Radiological Threat Detection by Canonical Correlation Analysis

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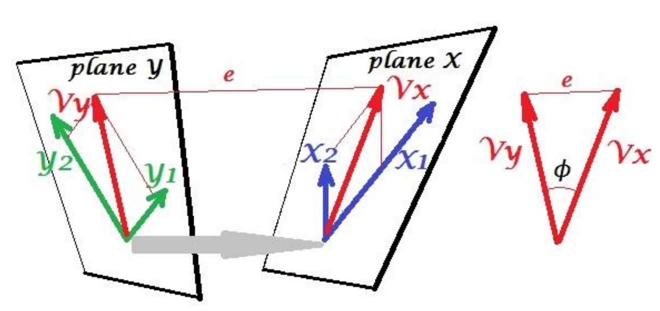
Exploiting Structured Correlations Between the Inside and Outside of an Energy Window

Introduction

- Given radiation data from noisy (urban) background environments, a popular method for threat detection is censored energy window (CEW).
- CEW does not fully exploit the data but instead aggregates in a way may lose information.
- It should be possible to develop a similar method that does not lose information.

Canonical Correlation Analysis

- CCA is a statistical method for finding structured correlations between sets *X* and *Y* of random variables.
- Finds linear combination of *X* and of *Y* such that the correlation between the combinations is maximized.



$$\max_{w_x, w_y} \operatorname{corr}(w_x^\top X, w_y^\top Y)$$

- The process can be repeated min{|*X*|, |*Y*|} times under the constraint that each combination of *X* is uncorrelated with every non-corresponding combination of *Y* and vice-versa.

Approach for Radiological Threat Detection

- Objective: Develop a classifier of photon count samples to detect a source signature.

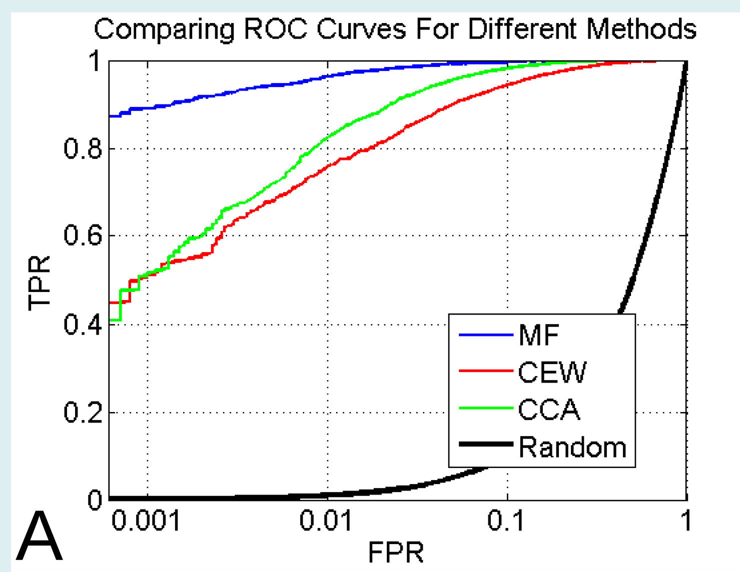
1. Compute energy window maximizing signal-to-noise ratio.
2. Apply CCA to find correlations between energy bins inside and outside the window.
3. Compute differences between corresponding linear combinations given by CCA:
$$w_x^\top X - w_y^\top Y$$
4. Use these differences as features to train a classifier.

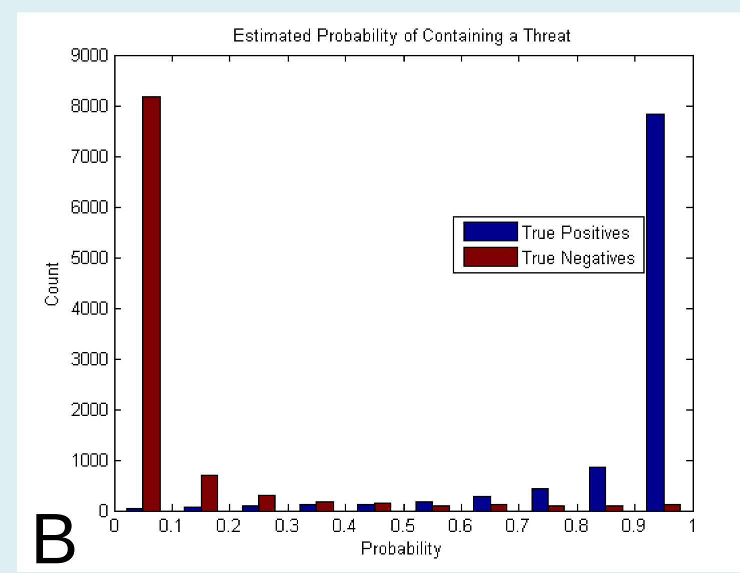
- Intuitively, the classifier learns the degree of correlation to expect with a source versus without.
- Our final method is a hybrid approach: Combine our CCA approach with CEW by adaptively switching between them based on ROC curves.

Experiments

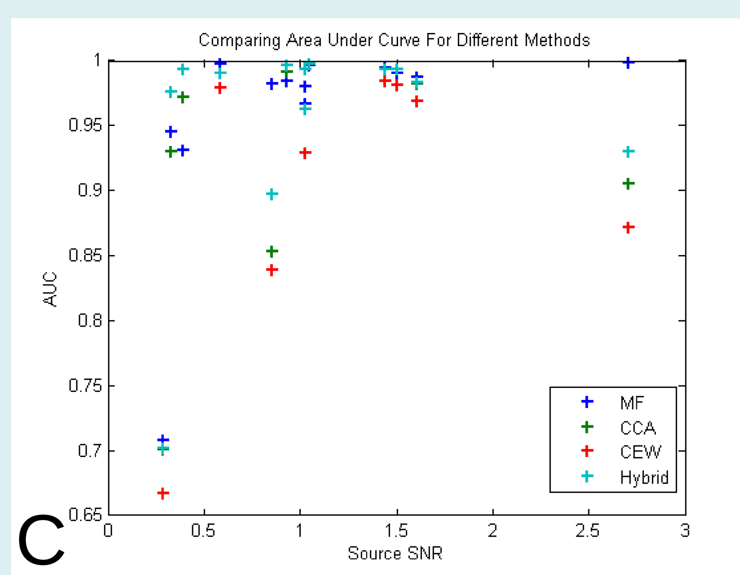
Comparing Methods for Classifying Threats

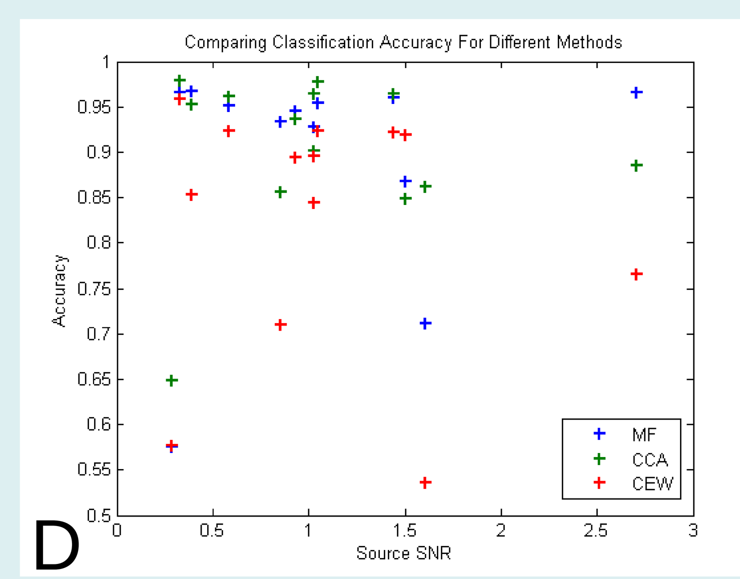
- Four methods: match filter (MF), CEW, random guessing, our CCA method, and a hybrid of CCA and CEW.
  - MF is source-aware—it uses more information than is usually known in practice, so it should perform the best.





- Figure A shows ROC curves on a particular source type.
  - CCA beats CEW except at low FPR.
  - MF beats both.
  - Hybrid CCA/CEW is the convex hull of CCA and CEW and so always beats both or matches the better of them.
- Figure B shows the CCA model's estimated probability of each sample being positive.

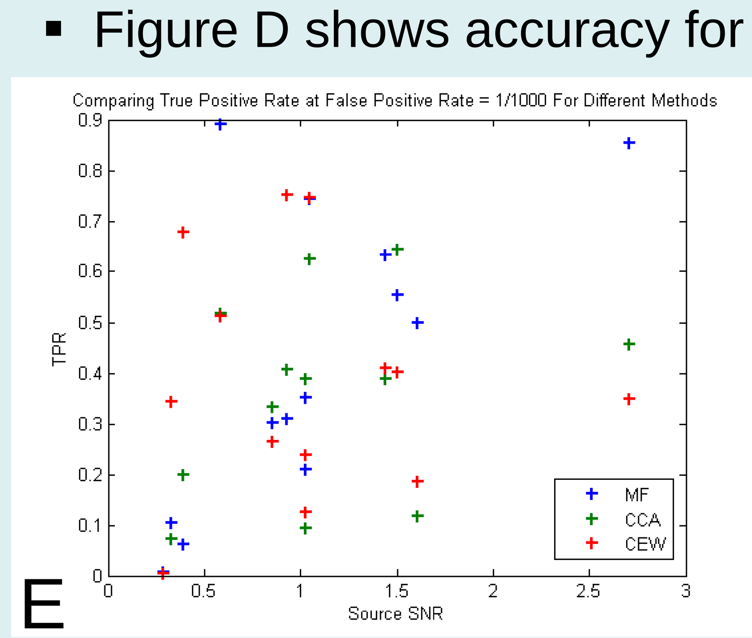


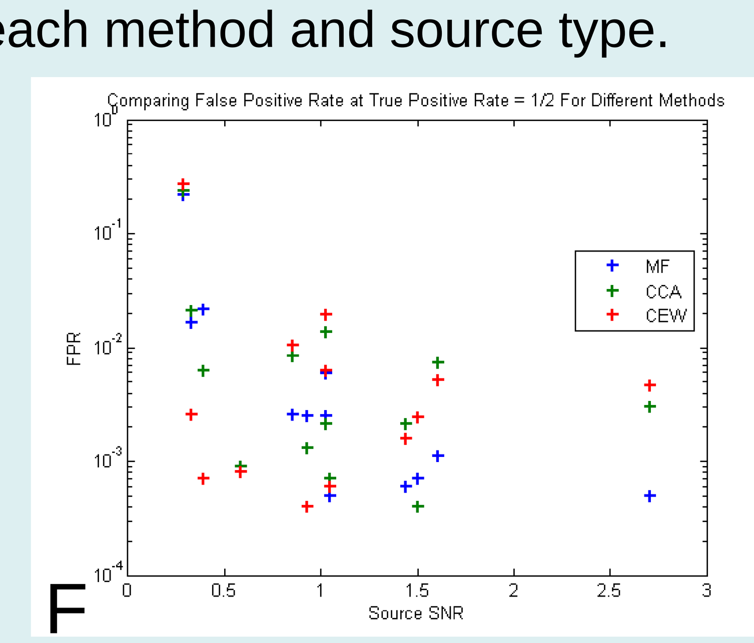


- Figure C shows AUC for each method and source type.
  - Comparing AUC leads to these *p*-values:

Hypothesis	*p*-value
CCA > CEW	9.0%
Hybrid > CEW	0.2%

- Figure D shows accuracy for each method and source type.





- Figure E shows true positive rate at a fixed false positive rate.
- Figure F shows false positive rate at a fixed true positive rate.
- Dataset: a collection of gamma-ray spectra measurements taken in Sacramento, California.
  - Synthetically injected to create positive samples.
  - Threat sources are shielded SNM sources with different configurations of fissile material and shielding.

Discussion

- CCA outperforms CEW on 9 of 13 tested source types.
- CCA sometimes even outperforms MF, which is unexpected.
  - MF uses exact source rates to detect the presence of a source.
- The hybrid method never loses to CEW and wins significantly on a paired test.
- CCA exploits the full distribution of counts in energy bins inside and outside the window.
  - This feature lets CCA leverage more information than CEW, making it more robust in theory.
  - In particular, CCA finds and leverages structured correlations between energy bins inside and outside the energy window.

Finding the Energy Window

- Task: Given a source type, find a set of energy channels with approximately maximum signal-to-noise ratio.

1. Compute S/B for each channel where
   - S is the channel source rate.
   - B is the channel's mean background rate.
2. Sort the channels by S/B in descending order.
3. For each possible integer k, add together the S and B for the top k channels, yielding S' and B' respectively.
4. Output the k channels maximizing $S'/\sqrt{B'}$.

Conclusion

- CCA is a method for finding correlations between two sets.
- CCA can be used to be competitive threat detection algorithms.
  - Sometimes outperforms even MF, which is unexpectedly positive.
- Exploits distribution of counts in energy window by applying CCA to the inside and outside of an energy window.
  - CEW simply aggregates the counts.
- In some cases, it loses to CEW, likely due to overfitting.
  - Remedied by hybrid CCA-CEW
- Needs more extensive tests on different source types and datasets.

References

Härdle, Wolfgang; Simar, Léopold (2007). "Canonical Correlation Analysis". *Applied Multivariate Statistical Analysis*. pp. 321–330

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