Tuning into Tumors: a 2D Fourier Frequency Filter Approach

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Abstract

Brain tumor segmentation from MRI is a critical step in diagnosis, treatment planning, and disease monitoring, yet it remains challenging due to tumor heterogeneity, low-contrast boundaries, and noise in medical images. Current manual and simple intensity-based automated methods are time-consuming and often struggle to capture complex tumor textures and irregular edges. Motivated by the need for more robust, signal-informed segmentation tools, we developed an image-processing pipeline that treats each MRI slice as a two-dimensional signal and analyzes it in both the spatial and frequency domains. Using high-pass and band-pass Fast Fourier Transform (FFT) filters alongside spatial-domain Canny edge detection, we aim to enhance tumor visibility and improve boundary detection and regional isolation of tumors. We benchmark these approaches against Otsu-based intensity thresholding baselines and evaluate segmentation performance using Dice coefficient and Intersection over Union (IoU) metrics.

Objectives

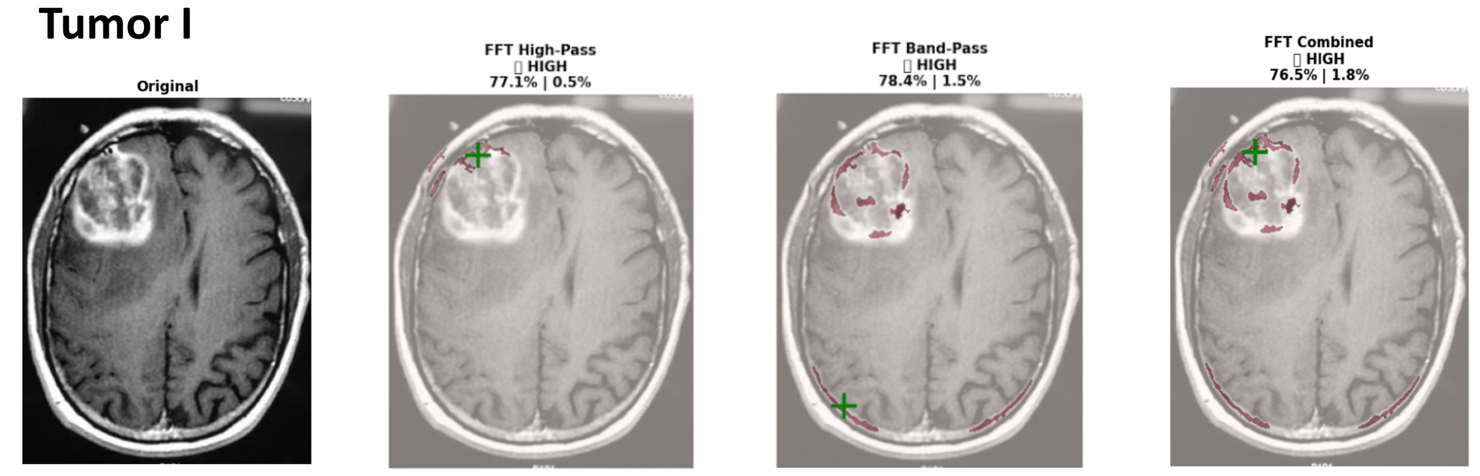
I. Develop an automated signal-processing-based tumor segmentation pipeline for MRI/CT images
II. Implement and evaluate frequency-domain filtering approaches using 2D Fast Fourier Transform (FFT) with high-pass and band-pass masks
III. Implement spatial-domain segmentation methods, including Canny edge detection and Otsu thresholding with morphological post-processing
IV. Establish and compare against intensity-based baseline methods (raw and Gaussian-smoothed Otsu thresholding)
V. Quantitatively evaluate segmentation performance using: dice similarity coefficient (DSC); intersection over Union (IoU / Jaccard Index); and boundary-based accuracy metrics
VI. Statistically compare segmentation performance across methods to assess the impact of frequency-domain vs. spatial-domain processing

Methods

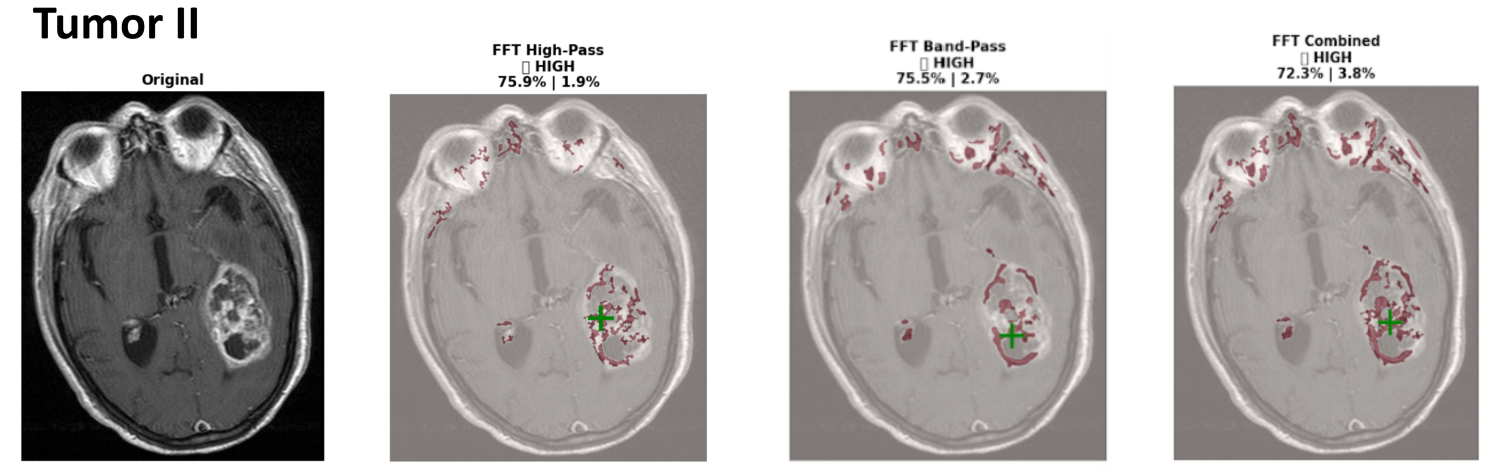
I. **Image Acquisition & Preprocessing:** MRI slices were loaded into Python, converted to grayscale, and normalized to [0, 1] intensity; ground truth masks were then loaded
II. **Frequency-Domain Transformation:** compute a 2D Fast Fourier Transform (FFT)
III. **Filter Design & Application:** *High-pass filters*: to suppress low-frequency, and enhance edge features; *Band-pass filters:* to isolate mid-frequency texture
IV. **Segmentation Pipeline:** FFT & Otsu thresholding, Canny edge detection, and baseline raw/smoothed Otsu. Morphological cleanup & large connected component selection were used to generate final tumor masks
V. **Quantitative Evaluation:** predicted segmentation masks were compared to ground truth using DSC, IoU, & boundary accuracy metrics to assess overlap accuracy

Results

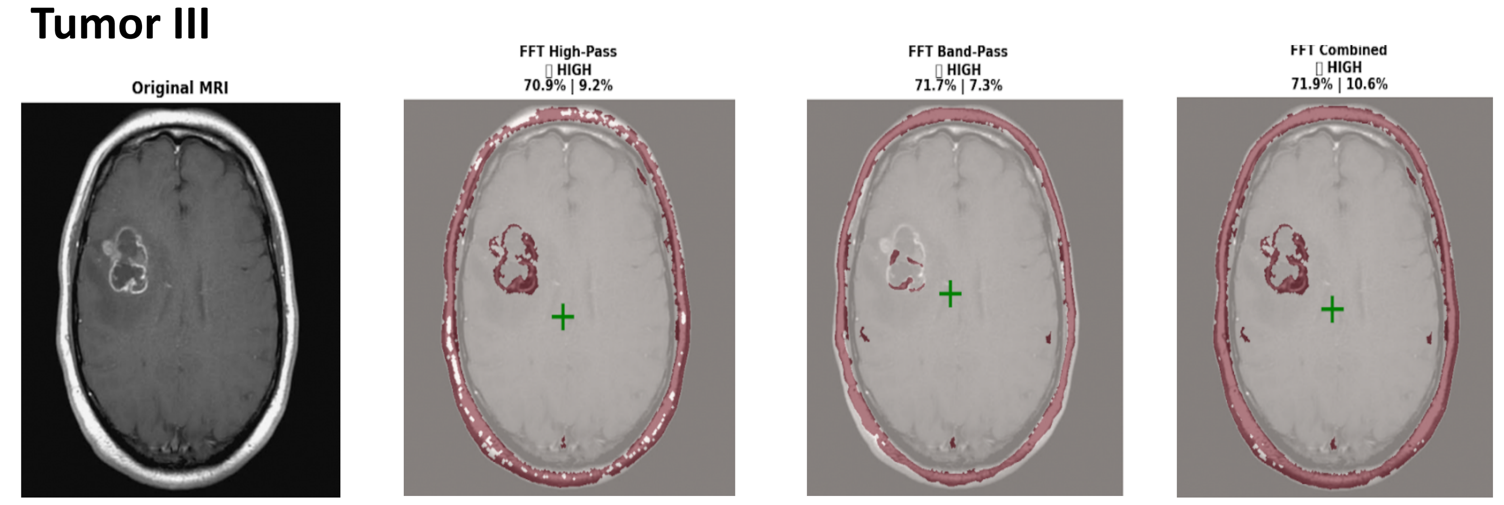
Tumor I



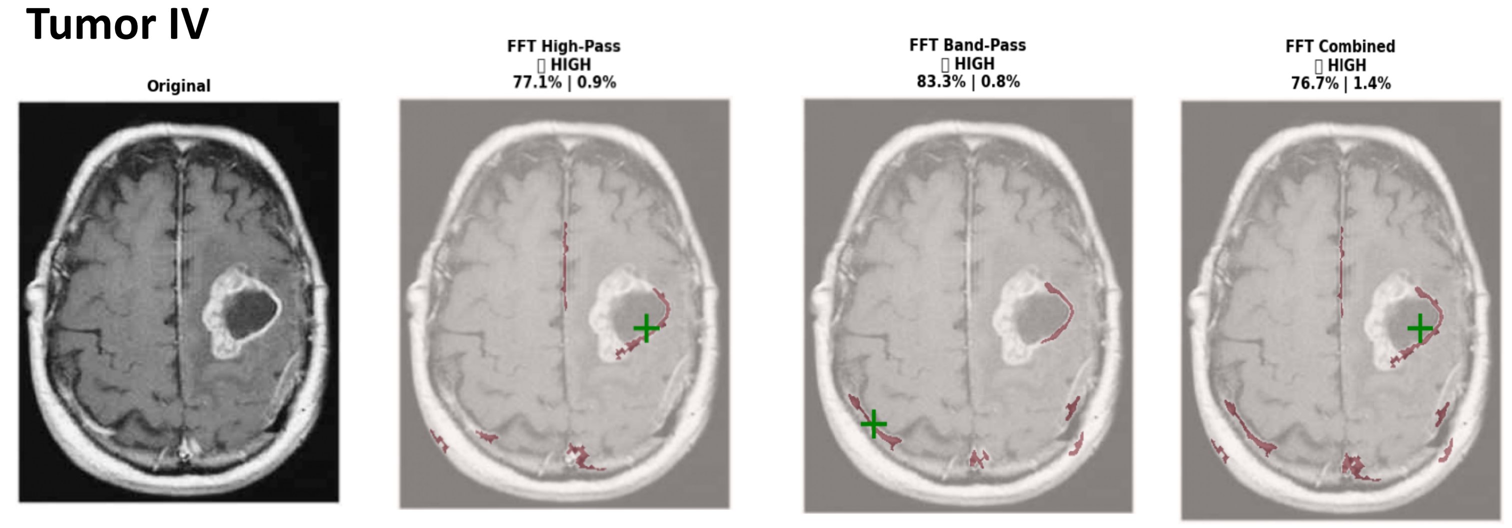
Tumor II



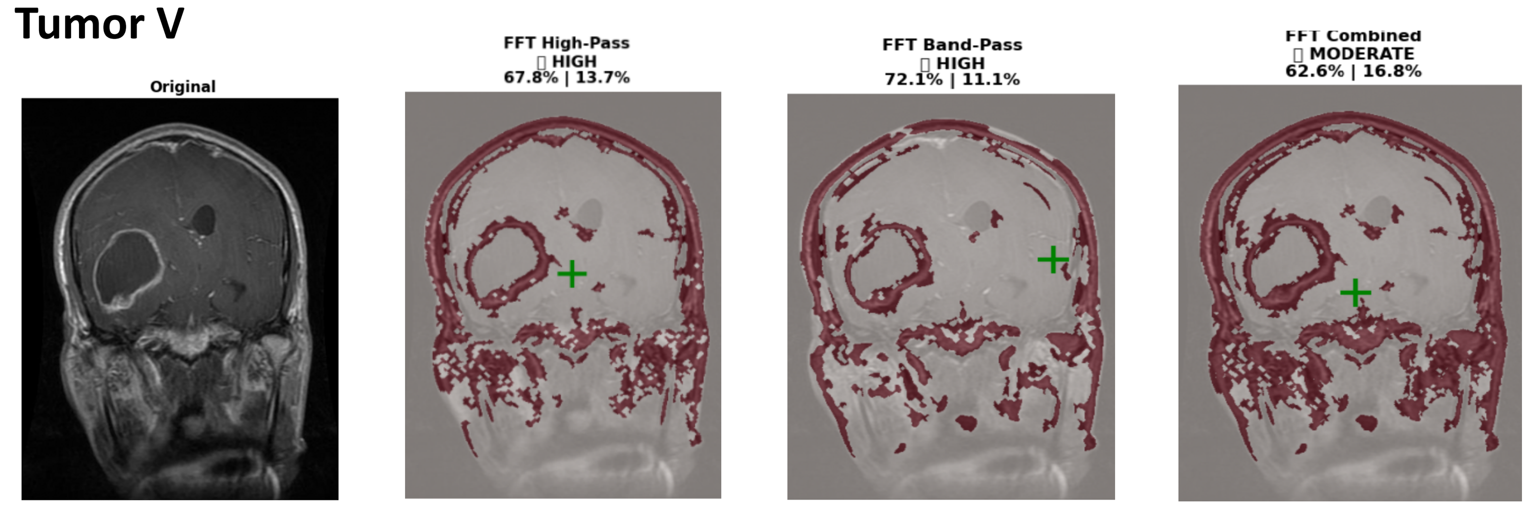
Tumor III



Tumor IV



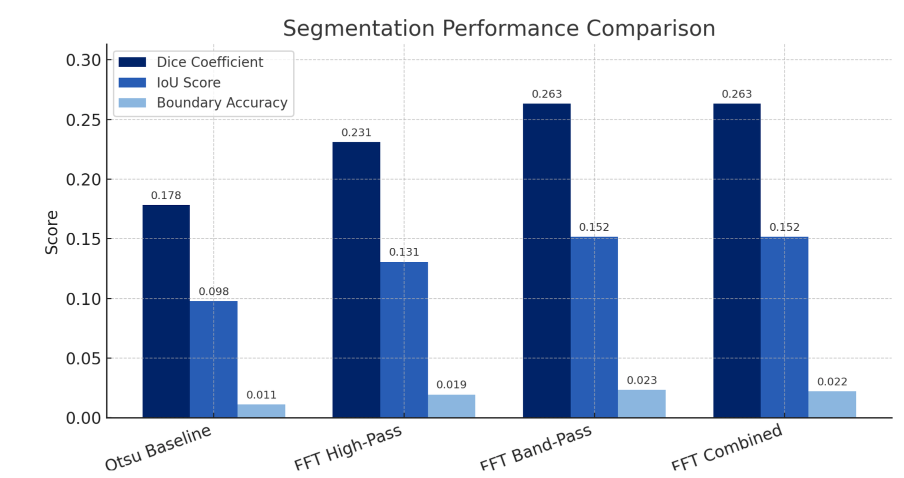
Tumor V



Left panel shows the original axial MRI slice. **Middle panels** show frequency-filtered reconstructions highlighting tumor-associated edges and texture patterns. **Right panels** display the corresponding binary segmentation masks produced by the algorithm, where highlighted regions with green crosses represent the predicted tumor area.

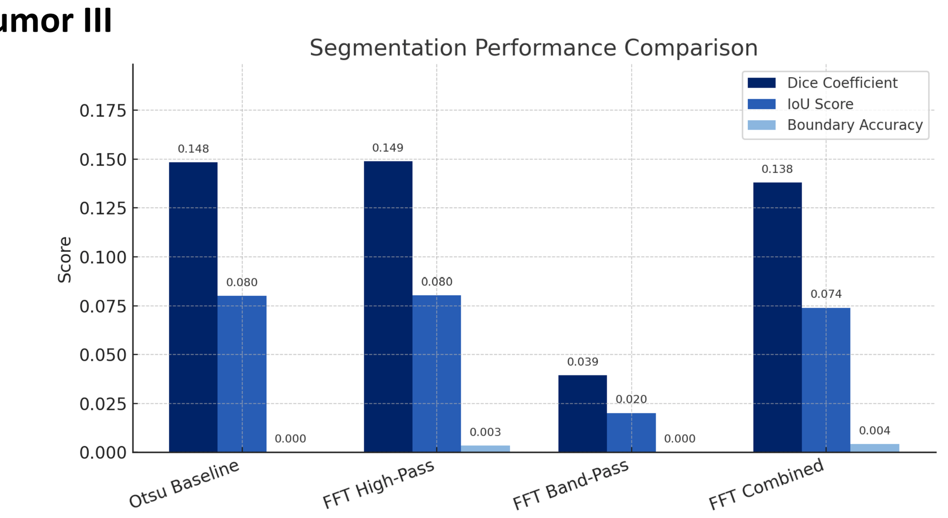
Quantitative Evaluation

Tumor IV



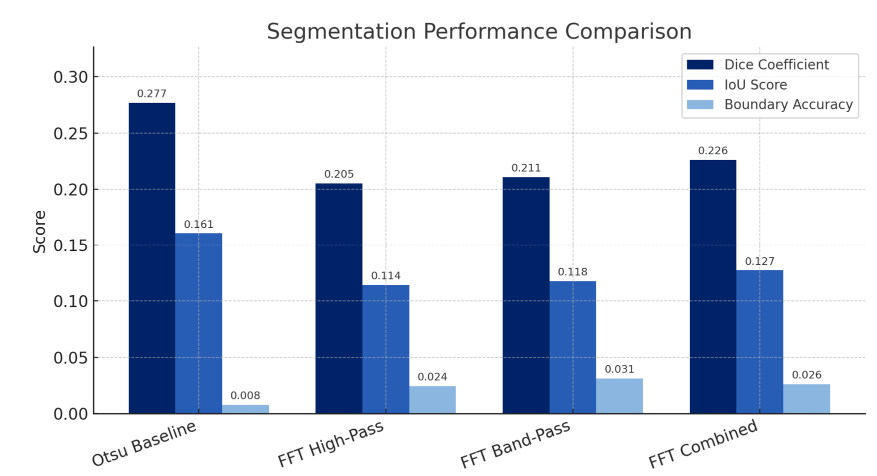
Method	Conf (%)	Area (%)	Dice	IoU
Otsu Baseline	45.6	29.37	0.178	0.098
FFT High-Pass	71.2	11.24	0.231	0.131
FFT Band-Pass	71.8	11.42	0.263	0.152
FFT Combined	65.8	14.44	0.263	0.152

Tumor III



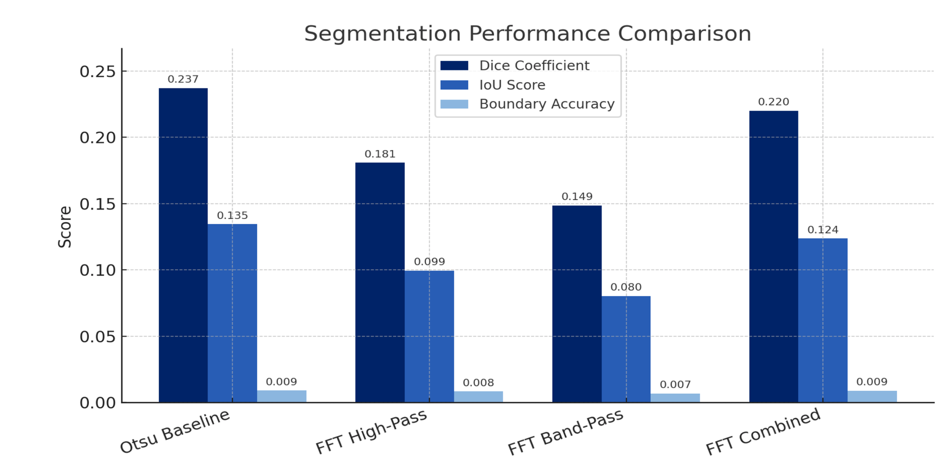
Method	Conf (%)	Area (%)	Dice	IoU
Otsu Baseline	57.6	51.44	0.148	0.080
FFT High-Pass	70.9	9.18	0.149	0.080
FFT Band-Pass	71.7	7.31	0.039	0.020
FFT Combined	71.9	10.65	0.138	0.074

Tumor V



Method	Conf (%)	Area (%)	Dice	IoU
Otsu Baseline	44.4	44.46	0.277	0.161
FFT High-Pass	67.8	13.71	0.205	0.114
FFT Band-Pass	72.1	11.07	0.211	0.118
FFT Combined	62.6	16.84	0.226	0.127

Tumor II



Method	Conf (%)	Area (%)	Dice	IoU
Otsu Baseline	42.2	59.70	0.237	0.135
FFT High-Pass	75.9	1.91	0.181	0.099
FFT Band-Pass	75.5	2.75	0.149	0.080
FFT Combined	72.3	3.78	0.220	0.124

Future Directions

I. Enhance segmentation agreement with ground truth:
- Optimize frequency-domain filter parameters and thresholding strategies to better align predicted masks with expert-annotated tumor boundaries
- Investigate post-processing techniques to reduce false positives/negatives while improving Dice and IoU scores

II. Implement tumor volume estimation:
- Incorporate pixel dimensions and slice thicknesses to enable physically meaningful measurements & extend current 2D segmentation outputs to multi-slice 3D volumetric calculations to quantify total tumor burden

III. Expand signal processing features:
- Implement multi-scale frequency filtering to better capture tumor texture and boundary heterogeneity
- Integrate spatial-frequency hybrid features to improve robustness across varying image contrast and noise levels

IV. Scale & benchmark the pipeline:
- Evaluate performance across larger and more diverse imaging datasets
- Standardize segmentation accuracy metrics to support reproducibility and cross-method comparison

V. Integrate skull-stripping to suppress non-brain signal
- Implement a skull-stripping step to remove bone and extracranial tissue, reducing high-intensity artifacts and improving the reliability of downstream segmentation

References

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AI Assistance*: ChatGPT and Claude were used for writing and coding support as permitted*

GitHub Repository