Deep Fission Track Analysis for Nuclear Forensics

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Abstract of Abstract

Fission Track Analysis (FTA) is a technique in nuclear forensics for detecting and characterizing fissile materials. This study presents an innovative approach leveraging advanced deep learning techniques for segmentation and classification of star-shaped patterns in microscopic images, addressing the challenging and time-consuming process of manually identifying fission track stars.

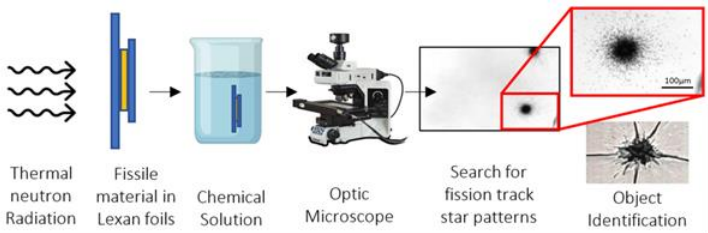

Figure 1: Schematic flow of fission track cluster creation process and star pattern identification

Methodology and Approach

The research employs a U-Net fully convolutional neural network (FCN) architecture specifically designed for segmentation and classification of microscopic star-like shapes. The methodology encompasses several key innovative components: **Comprehensive Data Generation and Preprocessing**: Development of a specialized simulation tool to generate artificial star shapes for model training; Creation of a new database of image stars with diverse characteristics; Characterization of different star types to enhance model robustness. **Advanced Deep Learning Model**: Implemented U-Net model with 5-fold cross-validation analysis; Developed separate models for different star characteristics: Small-sized stars (< 60µm, < 200 pixels, < 10 leaves, no black center), Larger and more complex star patterns. **Semi-Automated Adaptive Threshold Methodology**: Introduced novel approach for data labelling; Developed targeted research to set optimal thresholds for background noise filtering; Improved identification processes through adaptive threshold setting.

Key Results and Performance Metrics

The research achieved notable performance across multiple segmentation and classification tasks: **Single-Class Segmentation**: Classification accuracy of 92.04% for small-sized stars; ROC curve area of 0.84 for small star classification. **Multi-Class Segmentation:** 86.3% validation accuracy for dual-class (poor and rich) star segmentation; 82.63% accuracy in identifying simulated stars with 3 different leaf configurations (50, 100, and 300 leaves). **Advanced Star Classification**: Developed computational model for higher magnitude and brightness stars; Achieved ROC curve area of 0.90 for advanced star classification.

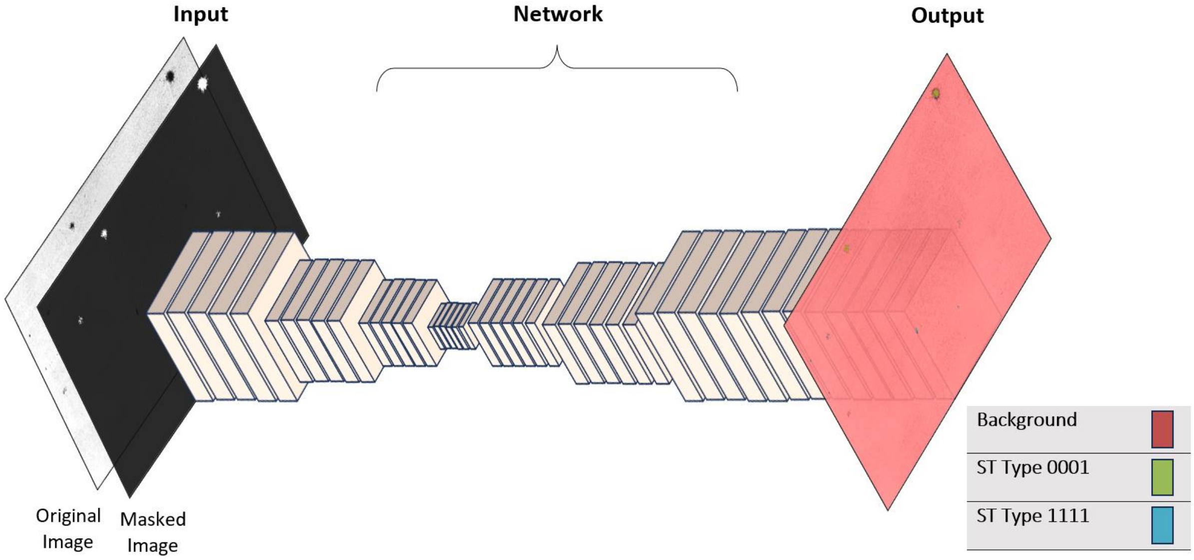

Figure 2: U-Net Architecture for image segmentation and star identification

Significance and Implications

The developed methodology addresses critical challenges in nuclear forensics, particularly the labour-intensive and error-prone manual identification of fission track stars. By automating and improving the segmentation and classification process, this research offers several significant contributions:

Reduced human error in microscopic image analysis; Enhanced efficiency in processing large volumes of microscopic images; Improved accuracy in detecting and characterizing fission track patterns; Potential application in various fields requiring precise microscopic pattern recognition.

Technological Innovation

The research introduces several technological innovations:

Automated segmentation for batch processing of multiple images: Frequency and epoch optimization techniques; Development of a semi-automated adaptive threshold setting for data labelling; Collaboration with simulation programs to enhance model training.

Future Directions

Potential future work includes: Further refinement of the U-Net architecture; Expanding the model's capabilities to handle more complex star configurations; Integration with advanced simulation tools for more comprehensive nuclear forensics analysis.

Conclusions

This study demonstrates the transformative potential of deep learning in nuclear forensics, specifically in the domain of fission track analysis. By combining sophisticated machine learning techniques with specialized domain knowledge, the research provides a robust framework for automated star pattern identification and classification.

References

1. N. Elgad, R. Babayew, M. Last, A. Weiss, E. Gilad, G. Katarivas Levy, I Halevy, “Image segmentation and classification for fission track analysis for nuclear forensics using U-net model”, Journal of Radioanalytical and Nuclear Chemistry, Akadémiai Kiadó, Budapest, Hungary, DOI: 10.1007/s10967-024-09461-2, 2024.
2. R. Babayew, Y. Yehuda-Zada, N. Elgad, J. Lorincik, I. Orion, A. Weiss, G. Katarivas Levy, I Halevy, “Simulation tools for improvement of the fission track analysis method for nuclear forensics”, Journal of Radioanalytical and Nuclear Chemistry, Akadémiai Kiadó, Budapest, Hungary. DOI: 10.1007/s10967-023-09313-5, 2024.