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Spatial Radiation Profile Characterization for Detection of Threat-like Sources

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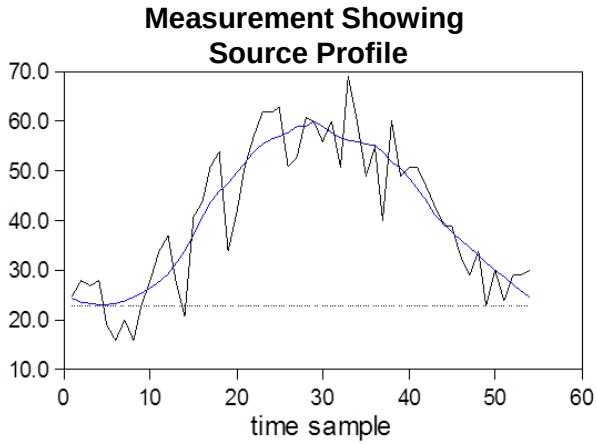
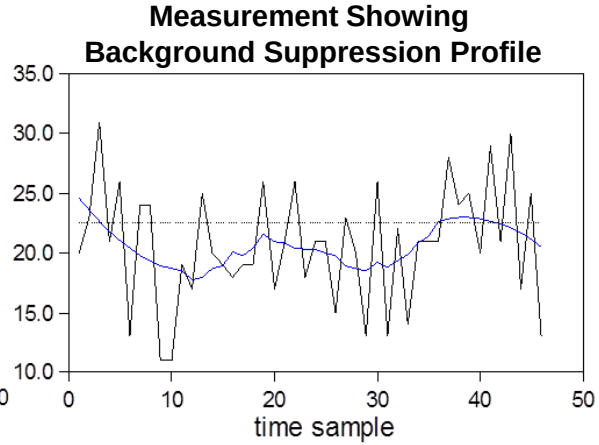
Outline

- RPM measurements
- Why profile characterization analysis
- Method for RPM profile characterization
- Metrics for profile characterization
- Method for optimization of metric thresholds
- Sample test data and results
- Summary and Conclusions

Radiation Portal Monitor (RPM) Measurements

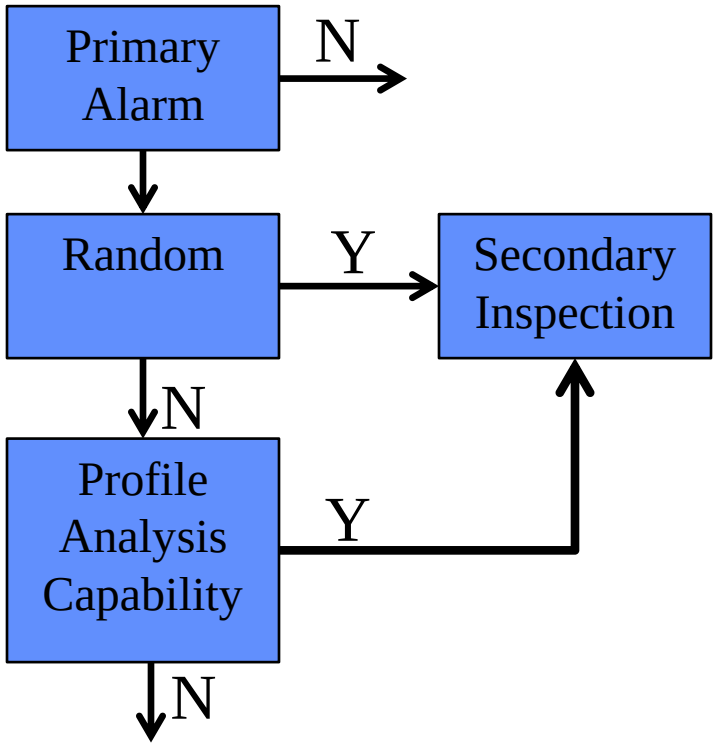
- **RPMs are deployed at border crossings and shipping ports (domestic and foreign)**
  - Most primary inspection RPMs use PVT detectors
  - Some RPMs have only one energy channel (gross counts)
- **Measure radiation counts as vehicles traverse RPM generating time series of counts**
  - Time profiles of counts are related to spatial distribution of sources
  - In the absence of sources, profiles show background suppression
  - Alarms are generated when signal amplitudes exceed specified thresholds





Why profile characterization analysis?

- **Hypothesis: At sites that are unable to send every primary alarm to secondary *may be* better than random selection alone**



Why profile characterization analysis?

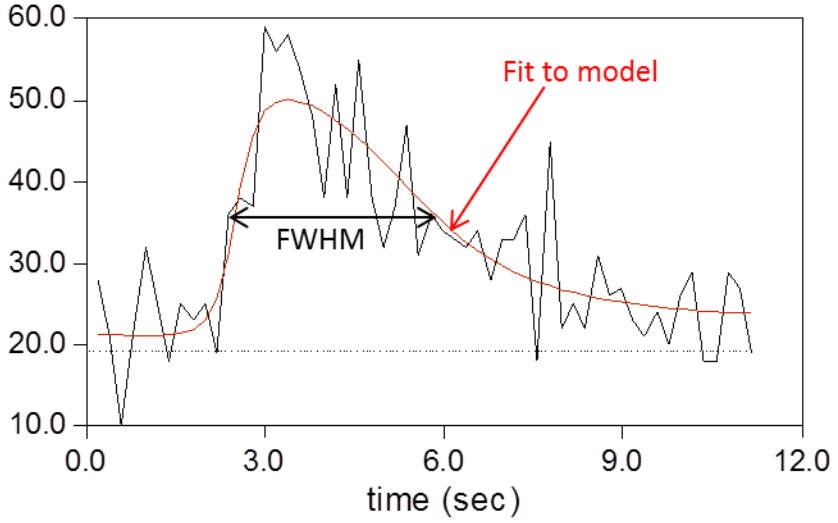
- **Exploiting spatial profile information *may help* to distinguish possible threat from non-threat primary alarms**
  - Spatial information: profile width, rise/fall length, how well it fits the hypothesis source model, etc.
- **Underlying assumption:**
  - Threat sources are likely to be small in volume resulting in point-like source radiation profiles
  - Cargo containing naturally occurring radioactive material (NORM) is generally expected to be large in volume resulting in distributed (wide) source radiation profiles
- **Limits:**
  - Masking and profile tailoring can be used to hide sources
  - Large amplitude NORM cargo can statistically hide small sources

Method for RPM Profile Characterization

- **Use nonlinear optimization to fit measured alarm profiles to a generalized source model**
  - Model used can represent localized and distributed sources
  - Account for effect of background suppression
    - Use shapes obtained from historical non-alarm data
  - Fit multiple detectors independently (also summed profile)
- **Fit parameters define metrics for discrimination between benign and potential threat sources**
  - Benign sources are assumed to be NORM in large and somewhat uniformly distributed cargo
  - Potential threat sources are assumed to be small resulting in localized profiles
  - An inadequate fit to the source model → unknown source → potential threat
- **Current method uses only one source but multiple sources can be used (SAND2008-3469)**

Metrics for Profile Characterization

- **Fit parameters, or quantities that are derived from them, can be used as metrics to characterize profiles. Some metrics:**
  - Profile width: use either FWHM or model width parameter
  - Width ratio metric: ratio of width at different signal levels
  - Residual metric: the overall variance weighted χ^2 of the fit
  - Spatial residual metric: maximum absolute residual averaged over a number of samples
    - Intended to detect local deviation (such as for a masking scenario)
    - Number of samples used should be close to localized source width
  - Rise-Fall length metric
  - Maximum amplitude metric



Method for optimization of metric thresholds

- **Datasets:**
  - Benign dataset (alarm data from the stream-of-commerce) → probability of false alarms (PFA)
  - Threat dataset (measured or simulated threat data) → probability of detection (PD)
- **Define algorithm and choose detection metrics:**
  - Two metrics: for a profile, is $m_1 > T_1$ or $m_2 > T_2$? → detection
- **PD & PFA are functions of the metric thresholds**
  - Characterize all data profiles and evaluate metrics
  - Evaluate PD & PFA on a grid in metric threshold space
  - For a given PFA value, move in metric threshold space to maximize PD while holding PFA constant
    - Constrained steepest ascent: move in direction that is perpendicular to ∇(PFA) and most parallel to ∇(PD)
  - Using different PFA values results in optimized ROC curve for the datasets and for the chosen set of metrics

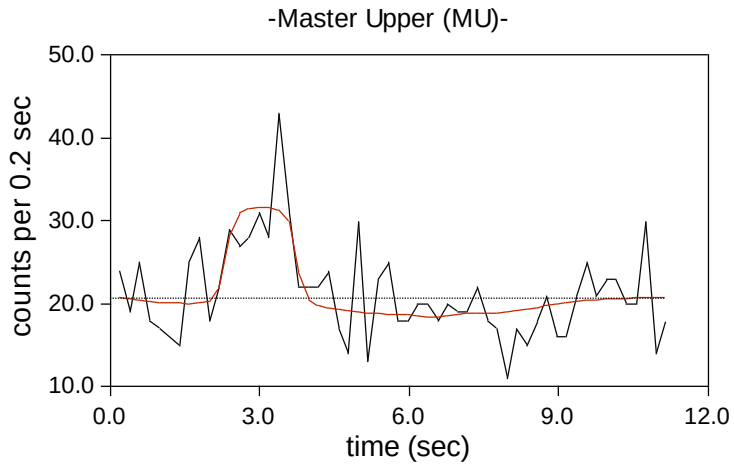
Sample Test Data and Results

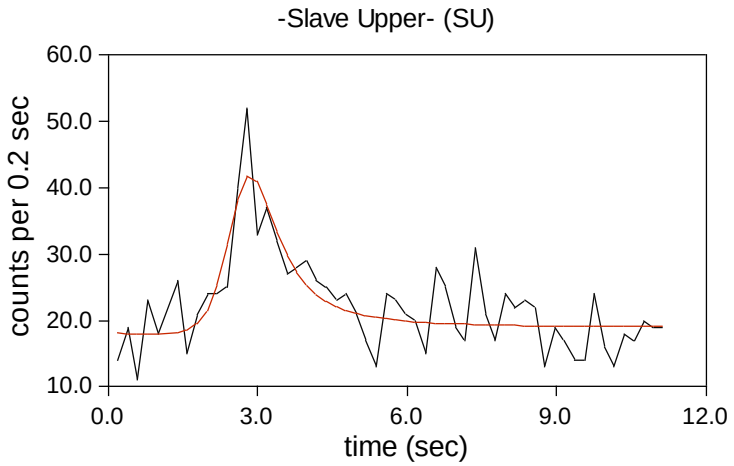
- **Three datasets were used for testing:**
  1. Benign dataset: alarm dataset from a port containing SOC data: 10,647 alarm occupancies processed – all are assumed non-threat
  2. Threat dataset-1: simulated dataset with localized sources + background
     - Fixed source parameters, varied location in profile
     - 40,000 profiles generated (4 detectors)
  3. Threat dataset-2: simulated dataset with distributed + localized sources (masking)
     - Fixed distributed source parameters, fixed localized source parameters, varied location
     - 40,000 profiles generated (4 detectors)

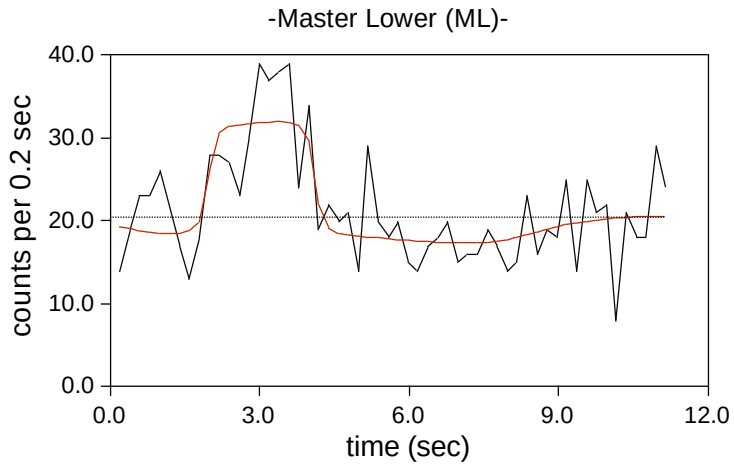
  – Proper Poisson noise is included in the simulated profiles

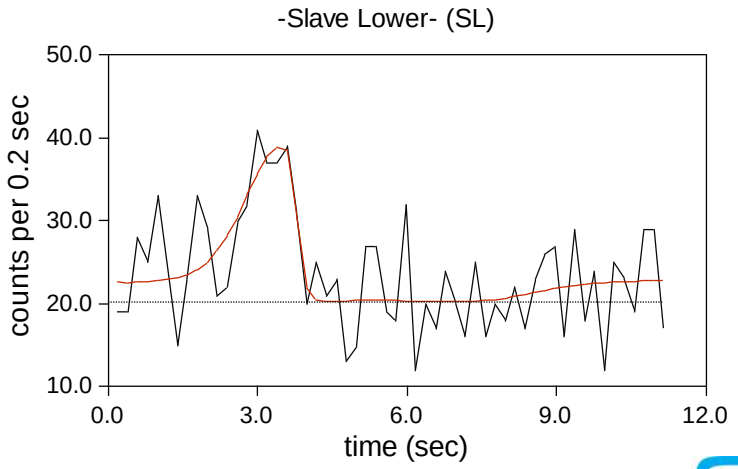
Sample Test Data and Results (cont'd)

Simulation with Localized Source



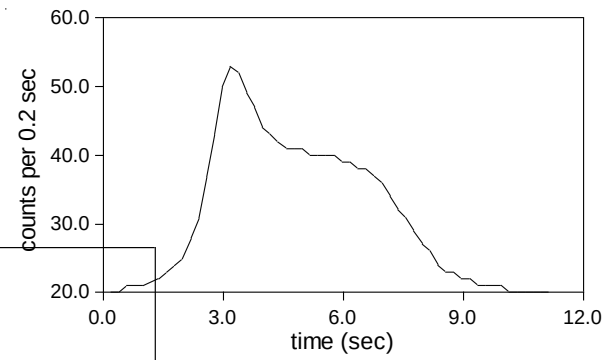




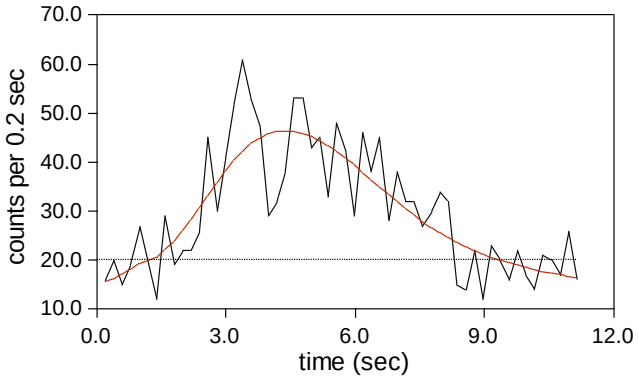


Sample Test Data and Results (cont'd)

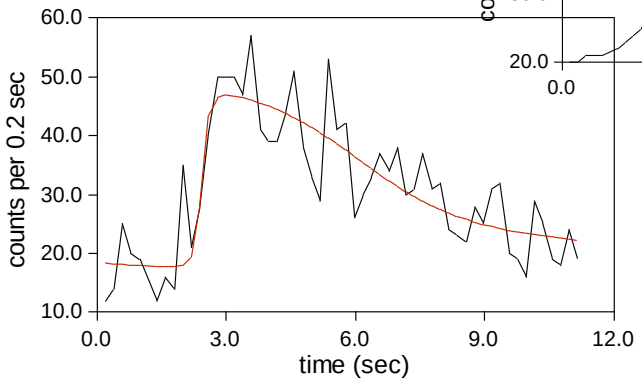
Simulation with Two Sources (Masking)



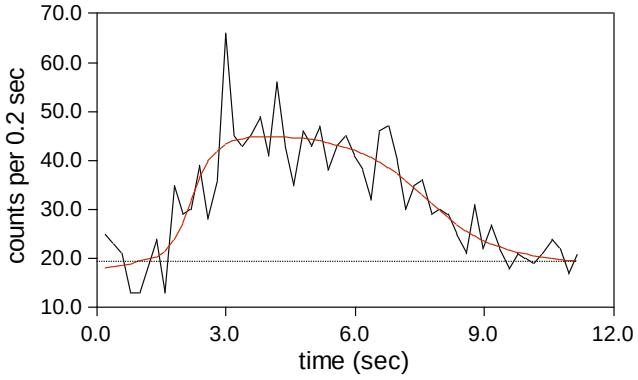
-Master Upper (MU)-



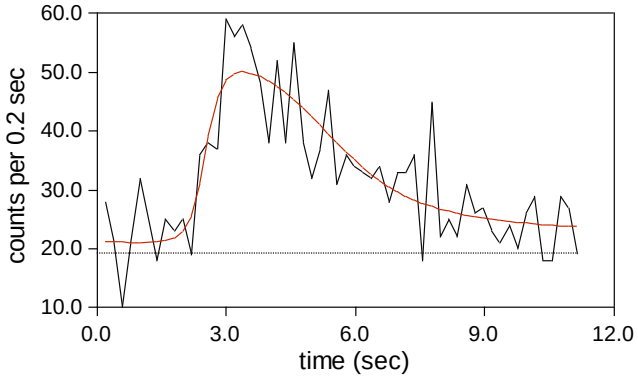
-Slave Upper- (SU)



-Master Lower (ML)-

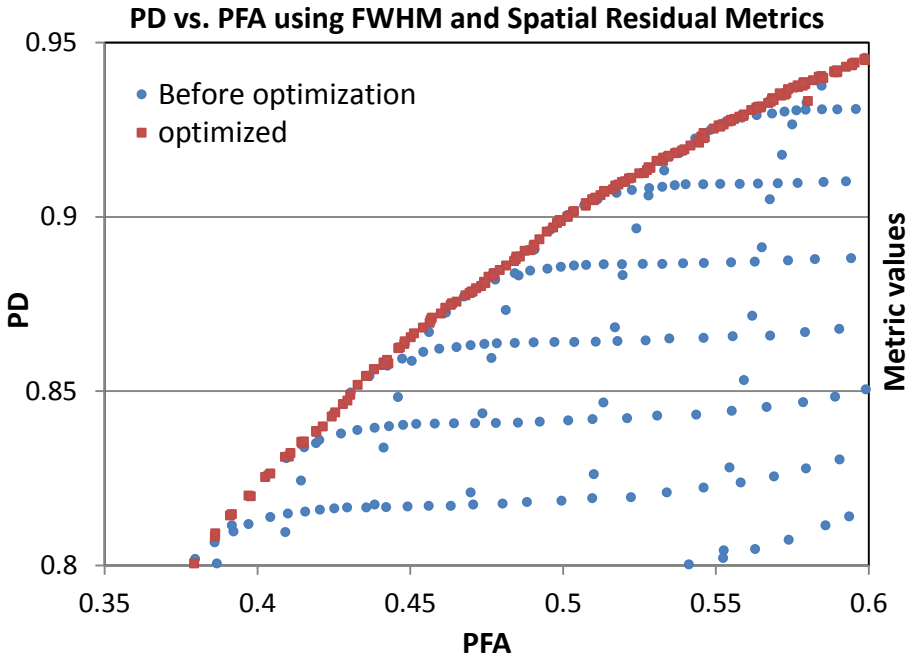


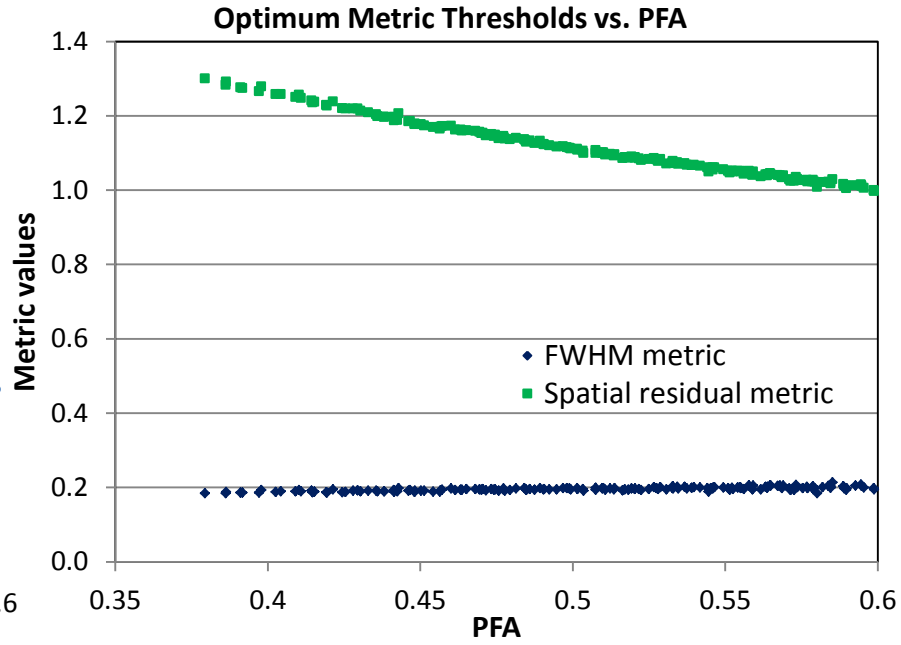
-Slave Lower- (SL)



Sample Test Data and Results (cont'd)

- **Metrics :** FWHM and spatial residual metrics
- **ROC curve:**
  - Blue points are starting points on grid of metric thresholds
  - Red points map out an optimized ROC curve for the chosen metrics





Summary and Conclusions

- **Using profile characterization with appropriate metrics and optimized thresholds has potential for identifying threat-like sources**
  - For the test data the PFA is relatively high for PD > 90%: **Can be acceptable since only primary alarm data is considered**
  - Because of the large variability of cargo types for different ports, optimum metric thresholds need to be evaluated for each port
  - For high signal amplitudes, method is not expected to be useful**: Sources can be hidden by statistical noise**
- **For a realistic assessment of potential benefits, data that represent threat scenarios need to be tested**
  - Test datasets need to be large to provide a good statistical sampling of the distributions of anticipated threats

Backup Slides

Source Model

- **An ideal line source model is used for representing source:**

$$f_{\text{line}}(z) = \alpha_0 \left\{ \frac{z - z_0 + \Delta}{\left[R_0{}^2 + (z - z_0 + \Delta)^2 \right]^{1/2}} - \frac{z - z_0 - \Delta}{\left[R_0{}^2 + (z - z_0 - \Delta)^2 \right]^{1/2}} \right\}$$

$$f_{\text{line}}(z = z_0) \equiv A_0 = 2\Delta\, \alpha_0 \,/\left[R_0^2 + \Delta^2 \right]^{1/2}$$

  - z represents time sample (or length along occupancy), z_0 is source mid-point, Δ is line source half-width, and R_0 is perpendicular distance from source to detector
  - The point source model is obtained in the limit $\Delta \rightarrow 0$:

$$f_{\text{point}}(z) = \lim_{\Delta \to 0} f_{\text{line}}(z) \rightarrow A_0 \left[\frac{R_0^2}{R_0^2 + (z - z_0)^2} \right]^{3/2}$$

Source Model (cont'd)

- **Line source model is generalized by replacing R_0 by R_L on left and R_R on right to allow for different rise and fall lengths of the profiles**

$$f_{\text{line}}(z) = \alpha_0 \left\{ \frac{z - z_0 + \Delta}{\left[R_L^{\,2} + (z - z_0 + \Delta)^2 \right]^{1/2}} - \frac{z - z_0 - \Delta}{\left[R_R^{\,2} + (z - z_0 - \Delta)^2 \right]^{1/2}} \right\}$$

- **The large number of fit parameters allows for fitting many measured profiles**
  - Because of the idealized model the fit parameters do not necessarily have a precise correspondence to the original physical interpretation