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A Dual-Task Semi-supervised Neural Network Based on Skew Normal Mixture Model for Brain MR Image Segmentation

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Abstract. Accurate segmentation of brain magnetic resonance (MR) images is critical in brain disease research and treatment. While deep learning methods have advanced image segmentation by extracting hierarchical features, they typically require large labeled datasets for precise results. Acquiring annotated medical data remains challenging due to the need for specialized expertise and privacy restrictions. To address this, we propose a semi-supervised model combining dual tasks: segmentation and boundary feature regression. For class imbalance in segmentation, the network employs focal loss to extract common features from annotated data. To handle asymmetric data distributions, a skew Normal Mixture-based Level set loss guides the network to learn individual image characteristics, enhancing class distribution fitting. This dual-feature integration enables strong performance on limited datasets. In regression, Level set signed distance functions focus the model on boundary information, mitigating partial volume effects on focal loss. Experiments on IBSR and MRBrainS18 datasets demonstrate our method's advantages over current state-of-the-art approaches.

AMS subject classifications: 62E99, 68T10

Key words: Brain MR image segmentation, Semi-supervised Learning, Skew Normal Mixture model, Level set functional, Dual task.

1 Introduction

The phenomenon of aging population has become one of the important issues in contemporary society, and more and more diseases are beginning to harm the health of the elderly. Among them, brain diseases have a high incidence rate and mortality, and are more

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frequent in the elderly. From a medical perspective, effective prevention, accurate diagnosis, and rational treatment of brain diseases are beneficial for promoting healthy aging. Medical imaging technology is widely used in the diagnosis of brain diseases. This technology can effectively obtain tissue information and pathological localization. Among numerous medical imaging technologies, magnetic resonance imaging has a higher resolution of soft tissues and is non-invasive and radiation free for the human body. In addition to its advantages, magnetic resonance (MR) images often exhibit noise, offset fields and partial volume effects, and there are also differences between different individuals. Meanwhile, brain tissue segmentation requires doctors to manually implement, which can consume a significant amount of time. Numerous studies are focusing on developing advanced automatic segmentation techniques to enhance generalization capability.

Currently, various techniques [1] are employed for brain MR image segmentation including unsupervised models [2], supervised models [3,4], semi-supervised models [5], and weakly supervised models [6]. Unsupervised models rely solely on the information within the image itself for analysis, often without utilizing any prior knowledge. This techniques can be further grouped into statistical model-based methods [7] and PDE-based methods [8, 9], etc. Statistical model-based methods typically involve fuzzy C-means clustering models [10], finite Mixture models [11, 12], and more. On the other hand, the level set model [13], a classical curve/surface evolution model based on PDE theory, is widely used in brain MR image segmentation as it can effectively segment multiple objects in an image. Despite its strengths, unsupervised methods face challenges in achieving optimal segmentation results due to factors such as bias field, noise, and weak boundaries.

Over the past few years, deep learning technology [14] has become increasingly prominent in the field of brain MR image segmentation. Deep learning techniques, such as the fully convolutional network (FCN) [15] and U-Net [16], have emerged as powerful tools in this domain, demonstrating remarkable performance. These models have the ability to extract pertinent features from bottom to top, enabling more accurate and effective segmentation of brain MR images. It is regrettable that deep learning techniques are heavily dependent on rich labeled data [17]. Brain MR image segmentation poses unique challenges due to the requirement of extensive clinical knowledge and time-consuming efforts in acquiring annotated data. Furthermore, ethical and privacy concerns regarding patient information restrict the availability of such data, making its acquisition a costly and difficult task. Additionally, different imaging devices from various manufacturers often produce images with distinct distributions, compounding the challenge of training accurate segmentation models.

Semi-supervised methods [18] have been widely employed in the field of medical image segmentation to address the challenge posed by limited sample sizes and have demonstrated promising results. For example, Guo et al. [19] expanded the limited annotated data by applying operations such as translation, rotation, and linear combinations to the training data to alleviate overfitting. However, it should be noted that the generated augmented data still falls within the distribution of the annotated data, which