PhD Thesis Title: 'Medical Image Segmentation Using Level Sets and Dictionary Learning**'**

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ABSTRACT:

In recent years, medical image analysis technology has grown rapidly. Several algorithms have been developed to segment and classify anatomical organs, using different medical image modalities such as computed tomography (CT), and magnetic resonance imaging (MRI). Medical image segmentation is a key problem in many applications, such as detection of brain tumors and disorders, or volumetric analysis of the normal brain. In this dissertation, I address the segmentation and classification problem of normal and abnormal structures in the human body. The segmentation objectives are to develop fully automatic methods for anatomical organ segmentation using prior knowledge. Prior knowledge is incorporated in terms of local and global image features using level set, and dictionary learning methods. The first part of this dissertation presents an efficient way to include global features to improve organ segmentation. I address the problem of the Mumford-Shah model in segmenting brain structures due to their boundary ambiguity by proposing a topological prior. It provides prior knowledge about the brain topology that helps to accurately segment brain structures. The classical level set energy functional is extended by adding the topological prior. Further, the topological graph is used as a feature to classify normal and abnormal brains. In the second part of this dissertation, I present an efficient strategy to couple the local features of grayscale, and label image data using both the level set formulation and the dictionary learning method. I show that the embedding of the sparse representation of local features in the level set formulation leads to a potential boost in segmentation accuracy compared to using only the voxel-wise dictionary learning method. This algorithm is applied to solve single- and multi-region segmentation problems. The third part of this dissertation focuses on a new method that combines the local, and global image information in a level set formulation using the dictionary learning approach. I show that such a combination leads to a significant improvement in the segmentation accuracy. Overall, I show that the embedding of prior knowledge in the level set formulation using the dictionary learning approach obtains more accurate segmentation results (92.7%). For all the proposed methods, I present extensive validation using real clinical data.

Contributions:

In this thesis, we mainly focus on two organs, brain and liver, and provide solutions for the challenging segmentation tasks. The main contributions can be divided into three parts and, in the following, these parts are briefly reviewed:

1. **Topological Prior For Brain Segmentation and Classification:** This contribution is a multi-region segmentation algorithm using a level set method with a topological prior in MRI brain images. Based on global image information, this method is based on a representation of topological relations of objects in an image. We compute image features based on the topological relations of different regions in the image. The topological prior is embedded in the level set energy equation, and acts as an additional prior term to identify both the overlapped and the weak boundaries between adjacent regions in the image. In the training stage, the topological relations of brain structures are computed. In the testing stage, the similarity between topological relations of the test image data and those in the training data is computed in terms of object similarity and topological relation similarity. This method gives an accurate segmentation of ambiguous regions. Moreover, topological relations do not depend on region shapes, thus they can handle the high variability in medical data. In our experiments, we concentrate on brain segmentation, however, it is worth noting that this method is general, and can be applied to other scenarios, for example abdominal organ segmentation, by computing the topological relation of abdominal organs.
2. **Voxel-Wise Coupled Dictionaries:** This contribution is a novel patch-based dictionary learning segmentation algorithm. It is applied to solve the multi-label brain tumor segmentation using BraTS-MICCAI 2013 challenge database. I present coupled voxel-wise dictionaries: one dictionary of grayscale image patches, and one dictionary of label image patches. Patches are extracted from the image data. Each grayscale patch is concatenated in a dictionary matrix and has its corresponding patch in a label dictionary. The label dictionary represents four foreground labels (necrosis, enhanced tumor, non-enhanced tumor, and edema) and one label for background. Testing data is encoded using the learned voxel-wise grayscale dictionary. The label dictionary is used to provide foreground and background labels for automatic graph-cut segmentation.
3. **Feature-Voxel-Wise Coupled Dictionaries in Level Set Formulation**: This contribution is an extension of the previous one. Instead of coupling two voxel-wise patches, in this algorithm, feature and label patches are coupled. We present coupled dictionaries: a feature dictionary of grayscale image data, and a voxel-wise label dictionary of label image data. Using online dictionary learning, the coupled dictionaries are learned from the training data. Then, the coupled dictionaries are embedded into a level set function to integrate a novel cost function. This algorithm is applied to segment a caudate nucleus, which is the structure in the brain responsible for memory and movements. The label dictionary provides prior knowledge about the location of a caudate nucleus in test image data to initialize the level set. Moreover, based on many medical studies, which have been proved that the reduction in caudate nucleus volume gives an indication of Alzheimer's disease, this method is used to detect Alzheimer's disease via automated 3D caudate segmentation. The classification step is based on measuring the similarity between the sparse representation of the shape features of the segmented caudate nucleus and a region-based feature dictionary.
4. **Local and Global Features-Based Image Segmentation Using Level Set and Dictionary Learning:** Based on local and global image features, the contribution is a novel framework for automatic 3D image segmentation via level set formulation. The level set is constrained by the dictionary learning and sparse representation of both global (region-based features) and local (voxel-wise) image information. The proposed level set energy equation consists of a

data and a regularization term. These terms have been integrated into the implicit framework in a novel manner. The data term consists of the sparse representation of image features and the shape prior. The shape prior represents the sparse representation of the shapes of the volume of interest (VOI). This method is generic and it is suitable for many scenarios using different image modalities. It can be applied to solve the binary image segmentation, such as in the liver and lung segmentation using CT images. Moreover, it can also be applied for multi-region segmentation of brain structures using MRI images.

References to author publications that relate specifically to the dissertation:

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