultrasound images.

Keywords: Colorectal cancer surgery, Ensemble learning, Data scarcity, Ultrasound.

1. Introduction

Colorectal cancer is the third most commonly diagnosed cancer worldwide, with more than 1.9 million new patients in 2020 (Sung et al., 2021). Adequate surgical tumor resection, with a sufficient margin of healthy tissue both around and distally to the tumor, is crucial for patient prognosis. However, tumor identification during surgery can be challenging and the current golden standard for resection margin evaluation based on pathological examination takes days. Currently, inadequate resection margin rates of up to 30 percent are reported for colorectal cancer surgery, showing the need for an intraoperative tumor detection technique (Orosco et al., 2018). Ultrasound (US) offers many advantages including real-time imaging and deep tissue penetration. Many studies have shown that ultrasonic wave propagation in tissues is strongly dependent on histological features including tissue microstructure, and tissue heterogeneity (Oelze et al., 2002). Ultrasound, therefore, presents the potential of being able to differentiate between tumor and healthy tissue during surgery. However, interpretation of US images for surgical margin assessment requires training and experience.

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Numerous applications of Deep Learning (DL) methods in medical imaging have shown good performance in facilitating image interpretation through automatic segmentation or classification. However, DL models require a plethora of labeled data samples for adequate training which is often scarce in the medical field. Ensemble deep learning combats data scarcity by combining different model predictions into a final prediction. Aggregating various predictions can negate errors of separate models thus yielding a higher overall accuracy (Zhao et al., 2019). In addition, pre-training models with similar data can further decrease the amount of data needed because the model does not need to be trained from scratch. This work presents a deep ensemble learning framework that aims to detect tumor in colorectal US images by harnessing pre-trained convolutional neural networks (CNN) for tumor segmentation in breast US images.

2. Material and Methods

US images from freshly excised colorectal cancer specimens of 110 patients undergoing surgery for colorectal cancer were acquired using a Philips CX50 US machine and a Philips L15-7io high-frequency US transducer (15-7 MHz). Per patient, one to three US images were acquired depending on the tumor size, which resulted in 277 US images in total. The measurement plane of each US image was marked with ink to correlate the data with histopathology results. H&E tissue sections containing these ink marks were reviewed by a pathologist, after which the corresponding US images were labeled as tumor or healthy.

Eight different models including AlexNet, U-Net, VGG16, VGG19, ResNet18, ResNet50, MobileNet-V2, and Xception which have been pre-trained and fine-tuned on 3061 breast cancer US images (Gómez-Flores and Coelho de Albuquerque Pereira, 2020) were utilized to detect colorectal tumors in US images using an ensemble learning technique (Figure 1). Model stacking was used to combine the pre-trained model predictions into one final prediction with an ensemble classifier using a voting approach such as majority voting. Segmentation results of the acquired colorectal US dataset, provided by the pre-trained models, were combined using weighted and unweighted majority voting on class labels and probabilities. A predicted tumor label was assigned to the US images in case of a segmented tumor region larger than $2mm^2$. The predictions were compared to the ground-truth labels provided by histopathology.

3. Results and Discussion

Individual models (pre-trained on breast US dataset) resulted in accuracy values of 65%-70% on the colorectal dataset. Weighted and unweighted majority voting based on segmentation results both showed accuracy values of 71%. Weighted and unweighted majority voting based on the probability maps achieved accuracies of 71% and 73%, respectively.

Models pre-trained on breast US datasets showed surprising performance in colorectal tumor detection, without ever seeing colorectal US images. While tumor was excellently detected and segmented, healthy colorectal anatomical features including the lumen were sometimes segmented as tumor. For future work, we will investigate the use of transfer learning techniques such as domain adaptation to address this issue. The ensemble classifier showed an improvement over the individual models. However, all models were trained on the

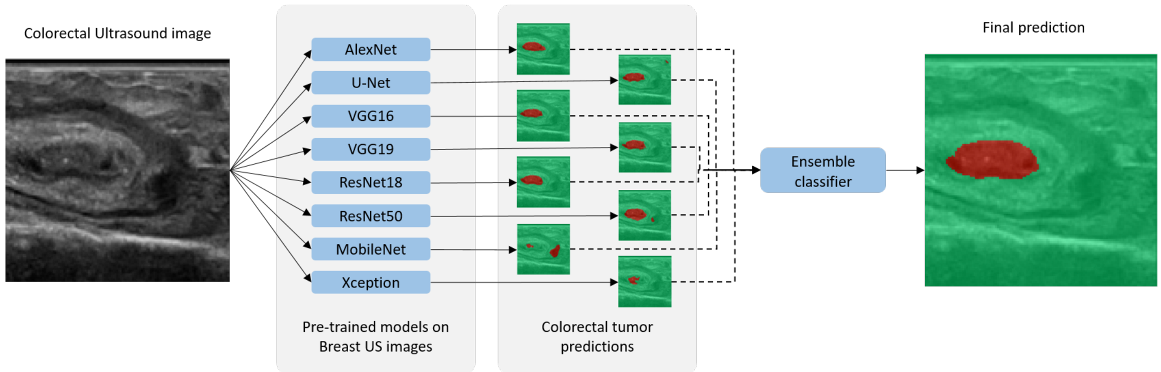

Figure 1: Visualisation of ensemble classifier framework with 8 pre-trained models. Healthy tissue is highlighted in green, tumor tissue is highlighted in red.

same dataset which could lead to a bias in all model predictions. Using models pre-trained on different tasks of similar data could improve the generalization of the ensemble classifier, which will be investigated in future research as well. Combining the proposed ensemble and transfer learning techniques could combat data scarcity for new image analysis tasks as in colorectal tumor segmentation.

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