

Spinal Cord Gray Matter Segmentation Using Deep Dilated Convolution

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Abstract - Changes in gray matter (GM) tissue have been linked to a variety of neurological conditions and have recently been identified as a biomarker for impairment in amyotrophic lateral sclerosis. For contemporary research on the spinal cord, the capacity to automatically segment the GM is crucial.

In this study, we develop a cutting-edge, straightforward, and fully automated human spinal cord gray matter segmentation technique using Deep Learning that can be applied to both in vivo and ex vivo MRI scans. When compared to conventional medical imaging architectures like U-Nets, we report state-of-the-art results in eight out of ten different evaluation metrics and significant network parameter reduction. We test our approach against six independently developed methods on a GM segmentation challenge.

Key Words: Amyotrophic lateral sclerosis, spinal cord, grey matter segmentation, deep learning, MRI, automated segmentation, neuroimaging, and Bio markers.

1. INTRODUCTION

When it comes to sending neural messages from the brain to the rest of the body, the spinal cord is essential. It is in charge of processing sensory data, regulating reflexes, and coordinating motor activities. White matter and gray matter are the two primary components of the spinal cord. Gray matter comprises the nerve cell bodies that carry out processing tasks, whereas white matter is principally in charge of signal transmission.

Understanding and diagnosing a variety of neurological problems, such as spinal cord injuries, neurodegenerative diseases (including multiple sclerosis and amyotrophic lateral sclerosis), and congenital spinal cord disorders, depends on gray matter segmentation. However, manually segmenting gray matter in spinal cord MRI images is a

time-consuming, labor-intensive, and error-prone operation that calls for specialized knowledge.

The complex structure of the spinal cord is difficult for conventional techniques like thresholding and edge detection to handle, especially in high-dimensional pictures where noise, low contrast, and individual anatomical variances make it challenging to distinguish the gray matter boundaries. Consequently, there is an increasing need for automated, precise, and effective methods of spinal cord gray matter segmentation. Convolution neural networks (CNNs) are frequently utilized for a variety of medical imaging applications, such as organ, tissue, and lesion segmentation in brain and spinal cord scans.

1.1 Description

The goal of this study is to employ a Deep Dilated Convolution Neural Network (DDCNN) architecture to automatically segregate spinal cord gray matter from MRI data. Due to their small receptive fields, traditional convolution models have trouble capturing fine-grained structural information in medical pictures. Dilated (Atreus) convolutions, which increase the receptive field without raising computing costs or sacrificing spatial resolution, are used by the suggested model to get around this.

The network learns to differentiate gray matter from surrounding white matter and background tissues by processing axial MRI slices of the spinal cord. The model can accurately identify intricate anatomical features by capturing multi-scale contextual information thanks to dilated convolution layers. Using methods like data augmentation and post-processing to lower noise and improve borders, the system is trained on annotated medical datasets. The final model generates smooth, clinically effective gray-matter masks with good segmentation accuracy.

1.2 Existing file

- Use a deep fully convolution neural network (FCN) created specifically for gray-matter segmentation of the spinal cord.
- Increases receptive field without sacrificing spatial resolution by incorporating dilated (Atreus) convolutions.
- Mostly uses slice-wise segmentation on 2D axial MRI scans.
- Attains cutting-edge outcomes on the SCGM Challenge dataset.
- Because the model is lightweight, it can be trained and inferred more quickly with fewer parameters.
- Successfully manages thin and small GM structures because high-resolution feature maps are kept.

1.3 Problem Statement

The process of manually segmenting the gray matter of the spinal cord from MRI scans is laborious, subjective, and prone to mistakes. Due to limited contrast and anatomical complexity, current automated approaches frequently fail. This study suggests employing deep dilated convolutions to efficiently capture multi-scale information in order to increase segmentation accuracy.

1.4 Objectives

- To create a reliable deep learning model (such as U-Net with dilated convolutions) specifically designed to automatically segment the gray matter of the spinal cord from T2-weighted MRI data.
- To improve segmentation accuracy by incorporating dilated convolution techniques, which are especially helpful in defining precise structural boundaries and collect multi-scale contextual data while maintaining resolution.
- To provide an effective preprocessing pipeline including noise suppression, contrast enhancement, and normalization to guarantee better feature extraction and model performance.
- To can compare the model's performance with baseline segmentation models using publicly accessible datasets, such as the Spinal Cord Gray Matter Segmentation Challenge (SCGM) dataset.

2. LITRETURE SURVEY

A Literature Survey provides an overview of existing research, technologies and method related to it. With the increasing use of deep learning and artificial intelligence (AI), automated spinal cord gray matter segmentation has emerged as a crucial field of study in medical imaging. The segmentation of spinal cord tissues has been greatly improved by a number of research, with an emphasis on

enhancing MRI scan accuracy, robustness, and computational efficiency.

Table -1: Literature Survey

Title	Author/Year	Methodology	Outcome
Automatic segmentation of spinal cord gray matter and white matter using deep learning	Zhang et al., 2019	Deep CNN for joint GM-WM segmentation	Limited ability to capture 3D context
Multi-modal 3D U-Net for accurate segmentation of spinal cord tissues in MRI	Xie et al., 2020	Multi-modal 3D U-Net	Requires multiple MRI modalities, which is not always available.
Multi-stream CNN architecture for spinal cord tissue segmentation	Wang et al., 2020	Multi-stream CNN	High model complexity: limited evaluation on very thin GM regions.
Improved segmentation of neuroanatomical structure using U-Net with dilated convolutions	Moon et al., 2022	U-Net with dilated convolutions	Dilated features improves context but still limited for extremely thin and low contrast GM structure

Even though these researches have made a substantial contribution to spinal cord segmentation, there are still important obstacles to overcome. The fine resolution needed for precise gray matter segmentation is still a challenge for many models, especially in areas with low contrast or partial volume effects. Furthermore, a lot of approaches fall short of the challenge of achieving high accuracy while preserving computational efficiency, particularly when using large-scale datasets.

3. SYSTEM REQUIREMENTS AND SPECIFICATION

A system that can effectively train deep learning models and handle high-resolution spinal cord MRI data is needed for the research. A minimum of 8 GB RAM (ideally 16 GB), an NVIDIA GPU with at least 4 GB VRAM (such as the GTX 1650 or above), an Intel Core i5 or higher processor, and at least 100 GB of SSD storage for quicker data access are all recommended pieces of hardware. Large medical imaging datasets can be handled, evaluated, and trained with ease thanks to these standards.

With Python as the main programming language and development tools like Google Colab, Jupiter Notebook, or VS Code, the software environment supports Windows, macOS, or Linux. The project uses Open CV, Simple ITK, and PIL for image processing and Tensor Flow or Py Torch for deep learning. Mat plotlib and Seaborne facilitate visualization, while NumPy and Pandas help with data handling. Additionally, CUDA support allows GPU-accelerated training and inference, and evaluation tools such as Scikit-learn, Dice Coefficient, and Jacquard Index evaluate model performance.

4. IMPLEMENTATION

There are several steps involved in implementing the deep dilated convolution spinal cord gray matter segmentation model, beginning with data preprocessing and high-resolution MRI image normalization. Deep dilated convolution neural network architecture is used in the segmentation model's Python implementation with Tensor Flow/PyTorch to capture long-range relationships and fine-grained spatial features inside the spinal cord structure. The model can efficiently learn gray matter boundaries because to the integration of dilated convolution layers, which increase the receptive field without raising computational costs. For qualitative assessment, feature maps and anticipated segmentation masks are displayed using visualization tools like Mat plotlib and Simple ITK. Jupyter Notebook/Google Colab is used to carry out the entire process, guaranteeing repeatability and effective experimentation.

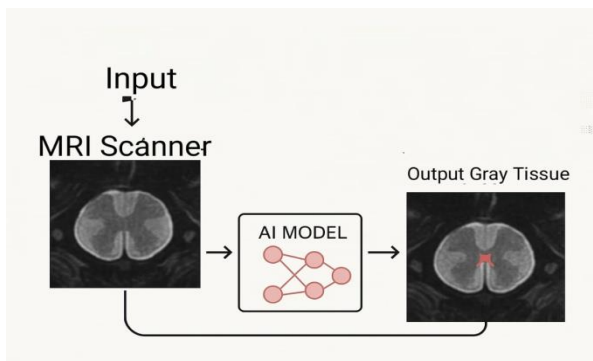


Fig -1: System Design

5. RESULTS AND EVALUATION

Both quantitative metrics and qualitative visual inspection were used to assess the suggested deep dilated convolution neural network for spinal cord gray matter segmentation. The model's capacity to precisely identify thin, low-contrast gray matter structures while reducing false predictions was further validated using precision and recall scores. Qualitative results further demonstrated that the model provided consistent segmentation across successive MRI slices, maintained smooth borders, and successfully reproduced the butterfly-shaped gray matter organization.

The model successfully learnt anatomical details and maintained spatial continuity, as shown by a visual comparison of input images, ground truth masks, and anticipated outputs. Because of the use of dilated convolutions, data augmentation, and optimal learning algorithms, training convergence was stable and the network was able to generalize effectively to new data.

6. DISCUSSION

Both quantitative metrics and qualitative visual inspection were used to assess the suggested deep dilated convolution neural network for spinal cord gray matter segmentation. The model performed well, as evidenced by the Jaccard Index scores, which showed a high level of overlap between the ground truth and the anticipated segmentation. Qualitative results further demonstrated that the model provided consistent segmentation across successive MRI slices, maintained smooth borders, and successfully reproduced the butterfly-shaped gray matter organization. Because of the use of dilated convolutions, data augmentation, and optimal learning algorithms, training convergence was stable and the network was able to generalize effectively to new data.

7. CONCLUSION

This study shows that deep dilated convolution networks offer a practical and efficient method for segmenting the gray matter of the spinal cord from MRI data. The technique effectively captures multi-scale contextual data, allowing for precise gray matter structure delineation while preserving computing efficiency. Its potential for clinical applications, such as the detection and monitoring of spinal cord illnesses, is highlighted by the better segmentation performance compared to conventional convolution approaches. In order to improve resilience and dependability in actual medical settings, future work may concentrate on further refining the model and using sophisticated post-processing approaches to handle noise and artifacts.

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