Using Fourier Analysis and Machine Learning to Detect Heart Irradiation in Deep Inspiration Breath Hold Breast Radiotherapy

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ABSTRACT

Purpose: Develop an automated method for detecting heart irradiation in DIBH breast radiotherapy using EPID cine images.

Methods: EPID cine images from 10 DIBH left breast radiotherapy treatments were labeled at the beam level for heart presence. Fourier analysis was used to enhance cardiac motion in the cine images. SNR profiles were extracted from these enhanced images and used as input features for machine learning classification.

Results: SNR-based classification performance using Naive Bayes achieved AUC = 0.69. Results suggest cardiac-related temporal signal can be detected, but confounding motion and treatment-specific anatomy limit robustness.

Conclusion: Fourier-derived SNR features show potential for detecting heart irradiation in EPID cine images. Future work will focus on CNN-based approaches that incorporate planning heart contours to guide classification.

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INTRODUCTION

Heart irradiation during breast radiation therapy leads to the risk of radiation-induced heart disease [1]. Deep Inspiration Breath-Hold (DIBH) can reduce heart irradiation by displacing the heart away from the radiation beam (Fig. 1) [1].

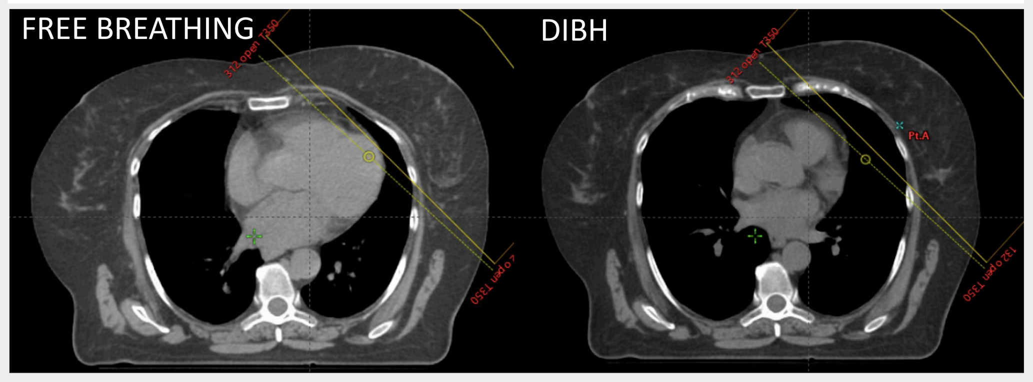

Figure 1. Heart position shown in free breathing (left) and DIBH (right).

However, studies have shown DIBH may be insufficient to avoid heart irradiation [1,2]. Therefore, a direct method to determine the presence of the heart in the treatment field is desired. Electronic Portal Imaging Device (EPID) images directly visualize the irradiated anatomy and can be analyzed to check for the heart within the treatment field (Fig. 2).

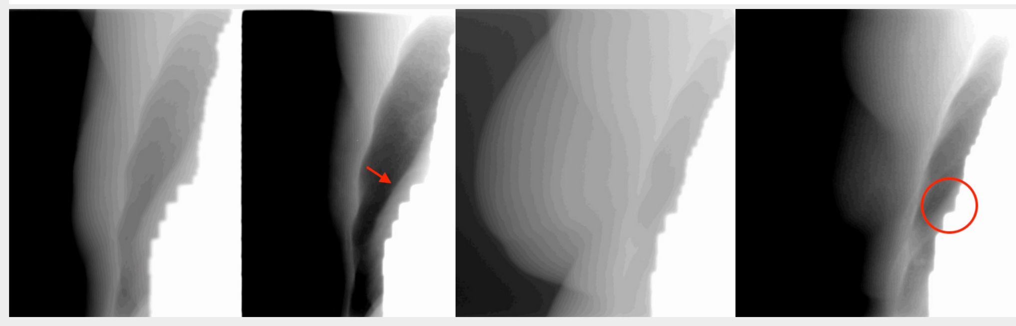

Figure 2. Two instances of heart irradiation seen in EPID images from tangential beams.

METHODS AND MATERIALS

EPID cine images from 10 DIBH left breast radiotherapy treatments were retrospectively reviewed and labeled at the beam level for presence or absence of heart irradiation.

For each tangential beam, Fourier analysis was applied to temporal changes in pixel intensity. Frequency-domain images were generated to emphasize periodic signal fluctuation (Fig. 3), and row-wise signal-to-noise ratio (SNR) profiles were extracted as beam-level features.

Row-wise SNR profiles were used as input features for Naive Bayes, K-Nearest Neighbors, Support Vector Machine, and Logistic Regression classifiers. Model performance was evaluated using leave-one-treatment-out cross-validation.

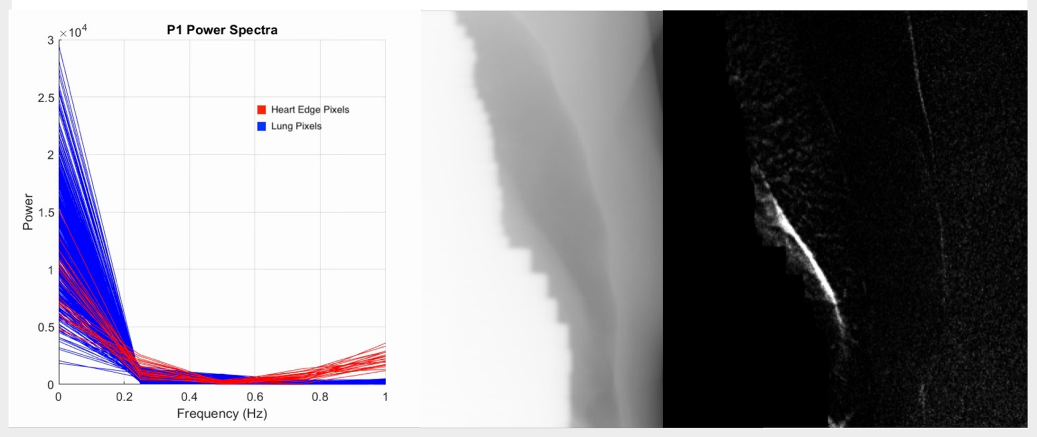

Figure 3. Spectral components of heart edge and lung pixels (left), original EPID image (center), spectral image highlighting cardiac motion (right).

RESULTS

Figure 4 displays the Receiver Operating Characteristic (ROC) curves from the SNR-based classification. The dataset contained 398 tangential beams from 10 DIBH treatments, with heart irradiation present in 221 beams and absent in 177 beams.

Using leave-one-treatment-out evaluation, Naive Bayes performed best, with an AUC of 0.69. K-Nearest Neighbors achieved an AUC of 0.58, while Logistic Regression and Support Vector Machine achieved AUC scores of 0.49 and 0.43, respectively.

Classifier	AUC
Naïve Bayes	0.69
K-Nearest Neighbors	0.58
Logistic Regression	0.49
Support Vector Machine	0.43

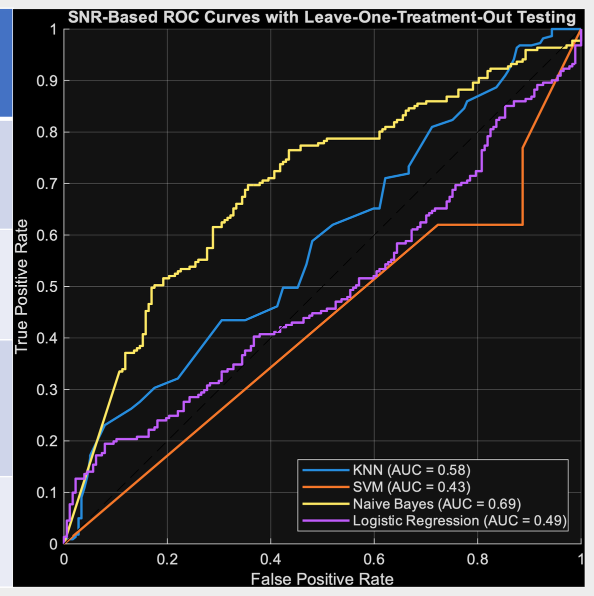

Figure 4. AUC and ROC results for SNR-based classification using leave-one-treatment-out validation.

DISCUSSION

Leave-one-treatment-out cross-validation was selected to maximize the available training data while preventing same-treatment data leakage.

As shown in Figure 5, spectral images demonstrated distinct patterns across cases:
- Clear heart-region enhancement in some heart-present beams
- Weak/noisy signal in some heart-absent beams
- Non-cardiac enhancement of structures such as ribs in confounded cases.

These examples suggest that Fourier-derived SNR features can capture cardiac-related temporal signal, but similar spectral enhancement from non-cardiac anatomy may limit classification performance. This may reflect a limitation of row-wise SNR profiles, which reduce the spatial information needed to distinguish cardiac signal from non-cardiac confounders.

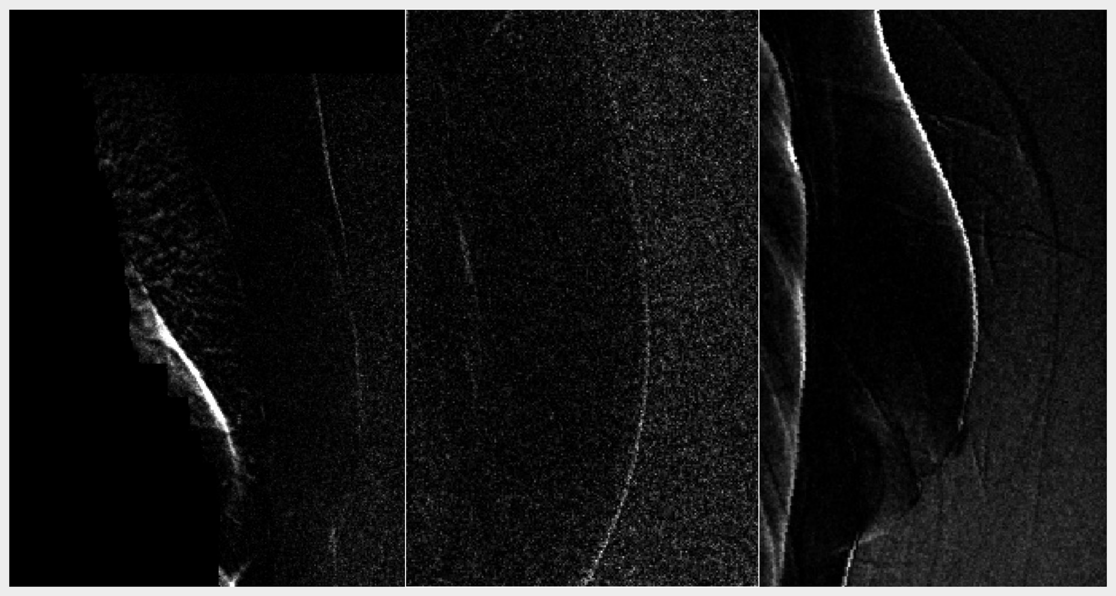

Figure 5. Representative spectral images showing cardiac enhancement (left), absence of cardiac signal (center), and non-cardiac enhancement (right).

FUTURE WORK

Preliminary CNN-based experiments using ResNet-18 feature extraction were also explored using raw EPID image sequences from a separate cohort of 13 DIBH treatments (478 beam sequences; 227 heart-positive, 251 heart-negative) (Fig. 6).

CNN-derived features can incorporate whole-image spatial information and may better capture subtle changes in EPID image appearance related to heart irradiation.

Temporal metrics derived from CNN features showed improved classification performance in this separate preliminary analysis, with the best model achieving an AUC of 0.73.

Future work will focus on anatomy-guided inputs using exported heart contours. Incorporating planned heart location may further improve classification and enable progression toward quantifying irradiated heart area rather than only detecting heart presence.

Classifier	AUC
TemporalRange SVM	0.73
TemporalStd SVM	0.71
MeanAbsDiff + DiffStd SVM	0.65
MeanAbsDiff SVM	0.63

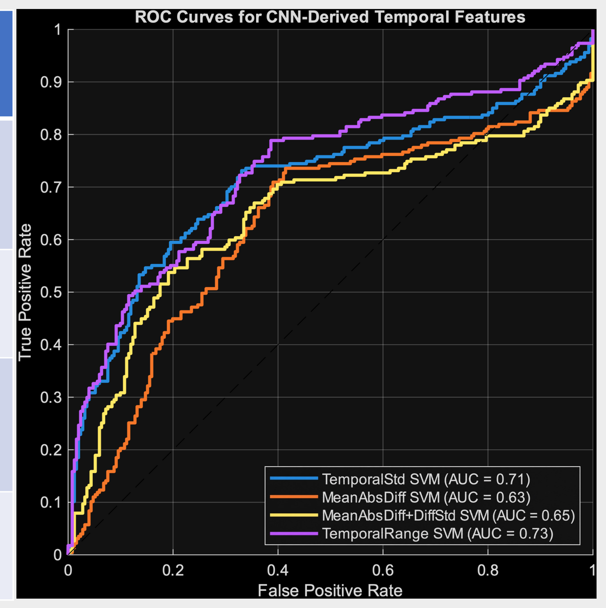

Figure 6. AUC and ROC curves for preliminary CNN-based classification using leave-one-treatment-out validation.

CONCLUSIONS

Fourier-derived SNR features from EPID cine images were investigated for detecting heart irradiation in DIBH breast radiotherapy, with best performance observed using Naive Bayes. Performance was limited under leave-one-treatment-out testing, highlighting the difficulty of separating cardiac-related temporal signal from non-cardiac motion.

Future work will focus on CNN-based analysis of EPID cine images, using larger datasets and anatomy-guided inputs such as planning heart contours to guide classification and support quantification of irradiated heart area.

REFERENCES

1. Conroy, L., et al. *Journal of Applied Clinical Medical Physics*, 17(4), 25-36, 2016
2. Poulsen, PR., et al. *Radiotherapy and Oncology*, 152, 189-195, 2020