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Comparing Single-Event Transient Data Using Traditional Statistical Approach and Machine Learning

Samuel Teye, and Samantha A. Woodward
Indiana University - Bloomington

Abstract

This study investigates the classification of experimental datasets of Single Event Transients (SETs) using a combination of statistical techniques and machine learning (ML) methodologies. These methodologies possess computational efficiency, interpretability, and adaptability making them essential for initial SET classification. Traditional statistical techniques, such as thresholding based on the mode and standard deviation, are combined with ML algorithms such as *k*-nearest neighbor (KNN) and *k*-means clusters to identify and classify SETs. The methodologies are validated using experimental datasets generated during radiation testing, utilizing an ion-induced SET in an Operational Amplifier (Op-Amp) with Quasi-Bessel Beam (QBB) Pulsed-Laser (PL). These approaches demonstrate their ability to handle noisy and complex SET data, paving the way for advancements in radiation effects research and electronic system resilience.

Motivation

- **Importance**: SETs, caused by radiation, can disrupt electronic systems and lead to failures
- **System Reliability:** Accurate classification of signals is crucial to ensure reliable hardware performance
- **Traditional Limitations:** Simple statistical methods may misclassify signals near edges
- **Advancements**: KNN machine learning model can improve classification accuracy

Project Description

Classifying NRL data to distinguish between transient and non-transient signals. By comparing two methods – statistical thresholding and machine learning classification using KNN- the project aims to determine the most effective approach for accurate SET detection.

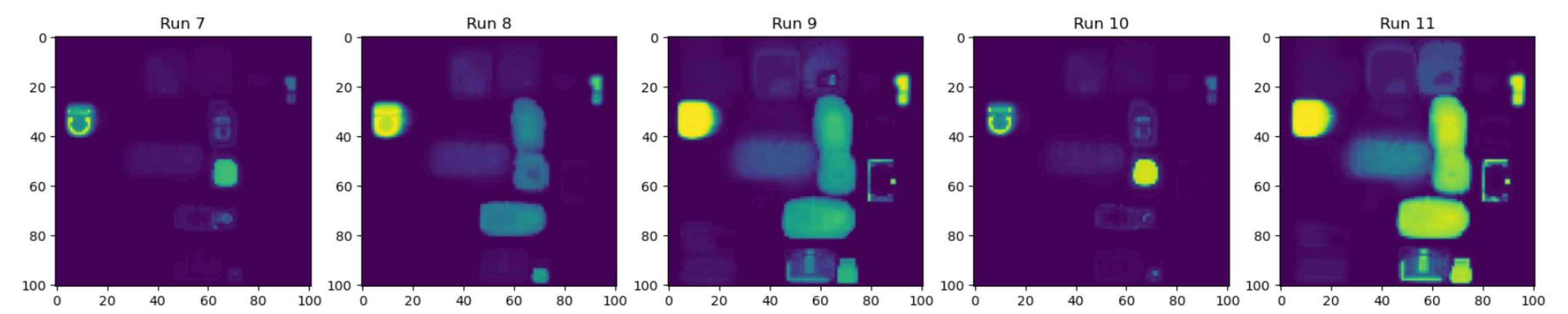


Figure 1 Heatmap of raw data illustrating Standard Deviation of the entire dataset

Methodology

Thresholding Approach

1. Calculate mode and standard deviation for each run
2. Calculate upper and lower threshold bounds
3. Determine k value for threshold sensitivity

Machine Learning Approach

1. Split training and test data
2. Determine k cluster value on training data
3. Label training clusters
4. Extract signal features from taining data
5. Train KNN Model on features and labels
6. Predict classification on testing set

Results

Thresholding Approach

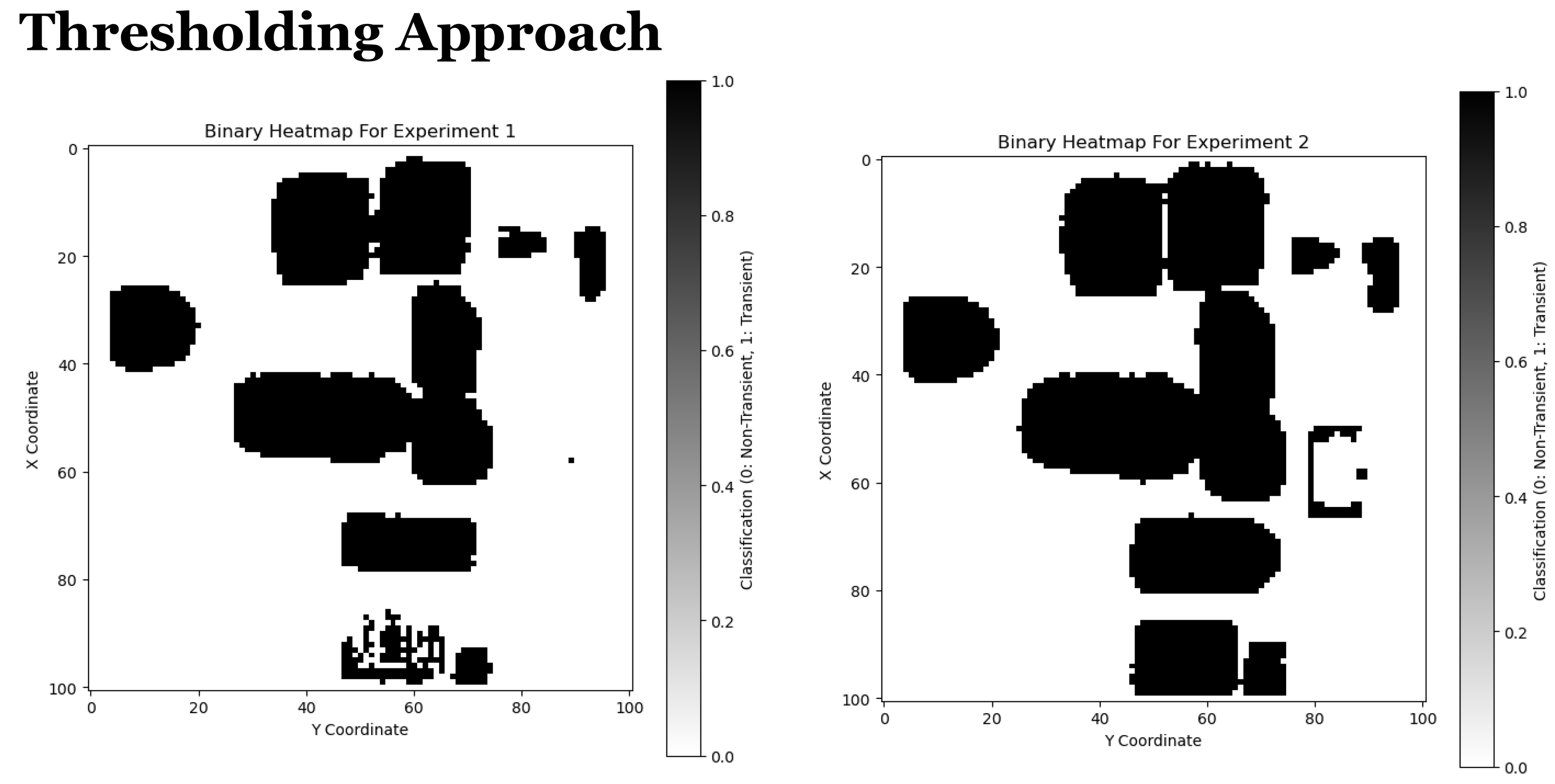


Fig.1. Binary heatmap showing transient and non-transient regions for Experiment 1

Thresholding Approach

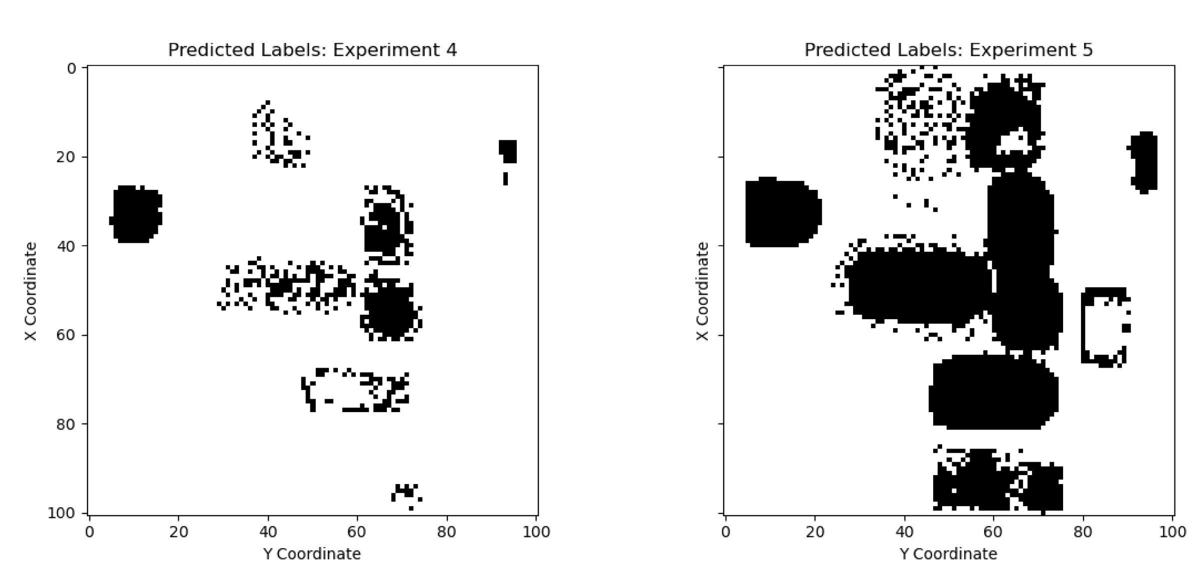
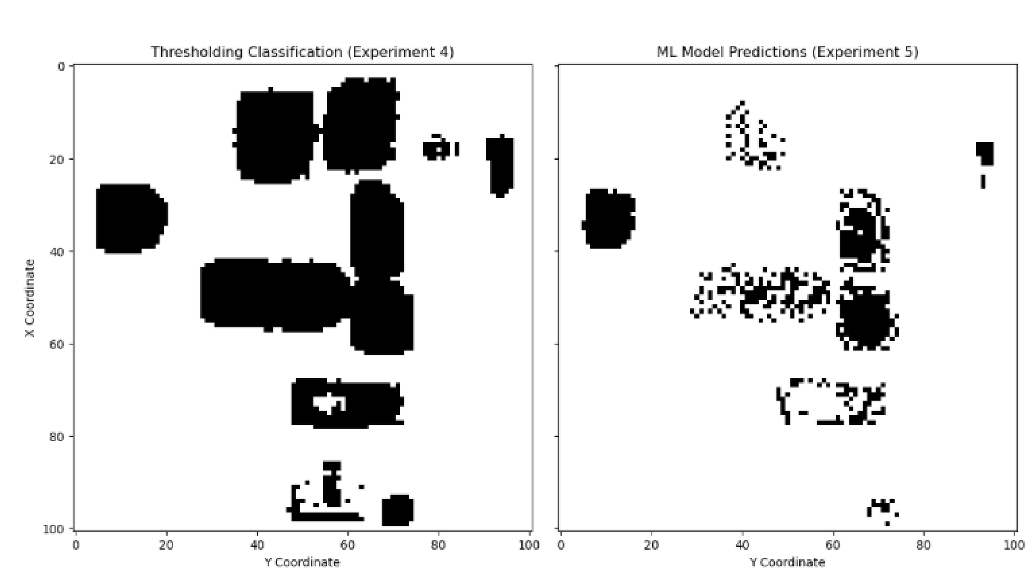


Fig.3. Binary Heatmap showing the classification results from KNN predictions for experiment 4 and 5



Conclusion

This study highlights the importance of classifying Single Event Transient (SET) datasets using traditional statistical methods and machine learning (ML) techniques. Statistical methods proved effective for binary classification, revealing patterns in SET behavior. Integrating ML algorithms like k-means and KNN further improved classification accuracy, though challenges remained with noisy and low-intensity transients. The combined approach of statistical and ML methods enhances precision, automates classification, and provides deeper insights into radiation impacts and how we can enhance microelectronic system resilience in radiation environments. Future research can focus on identifying additional features to refine classification and apply these methods to a wider range of circuits.

References

[1] A. Balakrishnan, T. Lange, M. Glorieux, D. Alexandrescu, and M. Jenihhin, “Modeling gate-level abstraction hierarchy using graph convolutional neural networks to predict functional de-rating factors,” in Proc. NASA/ESA Conf. Adapt. Hardw. Syst. (AHS), Jul. 2019
[2] T. D. Loveless, D. R. Reising, J. C. Cancelleri, L. W. Massengill, and D. Mcmorrow, “Analysis of single-event transients (SETs) using machine learning (ML) and ionizing radiation effects spectroscopy (IRES),” IEEE Trans. Nucl. Sci., vol. 68, no. 8, pp. 1600–1606, Aug. 2021.
[3] T. Peyton et al., "Supervised Deep Learning and Classification of Single-Event Transients," in IEEE Transactions on Nuclear Science, vol. 70, no. 8, pp. 1740-1746, Aug. 2023, doi: 10.1109/TNS.2023.3268987

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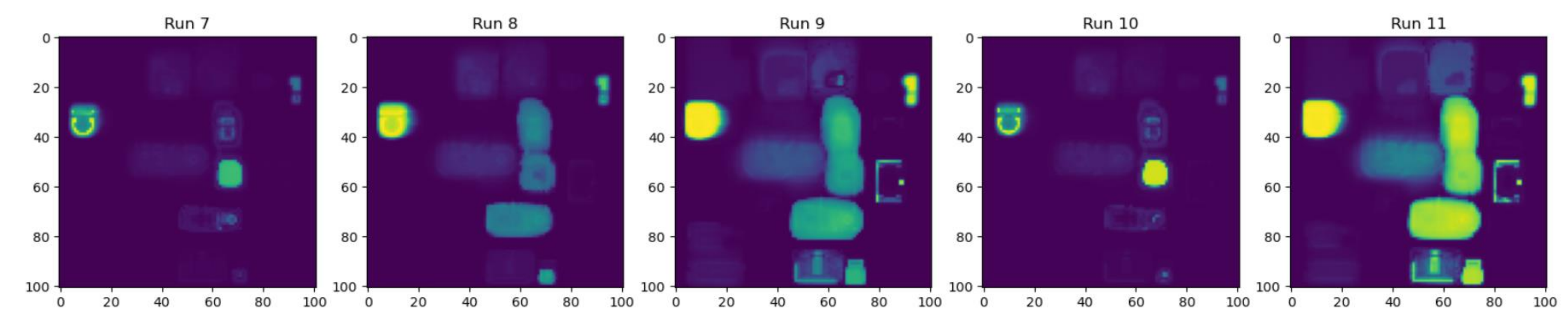

Figure 1 Heatmap of raw data illustrating Standard Deviation of the entire dataset

Methodology

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1. Calculate mode and standard deviation for each run
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3. Determine k value for threshold sensitivity

Machine Learning Approach

1. Split training and test data
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3. Label training clusters
4. Extract signal features from taining data
5. Train KNN Model on features and labels
6. Predict classification on testing set

Results

Thresholding Approach

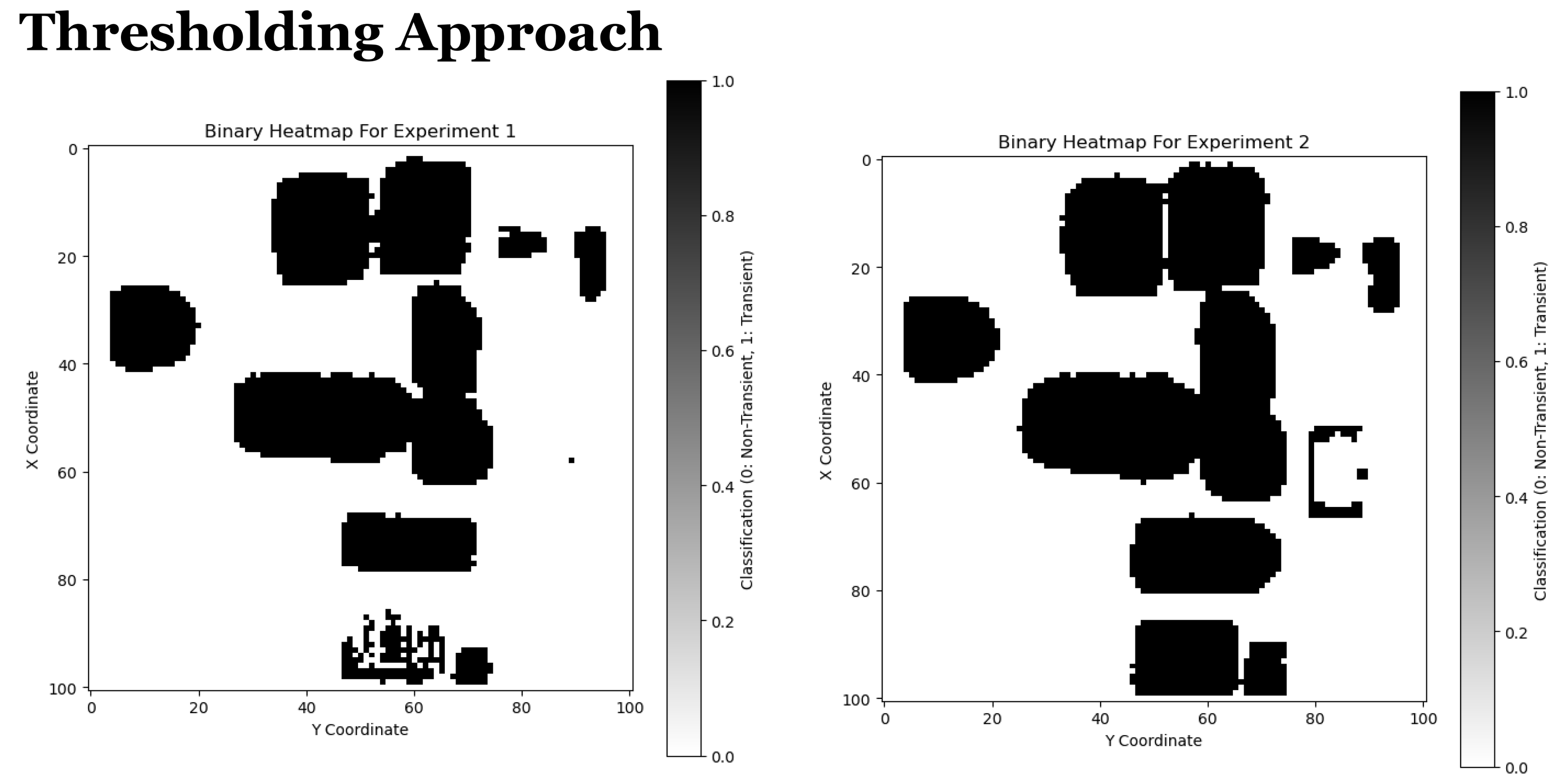


Fig.1. Binary heatmap showing transient and non-transient regions for Experiment 1

Thresholding Approach

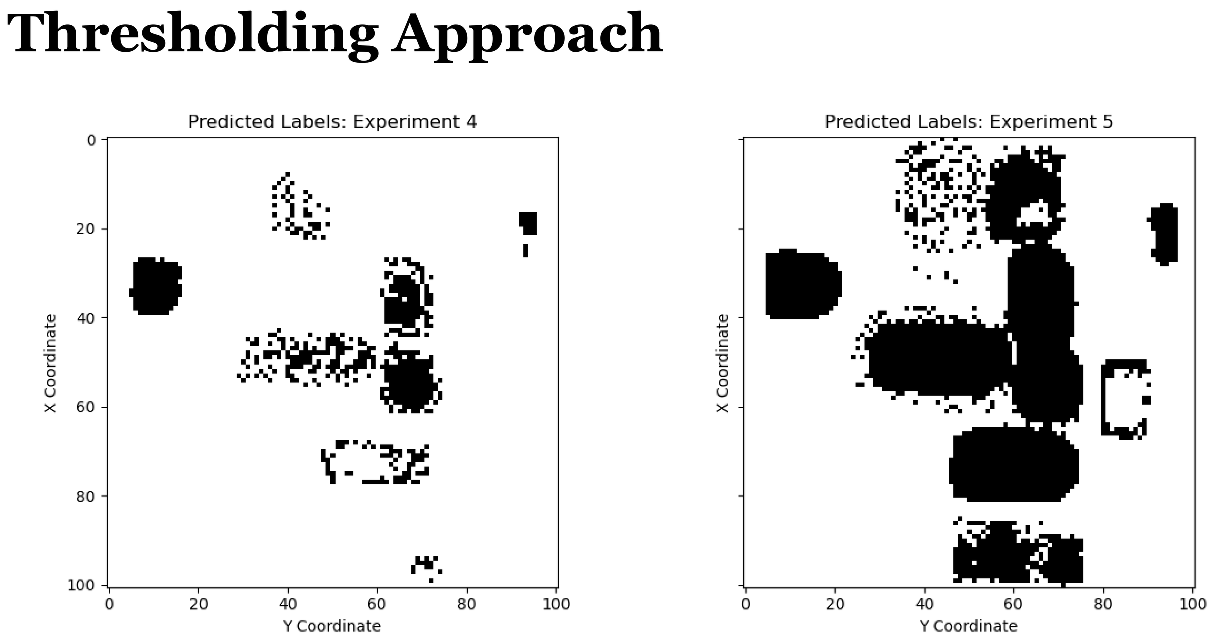
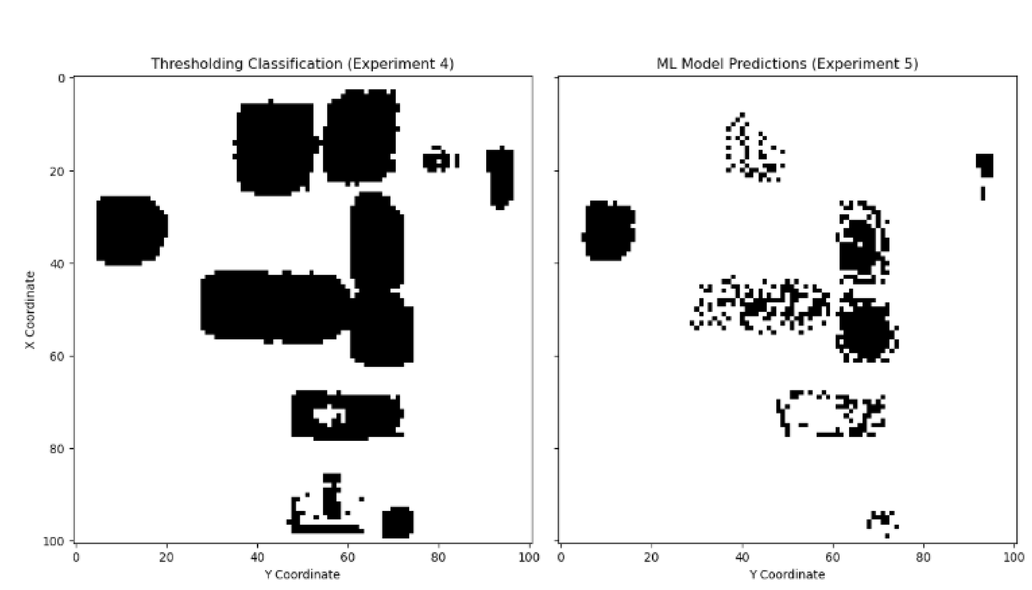


Fig.3. Binary Heatmap showing the classification results from KNN predictions for experiment 4 and 5



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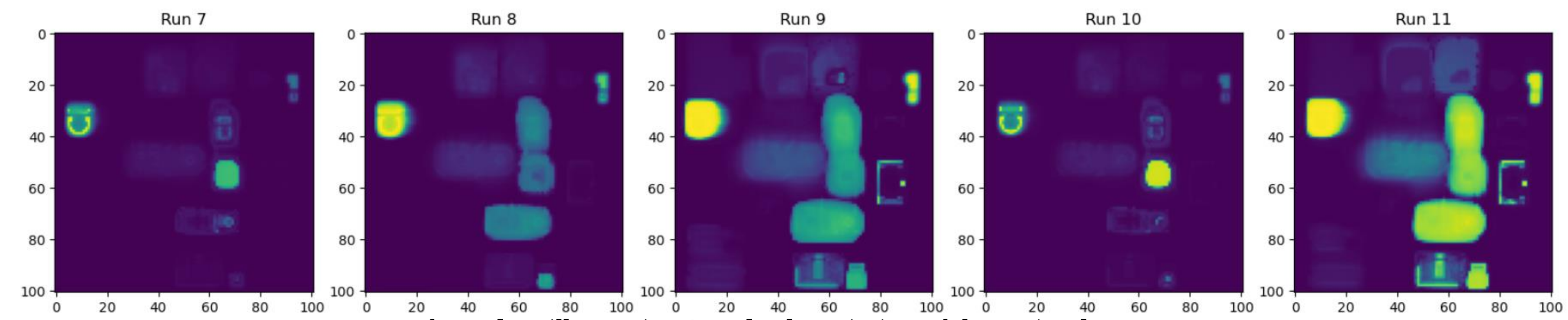
Motivation

- **Importance**: SETs, caused by radiation, can disrupt electronic systems and lead to failures
- **System Reliability:** Accurate classification of signals is crucial to ensure reliable hardware performance when testing
- **Traditional Limitations:** Near the Signal edges, the statistical methods are not reliable and require advanced computation and analysis
- **Advancements**: KNN machine learning model can improve classification accuracy

Project Description

This study aims to investigate an effective methodology for SET detection and classification for transient and non-transient signals by comparing two approaches: statistical thresholding and machine learning classification using *k*-nearest neighbors (KNN).



Heatmap of raw data illustrating Standard Deviation of the entire dataset

Methodology

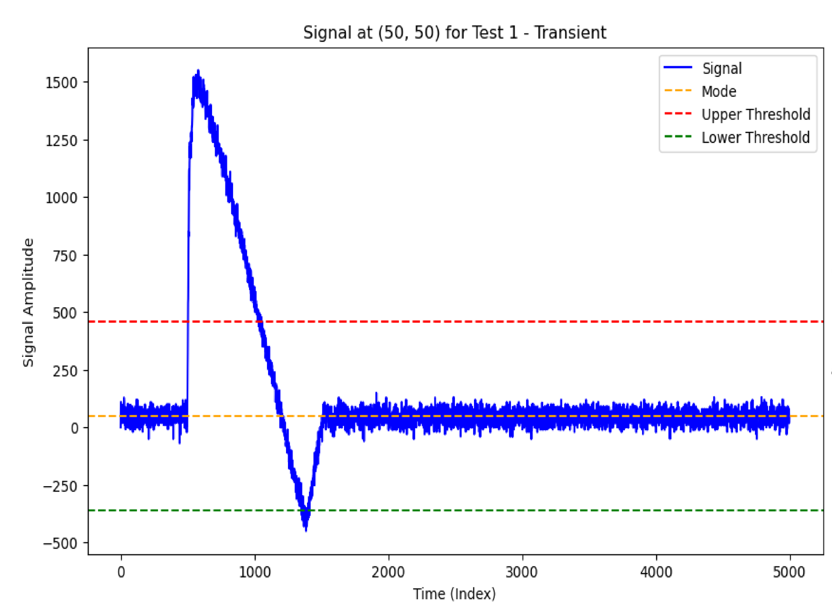
Statistical thresholding Approach

1. Determine the mode for entire dataset
2. Determine the standard deviation on each run
3. Determine the upper and lower threshold bounds
4. Determine k value for threshold sensitivity

Machine Learning Approach

1. Split training and test data (60%, 40% respectively)
2. Determine optimal *k*-means value on training data
3. Label training clusters
4. Extract signal features from training data
5. Train KNN Model on features and labels
6. Predict classification on testing set

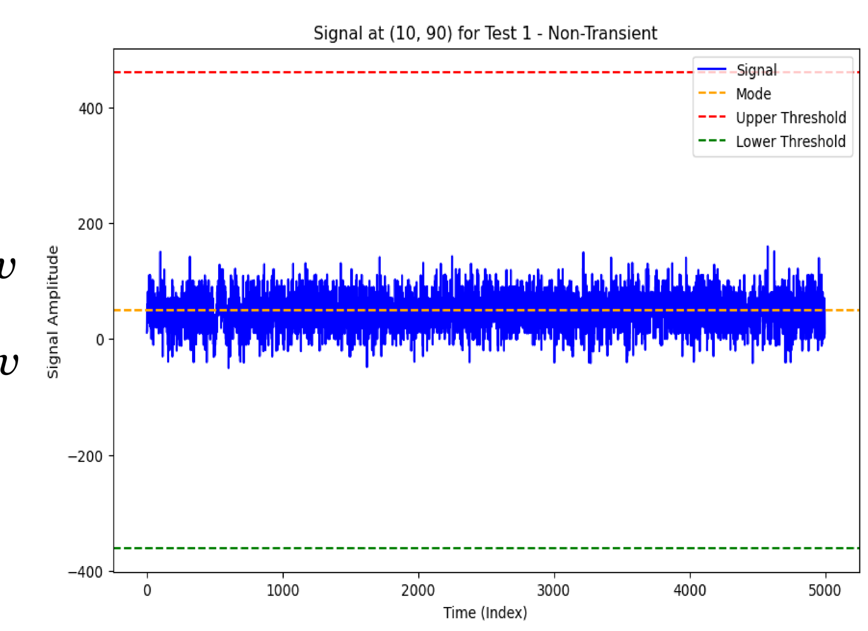
Transient and Non-Transient Signals



Transient Signal at (50,50) in Experiment 1

Upper threshold= *mode* + k * *std_dev*

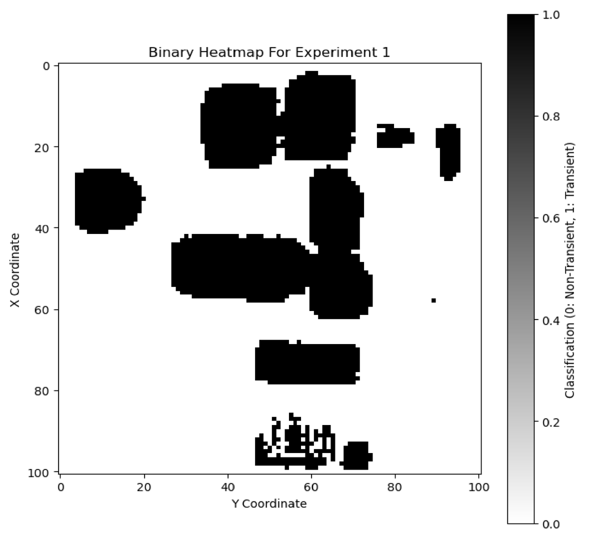
Lower threshold= *mode* - k * *std_dev*



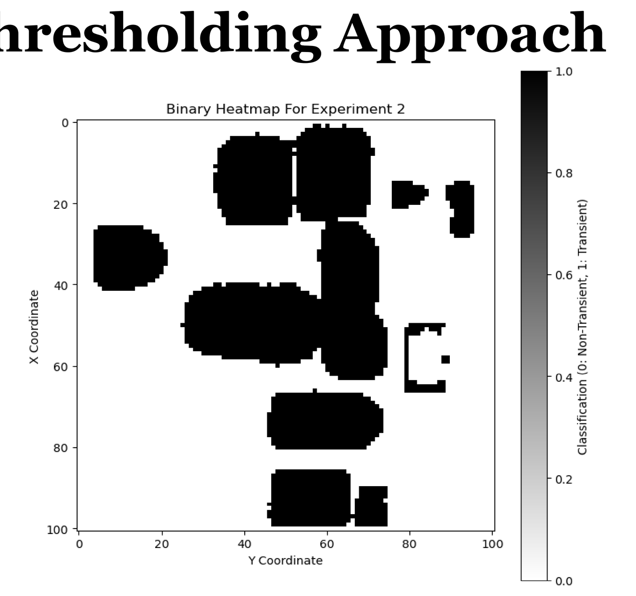
Non-Transient Signal at (50,50) in Experiment 1

Results

Thresholding Approach



Binary classification for Experiment 1



Binary classification for Experiment 2

Binary classification for Experiment 3

Thresholding Key Observations

- The accuracy of the thresholding results depends on selecting an optimal k value
- All transient sections were identified in each experiment
- Potential overclassification of transient signals at the boundaries at certain transient regions

Machine Learning Key Observations

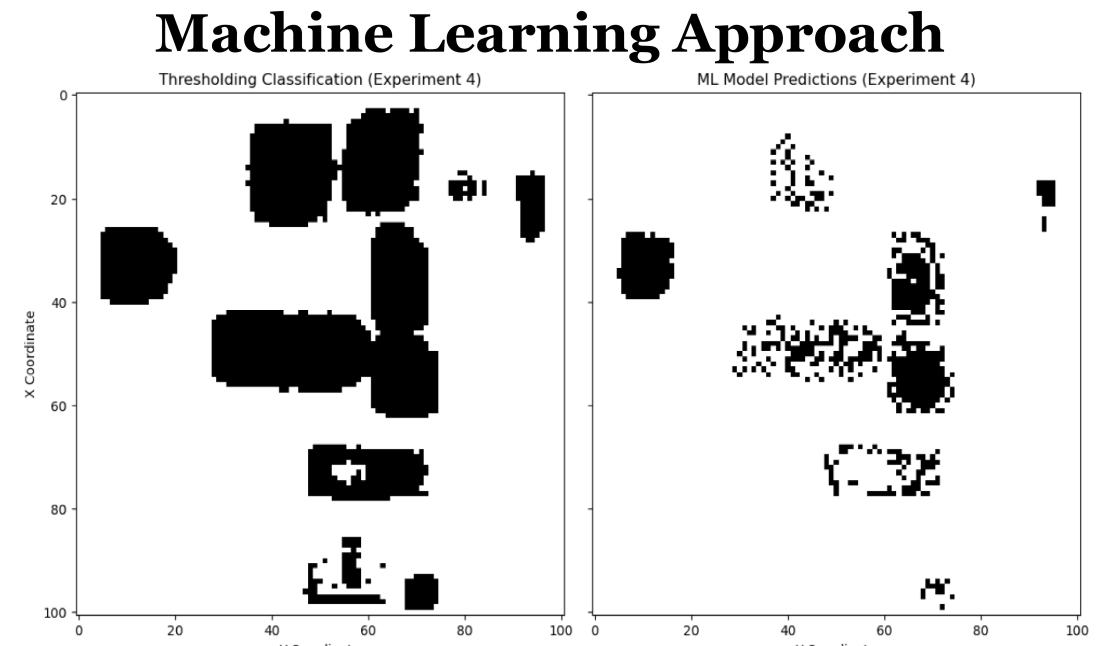
- KNN demonstrated effective classification of the most prominent transient sections
- KNN exhibited successful classification in certain less prominent regions

Comparison

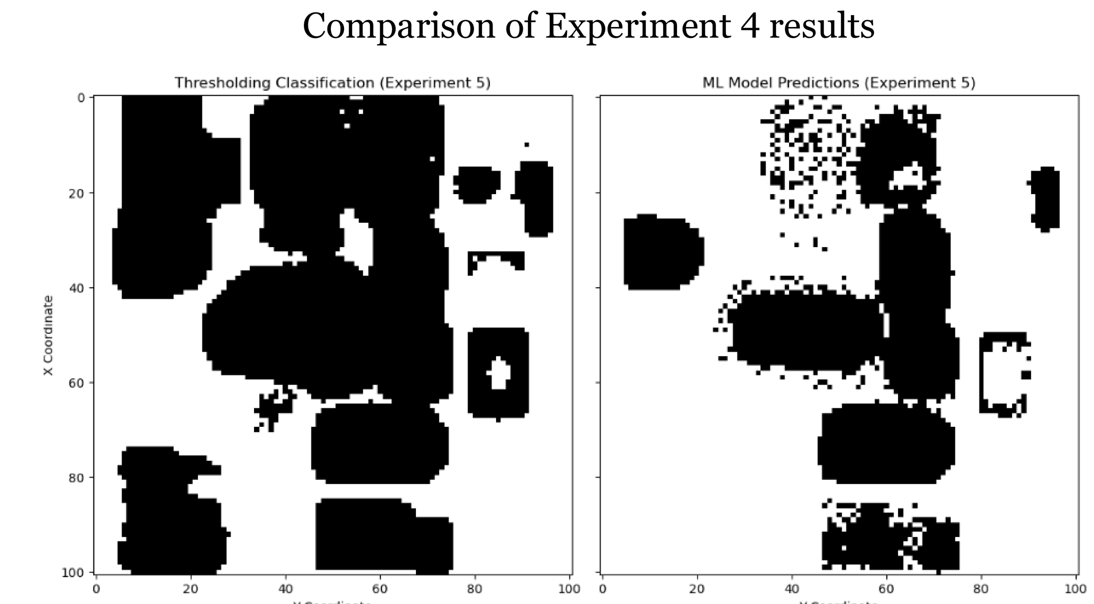
Experiment 4: 69% fewer transient detections using machine learning prediction with 85.1% similarity score

Experiment 5: 50.29% fewer transient detections using machine learning predictions with 73.51% similarity score

Machine Learning Approach



Comparison of Experiment 4 results



Comparison of Experiment 5 results

Conclusion

This study compares two methods for classifying Single Event Transient (SET) datasets: traditional statistical methods and machine learning (ML) techniques. The statistical method is effective for binary classification but may overclassify transient signals. ML methods like *k*-means and KNN are effective but may under classify noisy and low-intensity transients. Optimizing these methods can enhance precision, automate classification, and provide insights into radiation impacts and microelectronic system resilience. Future research can identify additional features to refine classification and apply these methods to a wider range of circuits.

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