Computational Approaches for Brain Tumor Segmentation: From Algorithms to Insights

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Abstract

Brain tumors are life-threatening and are typically identified by experts using imaging modalities like MRI, CT, and PET scan. In current clinical practice, the segmentation of brain tumors is typically performed manually, which is time-consuming and tedious for radiologists. However, any error due to human intervention in brain tumor segmentation can have disastrous consequences. To mitigate this issue, our research is focused on developing a fast and reliable tumor segmentation system for brain images that can benefit society. The development of a tumor segmenting system is becoming challenging and is still an open problem due to: (1) Variability in shapes, areas, and sizes of tumors; (2) Anomalies usually exhibit unclear and irregular boundaries with discontinuities; (3) Contrast uptake and image acquisition time after contrast injection can vary, which changes tumor appearance significantly. There has been substantial research in the domain of brain tumor segmentation. However, the existing algorithms for brain tumor segmentation still face several challenges that limit their reliability in clinical practice.

This thesis studies and proposes computational approaches for brain tumor segmentation. The first contribution introduces a novel image understanding based method for brain tumor segmentation, which utilizes entropy, intensity differences between tumor and surrounding regions, and superpixel segmentation for accurate tumor segmentation and localization. The second contribution proposes a novel, robust GAN inspired approach for segmenting intratumoral brain regions. This approach has been extensively analyzed and evaluated on the benchmark BRATS2020 dataset and demonstrated improved generalization across datasets with varying imaging modalities, tumor types, and acquisition settings. Further, this work is extended to perform anomaly segmentation across multiple organs. The subsequent contribution focuses on developing an improved variant of the U-Net architecture that effectively combines deep semantic features with fine spatial details for medical image segmentation. This contribution also introduces a novel diagnostic map to assist clinicians in making more accurate and informed decisions, and thus reducing the likelihood of missed lesions and improving diagnostic precision. Finally, this thesis introduces an IoMT-enabled smart healthcare system to enable secure medical data transmission and provide reliable remote brain tumor segmentation for patients requiring continuous monitoring of acute disorders, such as brain tumors. In summary, this thesis explores computational approaches for brain tumor segmentation to facilitate timely diagnosis, accurate monitoring, and improved clinical outcomes for patients with brain tumors.

List of Publications from the Thesis

1. **Nishtha Tomar,** Parkala Vishnu Bharadwaj Bayari, and Gaurav Bhatnagar, "SBTD: Secured Brain Tumor Detection in IoMT Enabled Smart Healthcare", *IEEE Journal of Biomedical and Health Informatics*, vol. 30, no. 1, pp. 39–50, 2026. DOI: 10.1109/JBHI.2024.3482465.

2. **Nishtha Tomar**, Gaurav Bhatnagar, Vandita Agarwal, "Attention inspired adversarial network for intratumoral brain regions segmentation", *Image and Vision Computing*, vol. 168, pp. 105940, 2026. DOI: 10.1016/j.imavis.2026.105940.

3. **Nishtha Tomar**, Sushmita Chandel, Gaurav Bhatnagar, "A visual attention-based algorithm for brain tumor detection using an on-center saliency map and a superpixel-based framework", *Healthcare Analytics*, vol. 5, pp. 100323, 2024. DOI: 10.1016/j.health.2024.100323.

4. **Nishtha Tomar**, Gaurav Bhatnagar, "Transformer-inspired adversarial network for Blood cell segmentation." (Submitted)

5. **Nishtha Tomar**, Gaurav Bhatnagar, Zheng Liu, "Progressive Adaptive Feature Fusion for Medical Image Segmentation." (Submitted)

6. **Nishtha Tomar**, Gaurav Bhatnagar, "Brain Tumor Detection in MRI: A Systematic Review". (Under preparation)

Other Publications

1. Parkala Vishnu Bharadwaj Bayari, **Nishtha Tomar**, Gaurav Bhatnagar, and Chiranjoy Chattopadhyay, "Watermarking Protocol Inspired Kidney Stone Segmentation in IoMT", *IEEE Journal of Biomedical and Health Informatics*, vol. 30, no. 2, pp. 828-838, 2026. DOI: 10.1109/JBHI.2025.3563955.

2. Vandita Agarwal, **Nishtha Tomar**, Gaurav Bhatnagar, "GAN-driven Brain Tumor Segmentation with Attention Residual U-Net", in *Computer Vision and Image Processing, Cham, Springer Nature Switzerland*, pp. 318–332, 2026. DOI: 10.1007/978-3-031-93709-5 23.

3. **Nishtha Tomar**, Prakhar Bhatt, Gaurav Bhatnagar, "A novel Grasshopper optimized ResU-Net for Brain Tumor Segmentation", in Proc. *2024 IEEE 8th International Conference on Signal and Image Processing Applications (ICSIPA)*, pp. 1–6, 2024. DOI: 10.1109/ICSIPA62061.2024.10687058.