Automated Skin Thickening Extraction in Post Radiotherapy Mammograms via Feedforward Neural Networks Using Histogram Based Segmentation and Continuous Hidden Markov Model Generated Features

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The purpose of this study is to establish an automated technique that accurately and effectively characterizes skin thickening in mammograms after breast conserving surgery and radiation therapy (BCS+RT).

The database of patients was retrospectively identified as those who were treated with Accelerated Partial Breast Irradiation (APBI), HypoFractionated Whole Breast Irradiation (HF-WBI), or Whole Breast Irradiation (WBI) after BCS with at least 3 mammograms. 89 female patients were identified with an average age of 66.65 +/- 10.5 from which 605 images were collected with at least 3 mammograms of each treated breast. A mammographer, with over 20 years of experience, established ground truth for the presence of skin thickening. The salient tissue region of each mammogram is identified by thresholding, using the maximal peak of the histogram of each image, which corresponds to the background black level. Following this is a sequence of dilation and erosion morphological filters. Regions of connectivity are then identified via a connected component analysis on the resulting image; the largest of which represents a fully segmented breast mask. This mask is used in a sampling operation in which a surface-orthogonal linear-fit, traversing into and out of the breast mask, is used. These samples are processed by a continuous hidden Markov model, which predicts the underlying tissue transition sequence. From these predictions, features are calculated for a neural network classifier. Leave-one-out analysis is used to train and evaluate the classifier's efficacy at predicting the extent of skin thickening per mammogram. Classifier performance is finally determined by ROC curve analysis.

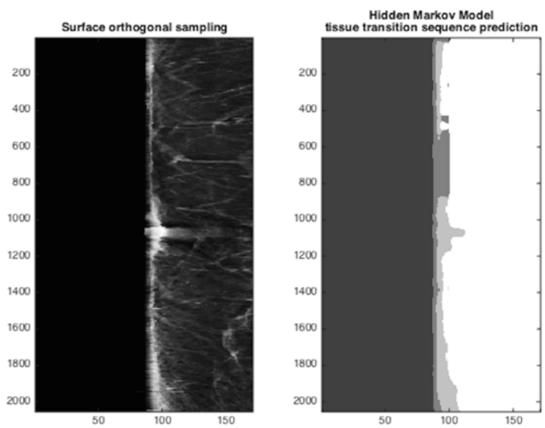

Figure 1. Continuous HMM prediction of tissue transition sequence of the orthogonally sampled mammogram

From the most efficient threshold of the ROC curve (threshold: .63, efficiency 90.48%), a test sensitivity of 85.71% and specificity of 100% is observed. In order to validate these numbers, a bootstrapping technique (N =100) is used to calculate a confidence interval of [0.6923,0.9176]. Since this lies above the 50% line (i.e. y=x) at this specificity, these values are seen as significant. In addition, the AUC was computed to be .9264, with a standard error of .0398 and a 95% confidence interval of [.85,1.00], which is statistically greater than 0.5.

An effective skin thickening detection scheme has been developed and shown to perform at a statistically significant level that nears the efficacy of a seasoned mammographer. This skin thickening detection scheme can be used to enhance an automated feature set for radiologists as well as powering future studies that evaluate the effects of various radiotherapy treatments on skin thickening.

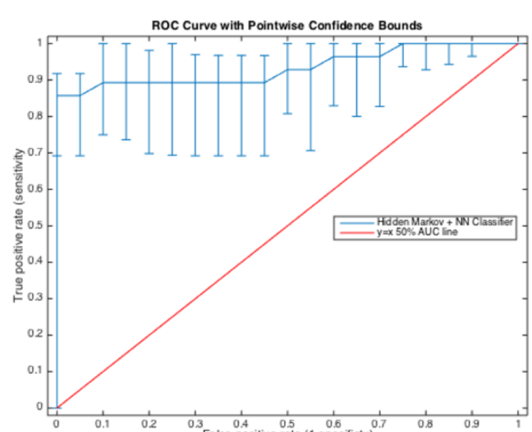

Figure 2. Bootstrapped ROC curve analysis of the proposed system.

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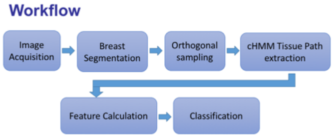
Purpose and Background

- The purpose of this study is to establish an automated technique that accurately and effectively characterizes skin thickening in mammograms after breast conserving therapy.
- Breast conserving therapy (BCT) refers to breast conserving surgery (BCS), followed by moderate-dose radiation therapy (RT) to eradicate any microscopic residual disease.
- Three dosing schemes were analyzed and an automated system to evaluate skin thickening was developed.

Data

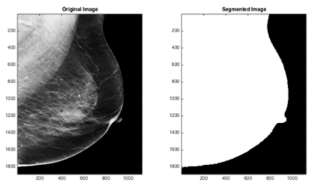
- 89 female patients from which 605 images were collected with at least 3 mammograms of each treated breast
- Average age of patients: 66.65 +/- 10.5
- Sample was retrospectively identified as those who were treated with Accelerated Partial Breast Irradiation (APBI), Hypofractionated whole breast irradiation (HF-WBI), or whole breast irradiation (WBI) after BCS:
  - 29 received APBI
  - 30 received HF-WBI
  - 30 received WBI
- Mammographer, with over 20 years of experience, established ground truth for the presence of skin thickening.

Workflow

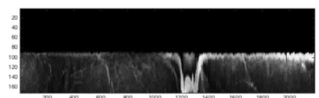


Feature Extraction and Classification

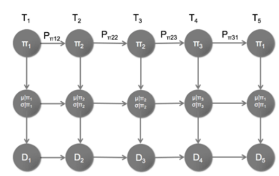
- The salient tissue region of each mammogram is identified via adaptive thresholding, using the maximal peak of the histogram of each image, which corresponds to the background black level.
- Following this is a sequence of dilation and erosion morphological filters to close any gaps in the mask.
- Regions of connectivity are then identified via a connected component analysis on the resulting image; the largest of which represents a fully segmented breast mask.



- This mask is used in a sampling operation in which a surface-orthogonal linear-fit, traversing into and out of the breast mask, is created.



- These samples are processed by a continuous hidden Markov model, which predicts the underlying tissue transition sequence via the Viterbi method.



- Viterbi Path calculation
- **Initiation:**

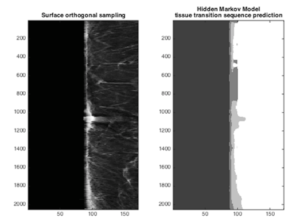
$$\delta_1(i) = P_i \times b_i(D_i)$$
$$\psi_1(i) = 0$$
$$1 \le i \le N$$

Induction:

$$\delta_{t+1}(j) = max_{1\le i\le N}\left[\delta_t(i)\times P_{ij}\right]\times b_j(D_j)$$
$$\psi_{t+1}(i) = argmax_{1\le i\le N}\left[\delta_t(i)\times P_{ij}\right]$$
$$1 \le t \le T$$
$$1 < i$$
$$j \le N$$

Termination:

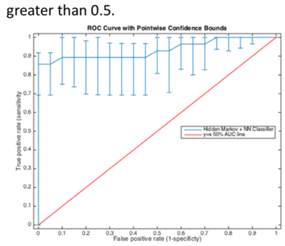
$$\mathbf{\Pi}_T = max_i\left[\delta_T(i)\right]$$
$$\mathbf{\Pi}_t = \psi_{t+1}\left[\mathbf{\Pi}_{t+1}\right]$$



- Features derived from the above Viterbi path were calculated via the following rules:
  1. The average continuous length of each predicted tissue state from the cHMM features across all orthogonal samples calculated as a percentage.
  2. The **absolute** average continuous length of each predicted tissue state from the cHMM features across all orthogonal samples.
  3. The percentage of rows that contained at least one predicted hidden state representing thickened skin.
- These features are fed as inputs into a simple Multi Layer Perceptron with 5 hidden nodes.
- Leave-one-out analysis is used to train and evaluate the classifier's efficacy at predicting the extent of skin thickening per mammogram. Classifier performance is finally determined by ROC curve analysis.

Results

- From the most efficient threshold of the ROC curve (threshold: .63, efficiency 90.48%), a test sensitivity of 85.71% and specificity of 100% is observed. In order to validate these numbers, a bootstrapping technique (N =100) is used to calculate a confidence interval of [0.6923,0.9176]
- AUC was computed to be .9264, with a standard error of .0398 and a 95% confidence interval of [.85,1.00], which is statistically greater than 0.5.



Summary

- An effective skin thickening detection scheme has been developed and shown to perform at a statistically significant level that nears the efficacy of a seasoned mammographer.
- This skin thickening detection scheme can be used to enhance an automated feature set for radiologists as well as powering future studies that evaluate the effects of various radiotherapy treatments on skin thickening.

Acknowledgements

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- This work was also supported by the Rutgers University Robert Wood Johnson Medical School.