Comparison of Semantic Segmentation Models for Bi-2212 Filament Segmentation

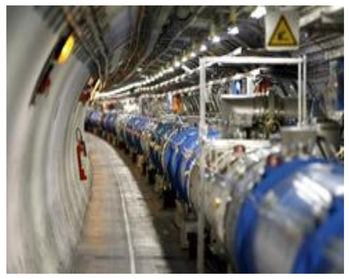
Asher Van Maanen[1], Dr. Matthew Jewell[2]

[1]Physics, Astronomy and Materials Science Department, Missouri State University
[2]Materials Science & Biomedical Engineering, University of Wisconsin - Eau Claire

Introduction

What are we studying?

- Superconductors are a class of material that can conduct electricity with zero resistance when chilled to temperatures below their unique critical temperature.
- Due to the lack of resistance, large electrical currents can be placed through superconductors, which create strong magnetic fields that can be used in particle accelerators, medical imaging devices, and nuclear fusion reactors.



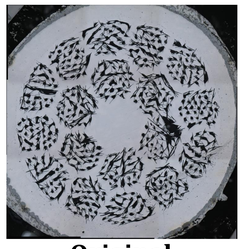
The superconducting magnets of the Large Hadron Collider at CERN in Geneva, Switzerland

Why is this important?

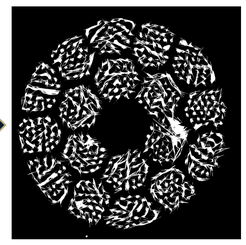
- When Bi-2212 filaments touch after the heat treatment process, there is a reduction in the performance of the wire overall.
- Assessing the extent of filament touching in Bi-2212 after the heat treatment process is an important step in accessing the quality of Bi-2212 wires in production.

Dataset

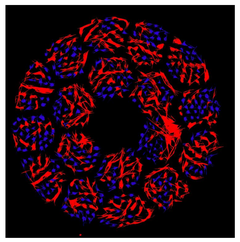
Semantic Classes:
Black = Background
Red = Touching
Blue = Non-Touching



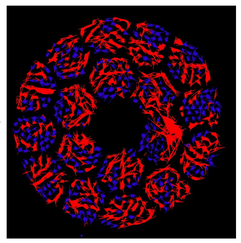
Original Microscope Image



Thresholded Filament Mask



Ground Truth Segmentation



Model Prediction

Models Compared

SAC-NET

Architecture:
- CNN
- Edge-preserving module
- Multi-scale feature extraction

Strengths:
- Designed for filament segmentation
- Preserves thin boundaries

Attention U-Net

Architecture:
- Encoder-decoder CNN
- Attention gates suppress irrelevant features
- Preserves fine filament boundaries

Strengths:
- Excellent local feature extraction
- Strong baseline performance

DeepLabV3+

Architecture:
- Encoder-decoder CNN
- Atrous convolutions
- Atrous Spatial Pyramid Pooling

Strengths:
- Captures multiple spatial scales
- Good contextual understanding

SegFormer

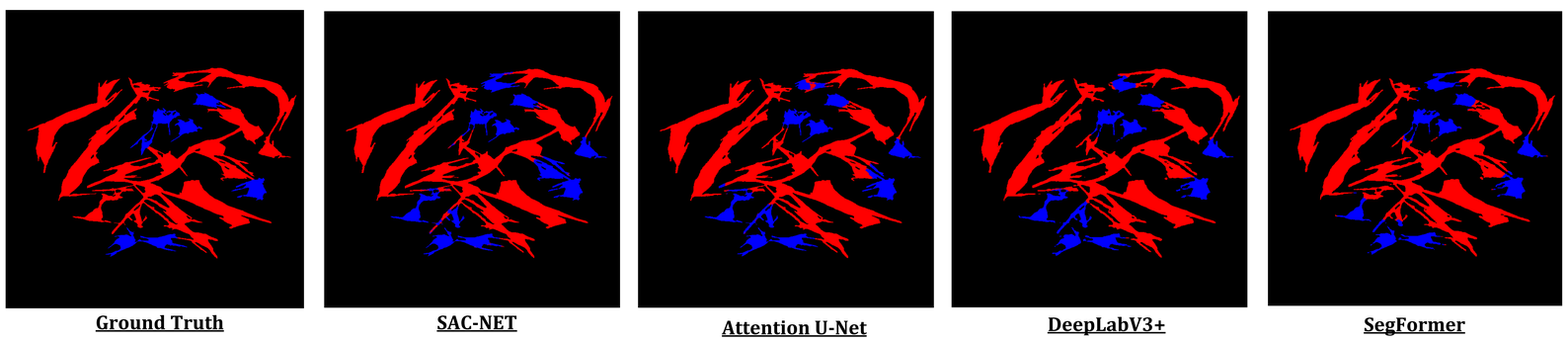
Architecture:
- Transformer encoder
- Lightweight decoder
- Multi-scale feature fusion

Strengths:
- Global context
- Parameter efficient
- State-of-the-art transformer segmentation

Machine Learning Model Performance Comparison

Model	Overall Accuracy	Filament Accuracy	Mean IoU
SACNet	98.1	89.06	0.83
Attention U-Net	98.06	89.01	0.88
DeepLabV3+	97.76	89.13	0.86
SegFormer	97.66	88.19	0.84

Table 1. Average performance of each semantic segmentation model on the Image7 evaluation dataset.



Ground Truth | SAC-NET | Attention U-Net | DeepLabV3+ | SegFormer

Figure 1. Representative semantic segmentation predictions for the same Bi-2212 wire cross section. Each model predicts three classes: background (black), touching filaments (red), and non-touching filaments (blue).

Discussion

Attention U-Net achieved the highest mean IoU (0.879) while maintaining competitive overall pixel accuracy (~98%). DeepLabV3+ produced similar segmentation quality despite using a CNN-based encoder. SegFormer did not outperform CNN-based methods on this dataset.

Future Work

- Implement a hybrid post-processing pipeline
- Wrap the hybrid pipeline into a useable program that future researchers can use to assess their wire quality

Acknowledgements

Acknowledgements: This research project was funded by the National Science Foundation (NSF)-Research Experience for Undergraduates OAC-2447779. The computational resources of the study were provided by the Blugold Center for High-Performance Computing under NSF grant CNS-1920220.
The authors also thank Tengming Shen at Lawrence Berkeley National Lab for providing the samples under study.