Deep Learning U-Net Model for Automated Segmentation of Inner Ear

The inner ear's intricate three-dimensional anatomy presents substantial challenges for diagnosis and surgical planning, requiring precise imaging to navigate its complex structures. Traditional manual segmentation of inner ear structures from computed tomography (CT) scans is time-consuming and can introduce variability due to human error. With the growing advancement of artificial intelligence (AI) and machine learning techniques, deep learning (DL) has shown promise in automating segmentation tasks, enhancing speed and accuracy. A recent article in European Radiology Experimental examines a study that developed and validated an open-source U-Net convolutional neural network (CNN) model to automate the segmentation of the inner ear from CT scans. The study's primary objective was to achieve reliable segmentation in both normal and pathological cases, streamlining clinical workflows and improving surgical planning.

Training the U-Net Model for Inner Ear Segmentation

The study utilised a U-Net-based architecture, a medical imaging model widely held for its ability to perform pixel-wise segmentation. A U-Net model consists of a symmetrical structure with an encoder to capture context and a decoder to enable precise localisation. Skip connections between the encoder and decoder are used to retain high-resolution features lost during down-sampling, enhancing segmentation quality.

The dataset comprised 271 CT scans for training and 70 external CT scans for validation. The training data included healthy temporal CT scans and scans with abnormalities, allowing the model to generalise to a wide range of inner ear anatomies. These scans were manually segmented by radiologists, and the resulting segmentations served as the ground truth for training the model. The training dataset was processed with specific parameters, including a bone analysis filter with a width of 4,000 HU and a centre range of 600 to 800 HU, providing clear images of the temporal bone structures.

The U-Net model was optimised through several iterations, improving its weights and overall performance for segmenting the inner ear structures, including the vestibule, cochlea, and semicircular canals. The final model weights were made publicly accessible for global use, and the study aimed to validate the model's accuracy and utility for clinical application.

Quantitative and Qualitative Evaluation of the Model

Quantitative and qualitative measures were used to assess the U-Net model's performance. The Dice similarity coefficient (DSC), a metric indicating the overlap between the automated segmentation and the manual ground truth, was employed for the quantitative assessment. The mean DSC achieved was 0.83, reflecting high accuracy in segmenting the inner ear across different patients and anatomies. A higher mean DSC value in the validation dataset (compared to the training dataset) further demonstrated the robustness and external applicability of the model. Moreover, the automated segmentation time was significantly reduced to an average of 12 seconds per volume, compared to approximately 463 seconds for manual segmentation.

The qualitative assessment used a four-level Likert scale (LS) to evaluate the clinical utility and accuracy of the segmentation, with a score of 1 indicating complete and accurate segmentation and a score of 4 representing major segmentation issues or loss of inner ear structures. The model achieved a Likert score of 1 in 42% of the validation cases, indicating that nearly half of the automated segmentations were accurate. However, 27% of cases received a score of 4, suggesting a need for improvement in certain scenarios, especially in segments with complex abnormalities or anatomical variations.

Performance Comparison and Implications for Clinical Use

The model's results showed favourable performance compared to other DL-based segmentation studies. While other studies reported higher

DSC values (such as 0.91 using AH-net or W-net architectures), using a U-Net model in this study demonstrated practical advantages in terms of simplicity, computational efficiency, and accessibility for clinical application. The U-Net model's segmentation quality was consistent across normal and pathological scans, though specific cases like otosclerosis presented challenges, resulting in slightly lower accuracy.

The model's performance suggests that it can be highly beneficial in clinical practice, particularly for preoperative planning in otologic surgeries, cochlear implant procedures, and treatment of ear malformations. The rapid processing time enables quick segmentation, allowing clinicians to visualise the inner ear anatomy in 3D without the time-consuming process of manual delineation. Furthermore, the model's open-source nature enables it to be refined and adapted to different clinical settings or CT protocols, enhancing its utility for diverse healthcare providers.

However, certain limitations need to be considered before widespread adoption. The variability in CT scan protocols, such as slice thickness and voxel size, can influence segmentation accuracy. Additionally, the model's performance needs further validation across a broader range of abnormalities and rare inner ear malformations to ensure robust clinical application. Continued development and optimisation, particularly with more extensive and more varied datasets, will enhance the model’s segmentation capabilities.

The use of deep learning for automated segmentation of the inner ear from CT scans offers significant potential in improving clinical workflows and precision in otologic care. The U-Net model developed in this study achieved a strong balance between accuracy and efficiency, achieving a high mean DSC and demonstrating quick segmentation times. Although some limitations exist in handling complex cases, the model’s performance underscores its promise as a valuable tool in medical imaging. Future refinements and validation in diverse clinical settings will further enhance its applicability, leading to better diagnostic and therapeutic outcomes for patients with ear-related conditions.

Source: **European Radiology Experimental**

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