Image Processing Challenges for X-ray Personnel Screening Systems

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Brian Tracey, Ph.D., Research Professor, ECE Dept., Tufts University

(also involved: Eric Miller, Tufts)

ADSA08, October 25, 2012

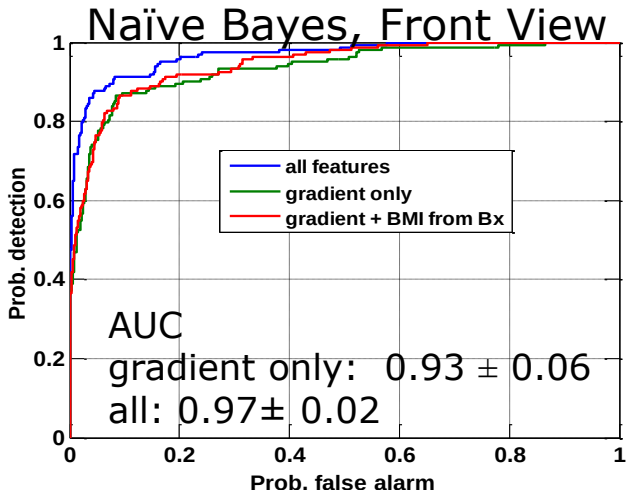
Tufts

Conclusions

- Technical conclusions
  - Tx-derived cues for BMI, symmetry can be fused with XBS Bx images to reduce false alarms
  - Pre-processing is important; in particular, NLM denoising is promising for XBS
  - Multi-patch NLM methods can offer improved performance
- Thoughts on industry/university collaboration
  - Careful problem definition by industry has been a major boost to our work
  - Collaboration has also benefited from time and money investments on both sides (specific examples below)

Problem 1: Lung false alarms

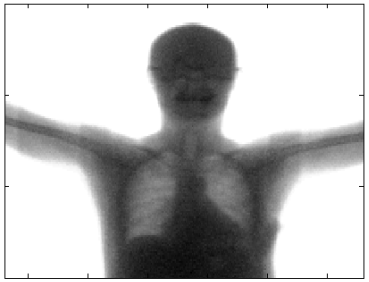
- Several classifiers trained using 148 images, manually denoted threats
- Results indicate that addition of Tx-derived cues (blue line) improves ROC
- In SPIE paper we also showed:
  - Male/female sorting is beneficial
  - Denoising approach affects ROC (NLM performs best)

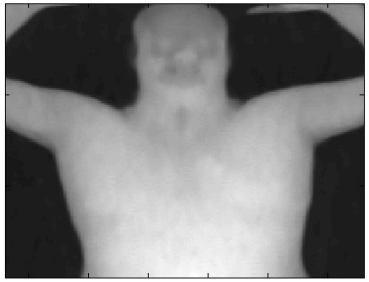


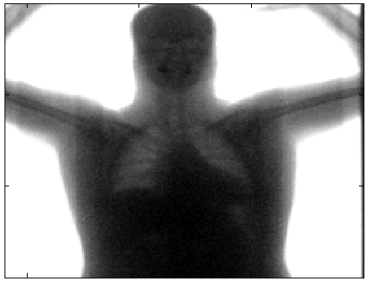
Preprocessing is important!

Denoised Bx

Log-scaled Tx







Disclaimer: Images in presentation are from non-TSA system

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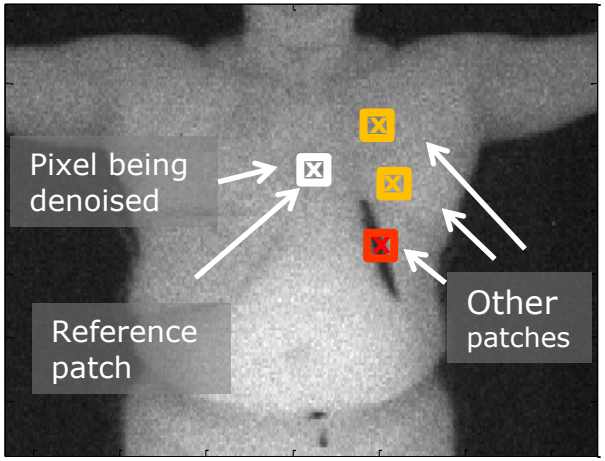
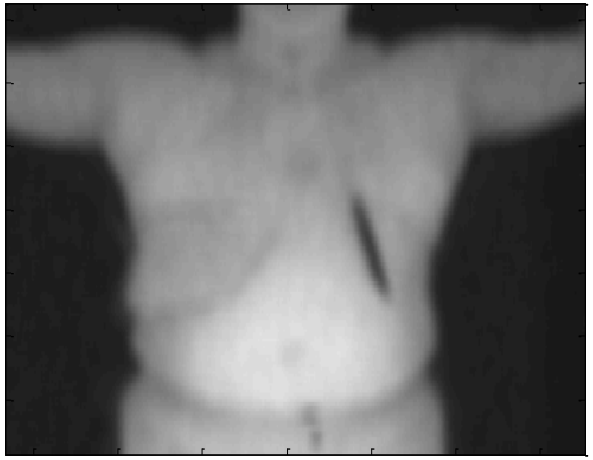
Problem 2: Patch-based denoising for XBS images

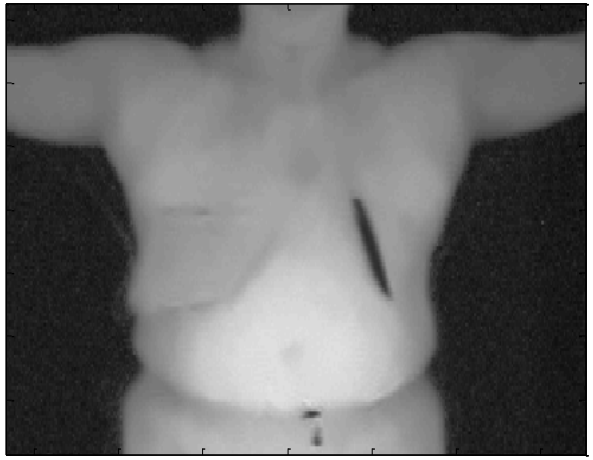
Raw image



7x7 smoothing window



7x7 NLM patch



- For XBS, *edge* information in image is critical
- Standard denoising uses local averaging, thus blurring edges
- Non-local means (NLM) averages based on **patch similarity**

Outline

- False alarm reduction efforts
- Improved denoising for XBS
- AS&E/ Tufts interactions

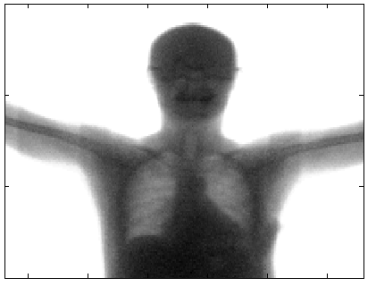
Problem 1: Lung false alarms

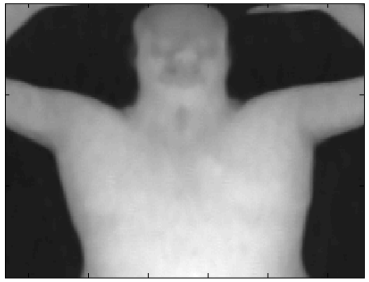
- In thin (low-BMI) subjects, lungs are clearly visible in Bx image
- High gradients at lung boundaries can trigger false alarms
- How can we reduce these?
  - –Exploit clearer view of lungs available from Tx images
  - –Other cues (BMI, symmetry, etc)
- Goal: Proof-of-concept that use of Tx data can reduce lung-related false alarms

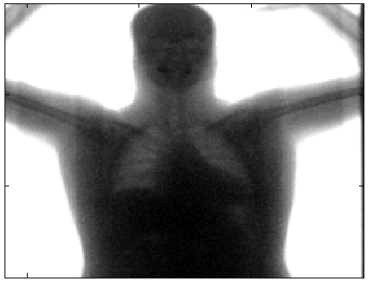
Preprocessing is important!

Denoised Bx

Log-scaled Tx







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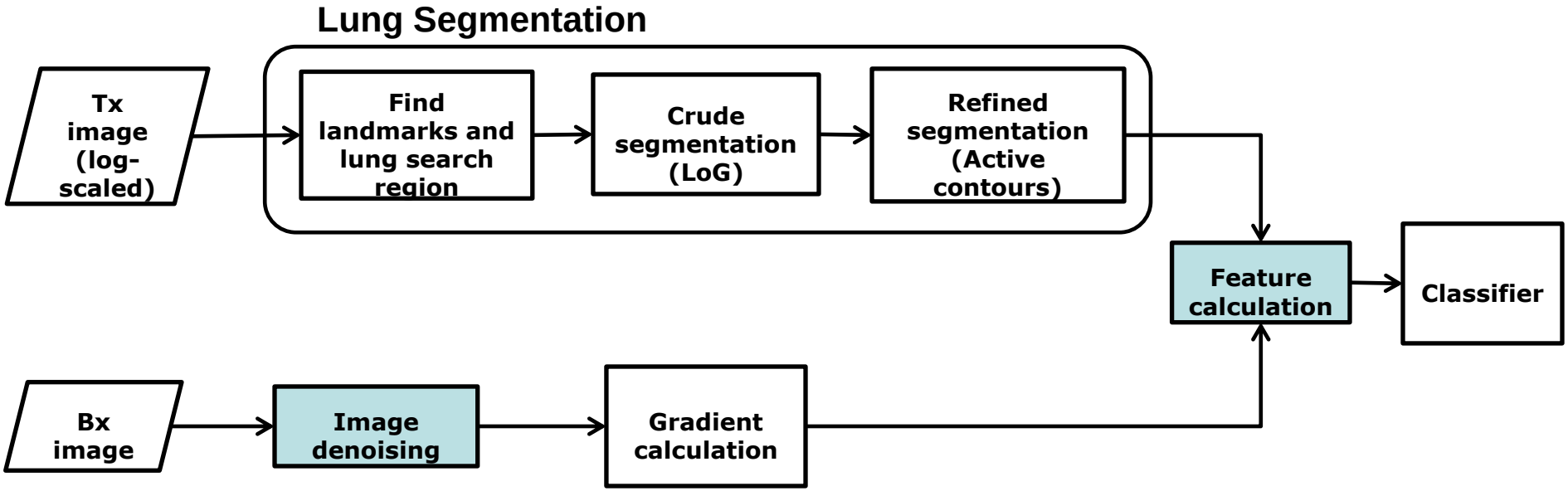
Processing Flow



- Bx-only processing corresponds to bottom path; essentially, look for edges in image after denoising
- For more details, see SPIE paper

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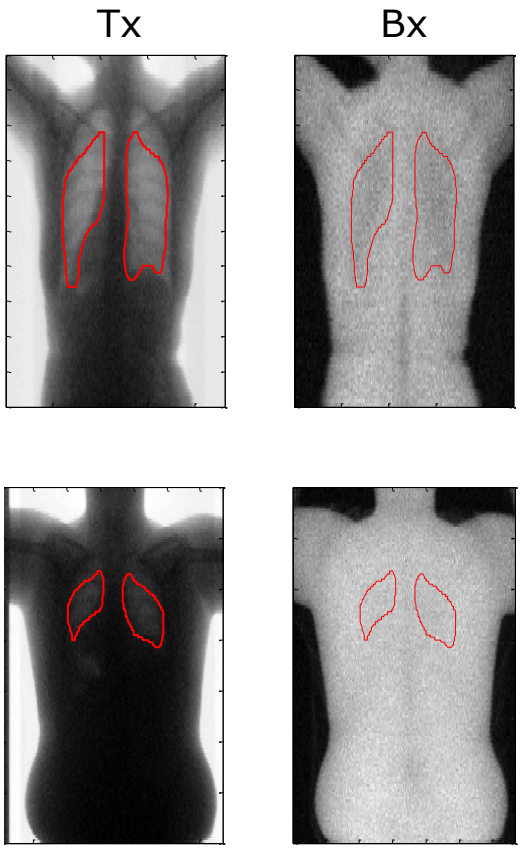
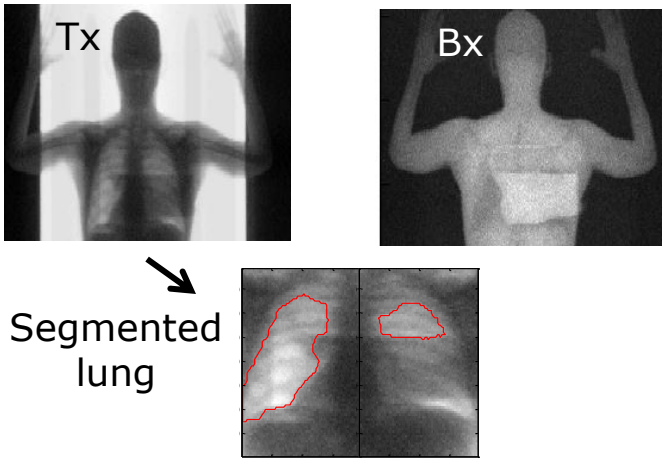
Classification features derived from Tx data

- **BMI: lung visibility is linked to body mass**
  - –Metric 1: Lung contrast (lung/exterior)
  - –Metric 2: Lung area ratio (segmented lung area as % of upper torso area)
- Proximity to segmented lung edge
- Asymmetry of segmented lungs (cue that more sensitive detection is needed)

BMI metric example



Asymmetry example



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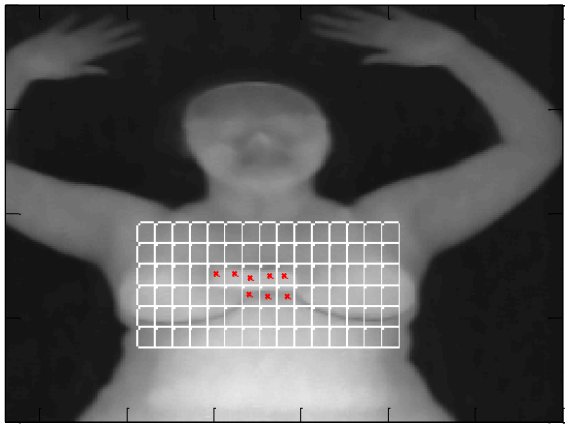
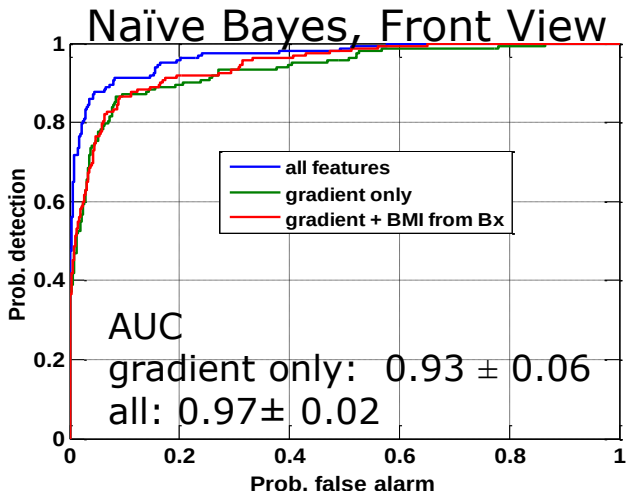
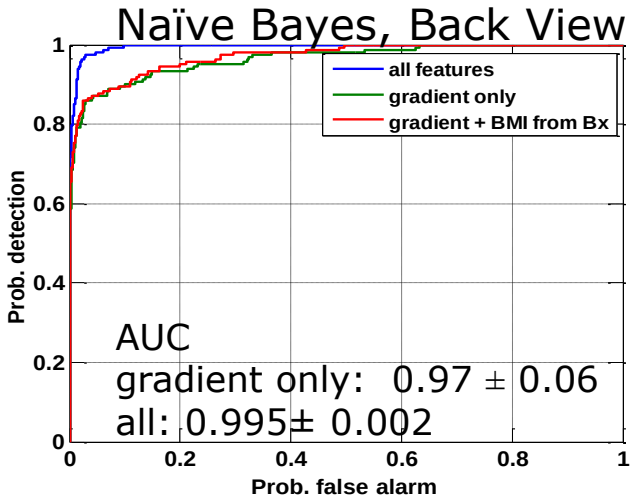
Classifier performance: Threat detection

- Several classifiers trained using 148 images, manually denoted threats
- Results indicate that addition of Tx-derived cues (blue line) improves ROC
- In SPIE paper we also showed:
  - Male/female sorting is beneficial
  - Denoising approach affects ROC (NLM performs best)







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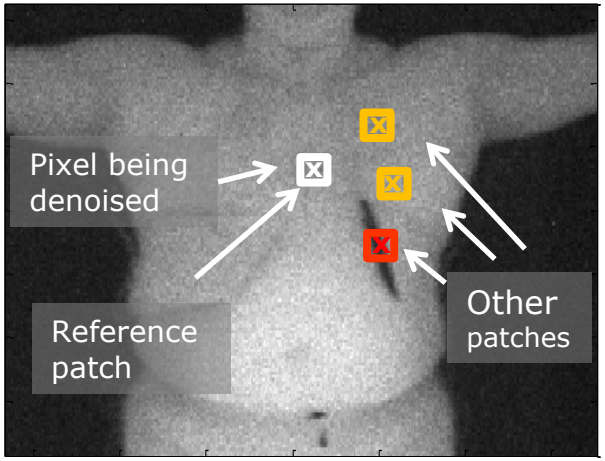
Outline

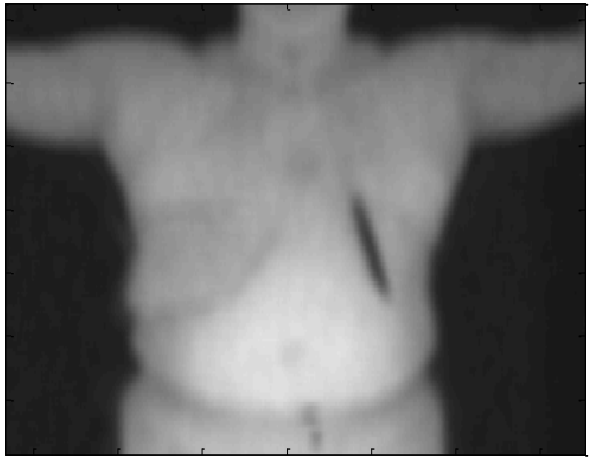
- False alarm reduction efforts
- Improved denoising for XBS
  - One of several possible topics suggested by AS&E
- Summary and future work

Patch-based denoising for XBS images

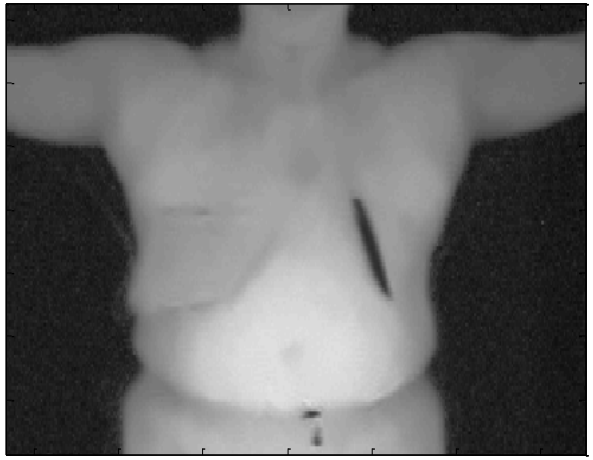
Raw image



7x7 smoothing window



7x7 NLM patch



- For XBS, *edge* information in image is critical
- Standard denoising uses local averaging, thus blurring edges
- Non-local means (NLM) averages based on **patch similarity**
  - Weighted average, weight ~ exp(-MSE/h)

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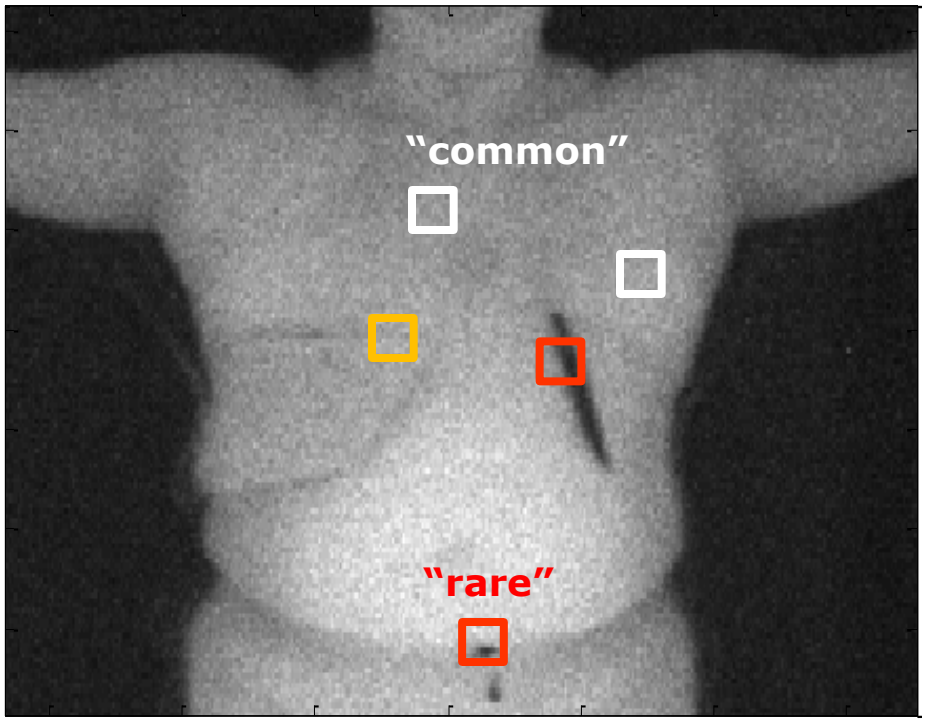
Problem 2: NLM Improvement

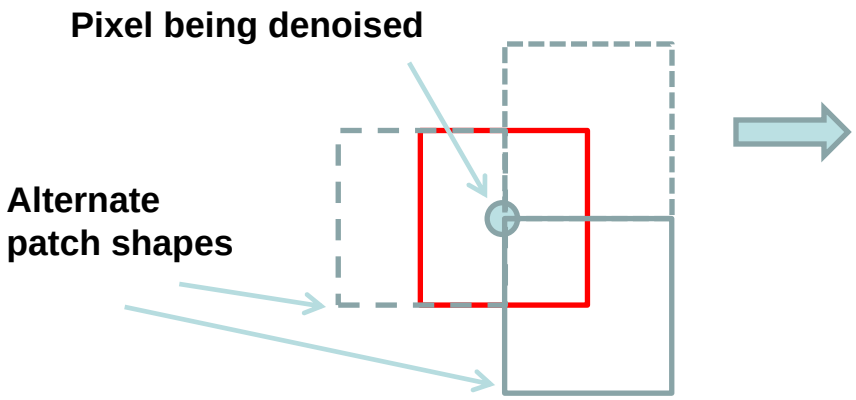
Raw image



- **Computation**: patch comparisons are costly
  - We identified ~20x speedup, both from literature and application-specific "tweaks"
- **"Rare" patches** remain noisy
  - Rare patches have fewer matching patches than others
  - Thus, they get less benefit from averaging
  - Often in XBS, rare patches are the interesting patches!
- **Weak edges** can be smeared (though generally less than in fixed kernel filters)
  - Directly impacts ATR

Improved edge handling via *shape-adaptive* patches

1) At each pixel, denoise data using several **candidate patch shapes**

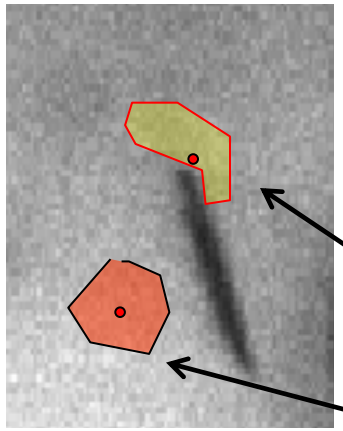


2) **Solve for patch combination weights** that minimize a desired penalty function

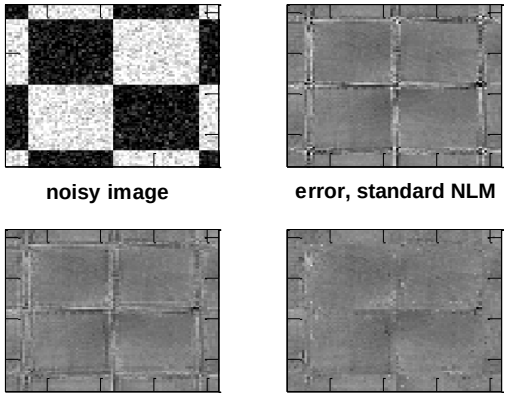
- denoised image should "match" data
- local patches should be flat (encourages sharp edge transitions)

$$\underset{\mathbf{w}}{\operatorname{argmin}} \|\nabla \hat{\mathbf{u}}(\mathbf{j})\|_1 + \lambda_2 \mathbf{J}_{\mathbf{bias}}(\mathbf{j})$$

3) These weighted sums **create custom patch shapes** at each pixel



4) Result: **less error** near edges



"noisy image" on 0-1 scale; error plots on 0-0.1 scale

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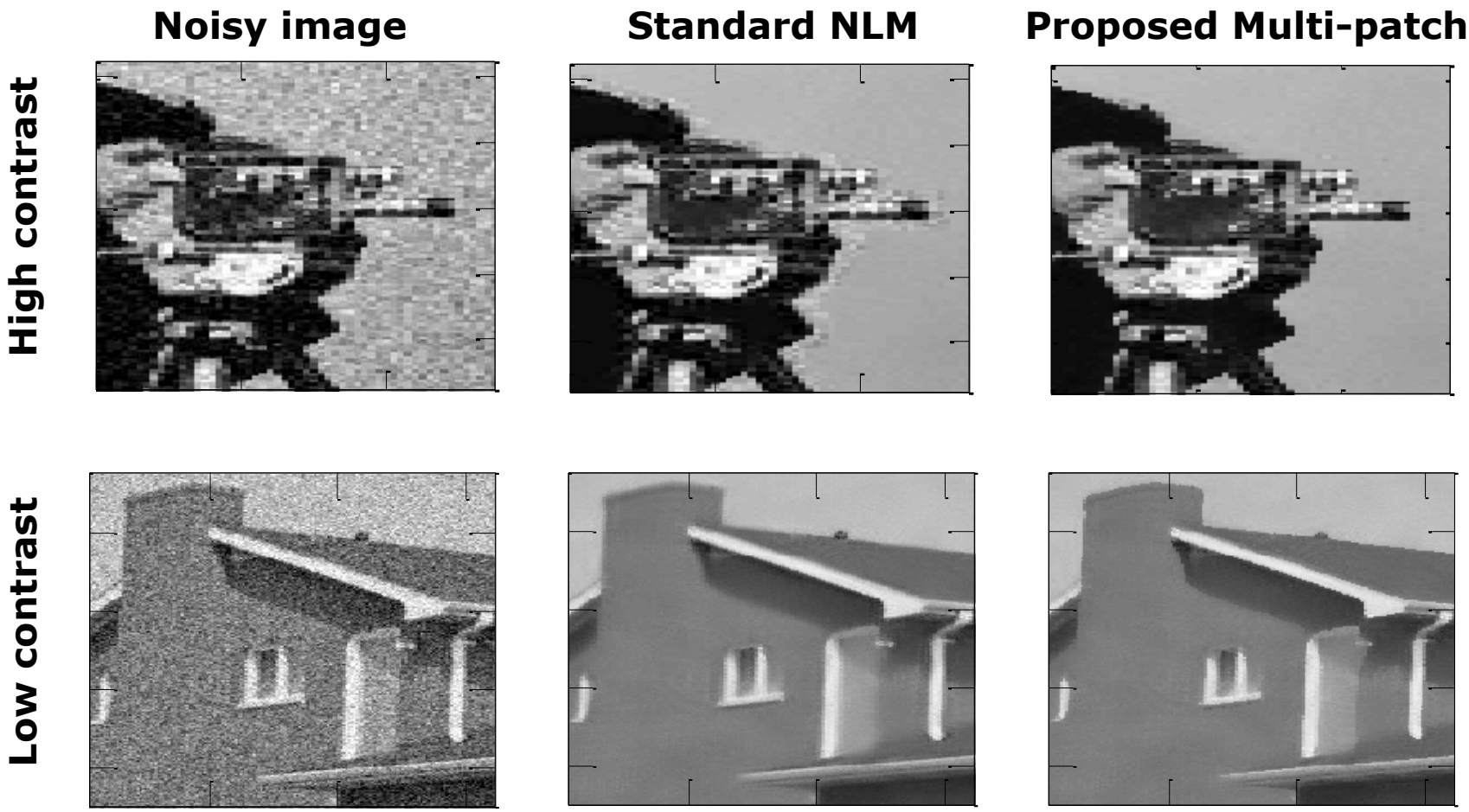
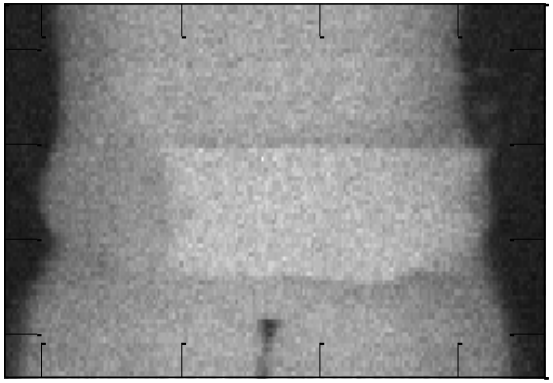
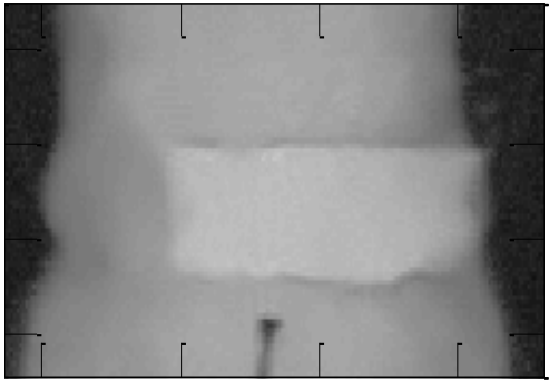
Multi-patch helps both high-, low-contrast edges



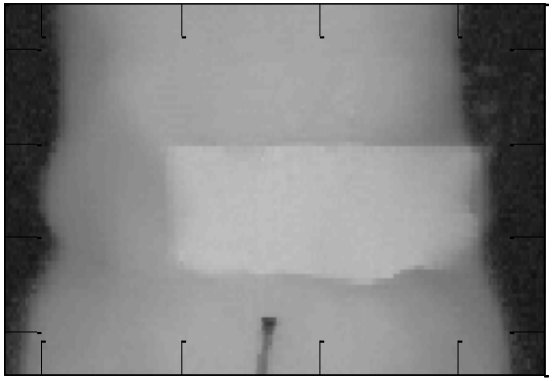
XBS Example 1
raw(a), standard NLM (b), NLM-SAP(c), proposed (d)



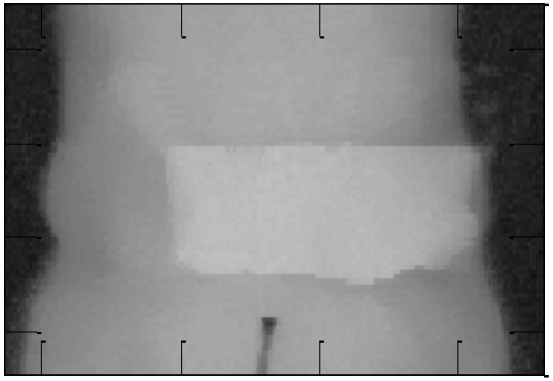
a)



b)



c)



d)

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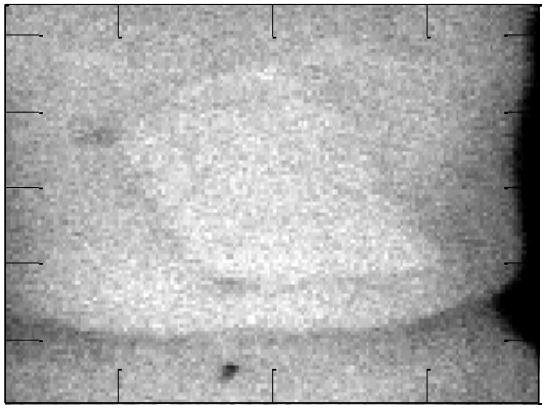
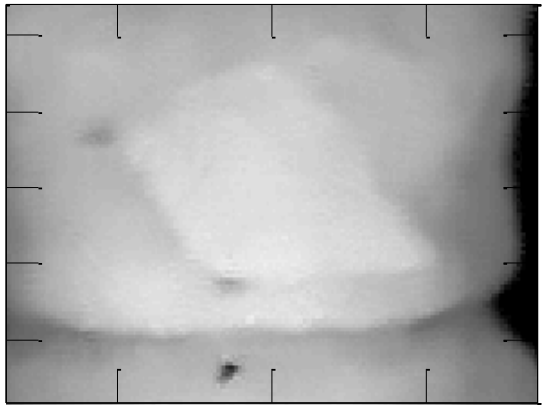
XBS Example 2

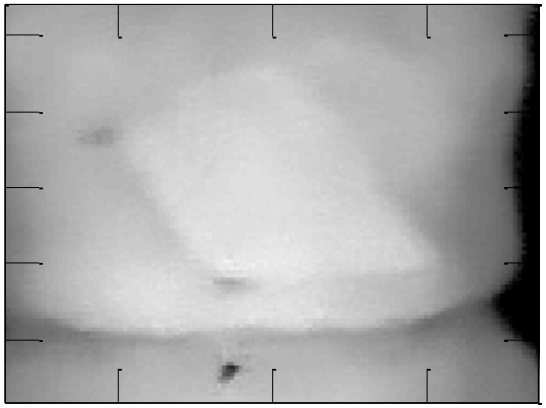
raw(a), standard NLM (b), NLM-SAP(c), proposed (d)



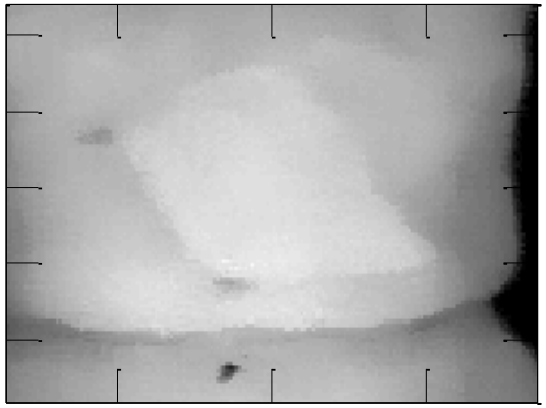
a)



b)



c)



d)

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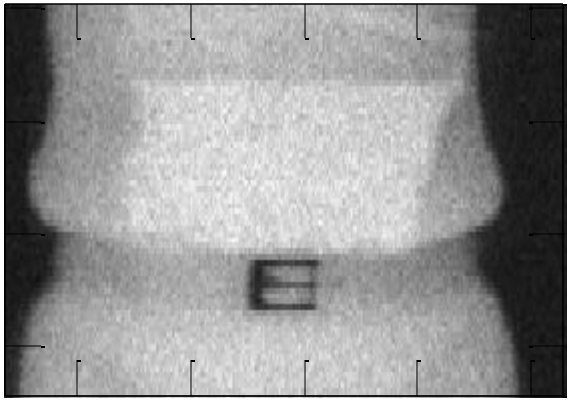
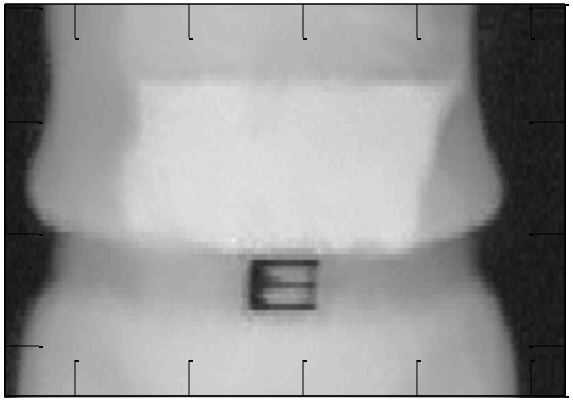
XBS Example 3

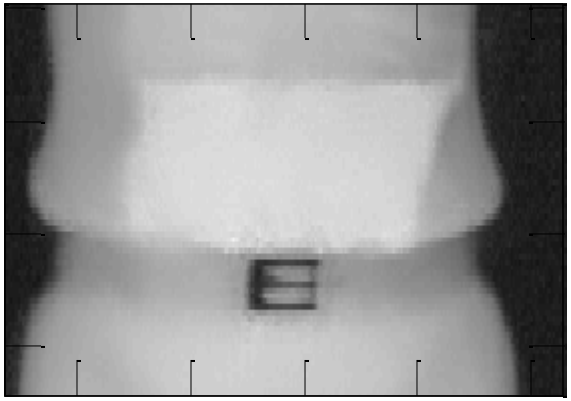
raw(a), standard NLM (b), NLM-SAP(c), proposed (d)



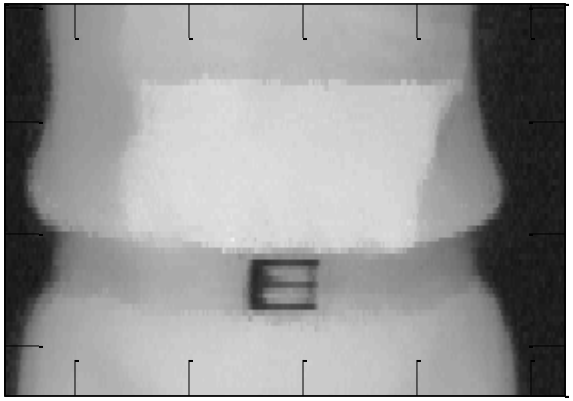
a)



b)



c)



d)

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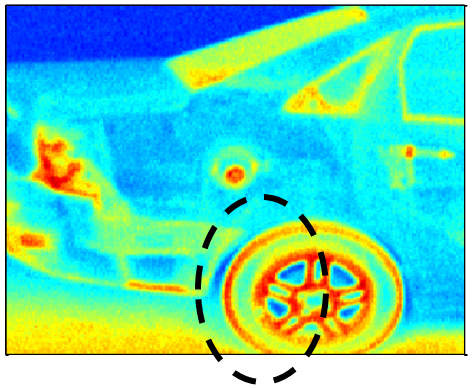
Initial results: image super-resolution for vehicle checkpoints

- During checkpoint scans, vehicle speed can cause X-ray "flying spot" to under-sample image, degrading ATR

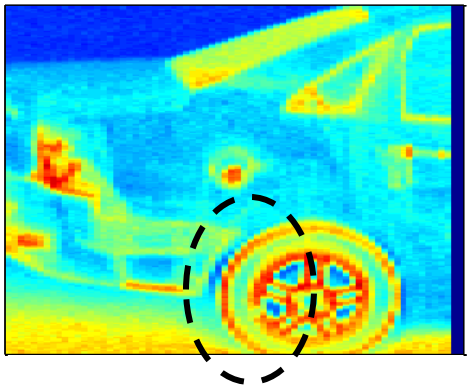
- Tufts summer student (Chris Lo) implemented a testbed for **super-resolution** approaches exploiting image sparsity

- Initial results promising
  - Improvements seen *re* standard interpolation
  - Block artifacts are seen but can be reduced

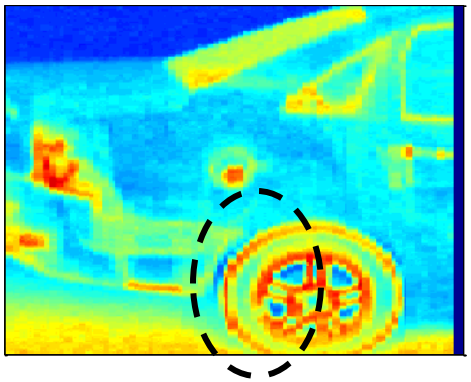
Low-speed scan



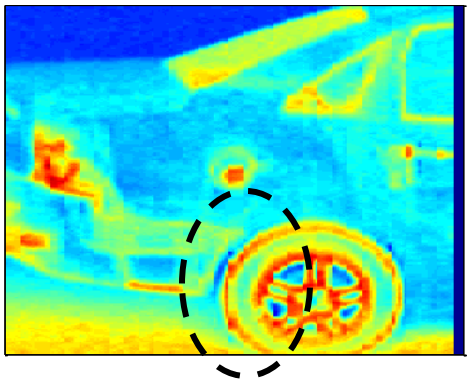
High-speed scan



Standard interpolation



L1+DCT basis



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AS&E / Tufts interactions

AS&E has provided:

- Well-posed problems
  - Meaty, relevant, general enough to avoid IP concerns
- Time: "getting started" help as well as feedback
  - Help includes data, compiled code and intermediate results
- Funds: Gift to Tufts (through ALERT) supported denoising effort

Tufts has provided:

- ALERT support for 2 summer students, research prof, Eric Miller
- An outside perspective that is, hopefully, useful to AS&E
- Longer-term exploratory research: shows which paths are most promising

Published / submitted work

1. "Combined use of backscattered and transmitted images in x-ray personnel screening systems", Tracey, B., Schiefele, M, Alvino, C, Miller E, Al-Kofani O., in Proceedings of SPIE (DSS), Vol. 8392, 839219, April 2012
2. "Non-local means denoising of ECG signals," Tracey, B. and Miller, E, IEEE Transactions on Biomedical Engineering, DOI 10.1109/TBME.2012.2208964, September 2012.
3. "Denoising approaches for X-ray personnel screening systems," Tracey, B. Miller, E., Schiefele, M., Alvino, C. and Al-Kofahi, O., accepted paper ID-96, IEEE International Conference on Technology for Homeland Security, Waltham MA, 2012.
4. "Multi-patch non-local means denoising using variational methods," Tracey, B. Miller, E., Alvino, C., Schiefele, M. and Al-Kofahi, O., submitted to Computer Vision and Image Understanding (CVIU).
5. "Localized SURE-based Moving Average Filters for Image Denoising," Wu Y., Tracey, B. and Noonan J., submitted to Electronics Letters.

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Conclusions

- Technical conclusions
  - Tx-derived cues for BMI, symmetry can be fused with XBS Bx images to reduce false alarms
  - Pre-processing is important; in particular, NLM denoising is promising for XBS
  - Multi-patch NLM methods can offer improved performance
- Thoughts on industry/university collaboration
  - Careful problem definition by industry has been a major boost to our work
  - Collaboration has also benefited from time and money investments on both sides (specific examples below)