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A Rapidly Deployable Virtual Presence Extended Defense System

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

System Concept

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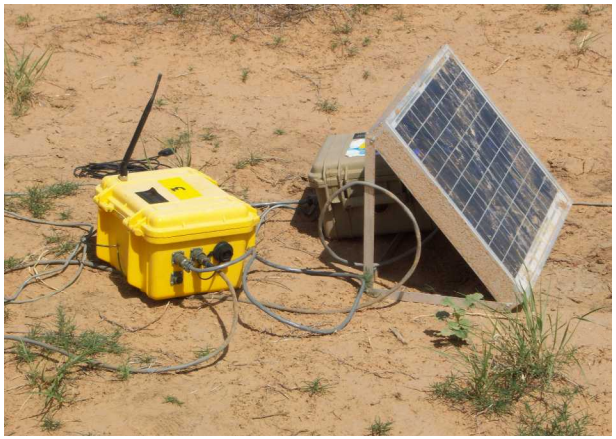
System Requirements

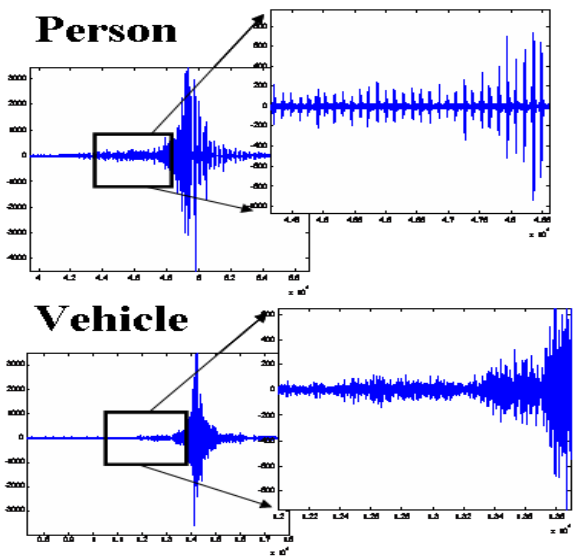
- Automatically learn a detection map
- Incorporate a-priori information / knowledge about the sensors, but
- Adapt to site's local terrain and soil conditions as more information becomes available
- Automatically identify vulnerabilities or gaps in the detection map
  - User identifies minimum acceptable PD and algorithms identifies any gaps
- Have concept work with different types of sensors

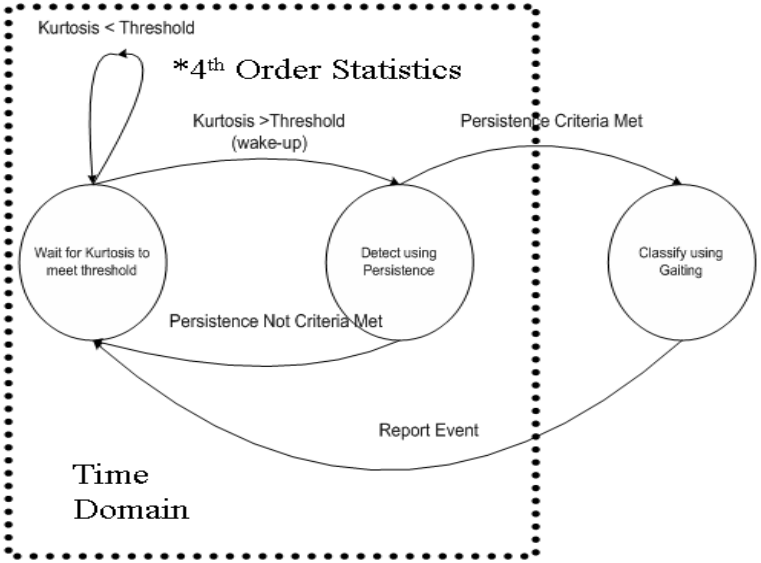
Current Approaches

- Determine detection map manually
  - Approach sensor network from different directions and multiple trials
  - Record range of initial detection
  - Use binomial distribution and average range for a 90% PD and 95% confidence interval
- Time intensive
- Not automatic
- Determines a single detection line
- Doesn’t incorporate prior information
  - Makes periodic updates difficult

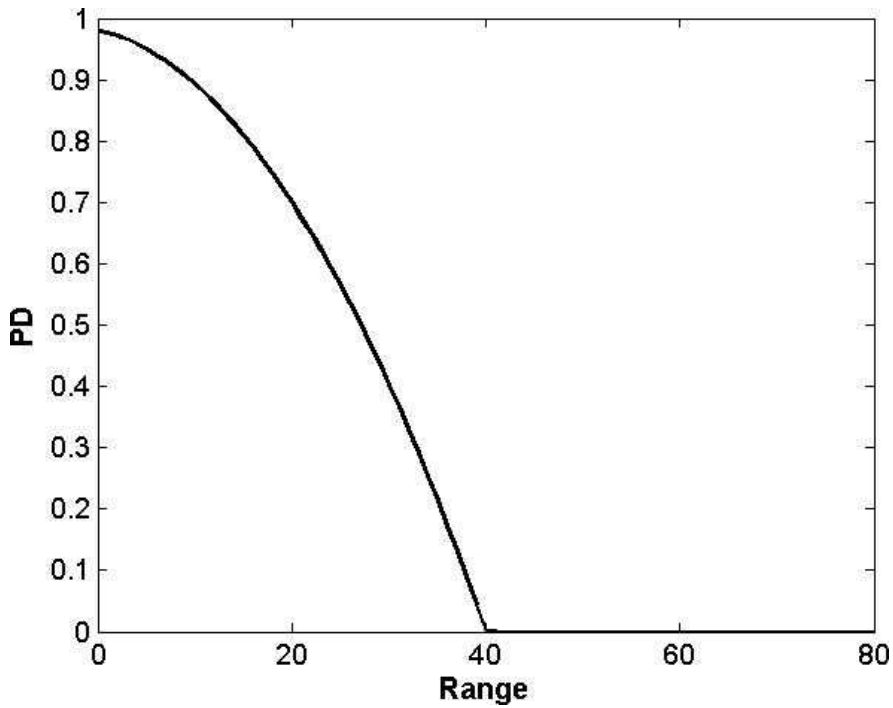
Sensor Pods




Person
Vehicle

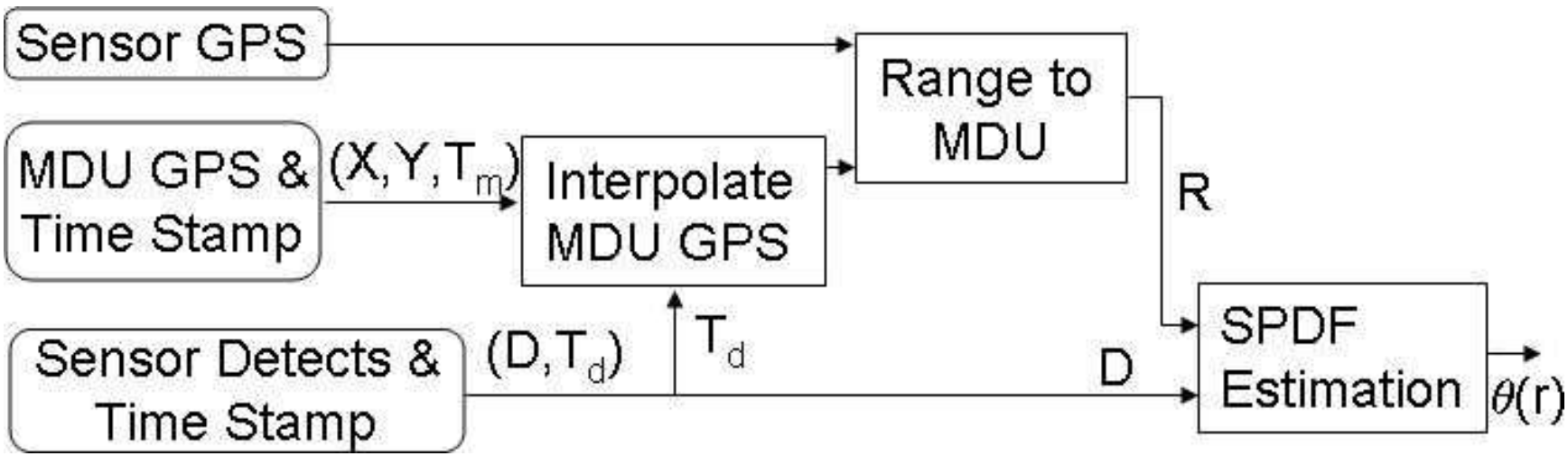

Kurtosis < Threshold
*4th Order Statistics
Kurtosis >Threshold
(wake-up)
Persistence Criteria Met
Wait for Kurtosis to meet threshold
Detect using Persistence
Classify using Gaiting
Persistence Not Criteria Met
Report Event
Time Domain

Sensor Probability of Detection Function (SPDF)



- **Assume isotropic**
  - **Sensor detection probability varies with range only and is constant in azimuth**

SPDF Estimation Approach



- **SPDF – sensor probability of detection function**
- **MDU – mobile deployment unit**
  - **(X,Y) = GPS location 6 cm accuracy**
  - **Tm = GPS time stamp updates every 1 sec**
- **Sensor Detects**
  - **D = {0,1}**
  - **Detection updates every 1 sec**

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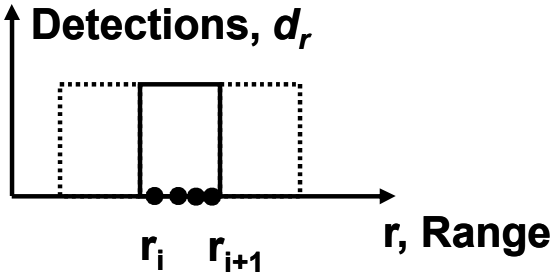
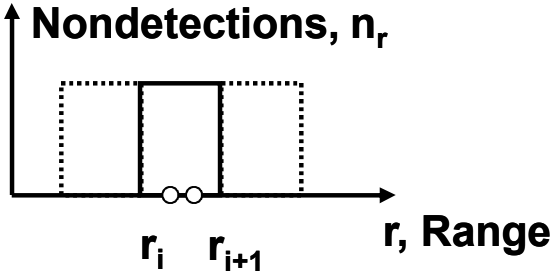
Estimating an SPDF



$$s_i = \sum_{r_i \le r < r_{i+1}} s_r$$

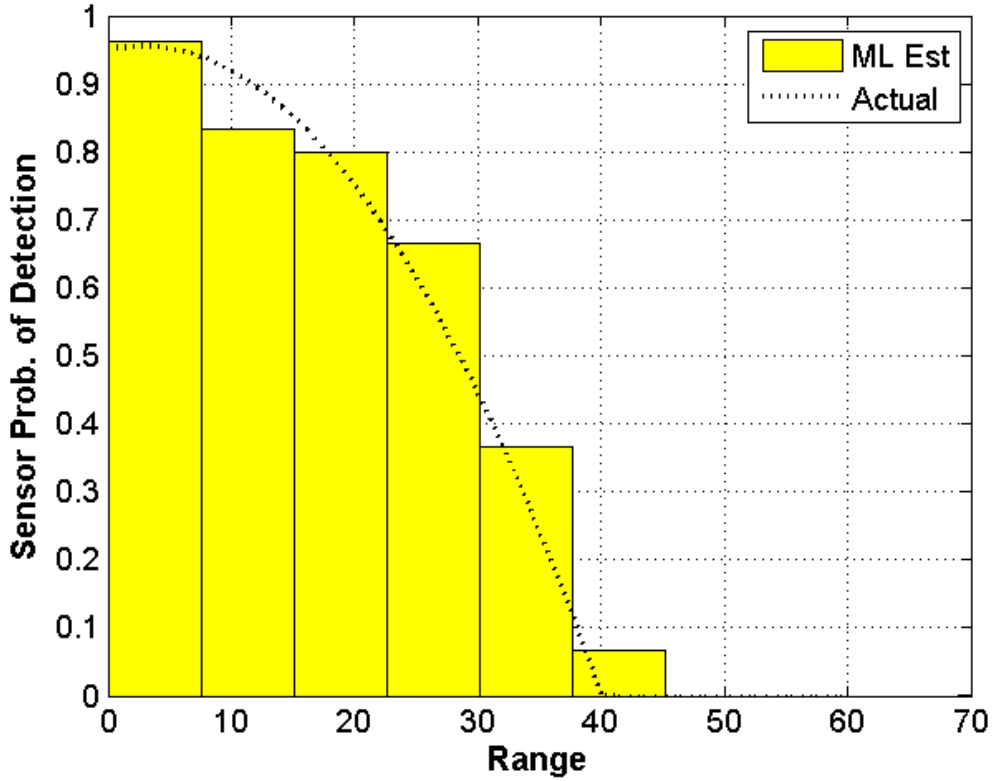


$$u_i = \sum_{r_i \le r < r_{i+1}} u_r$$

$$g(r) = \frac{s_i}{s_i + u_i}, \quad r_i \le r < r_{i+1}$$

- S_i = Number of successes
- $S_i + U_i$ = Number of trials

Estimating an SPDF



- In each bin count the
  - Number of success, *S*
  - Number of tries, *S+U*
- SPDF is assumed to be smooth but estimate isn't

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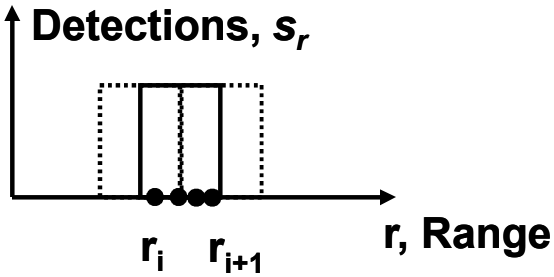
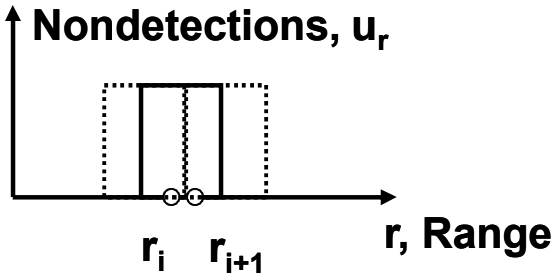
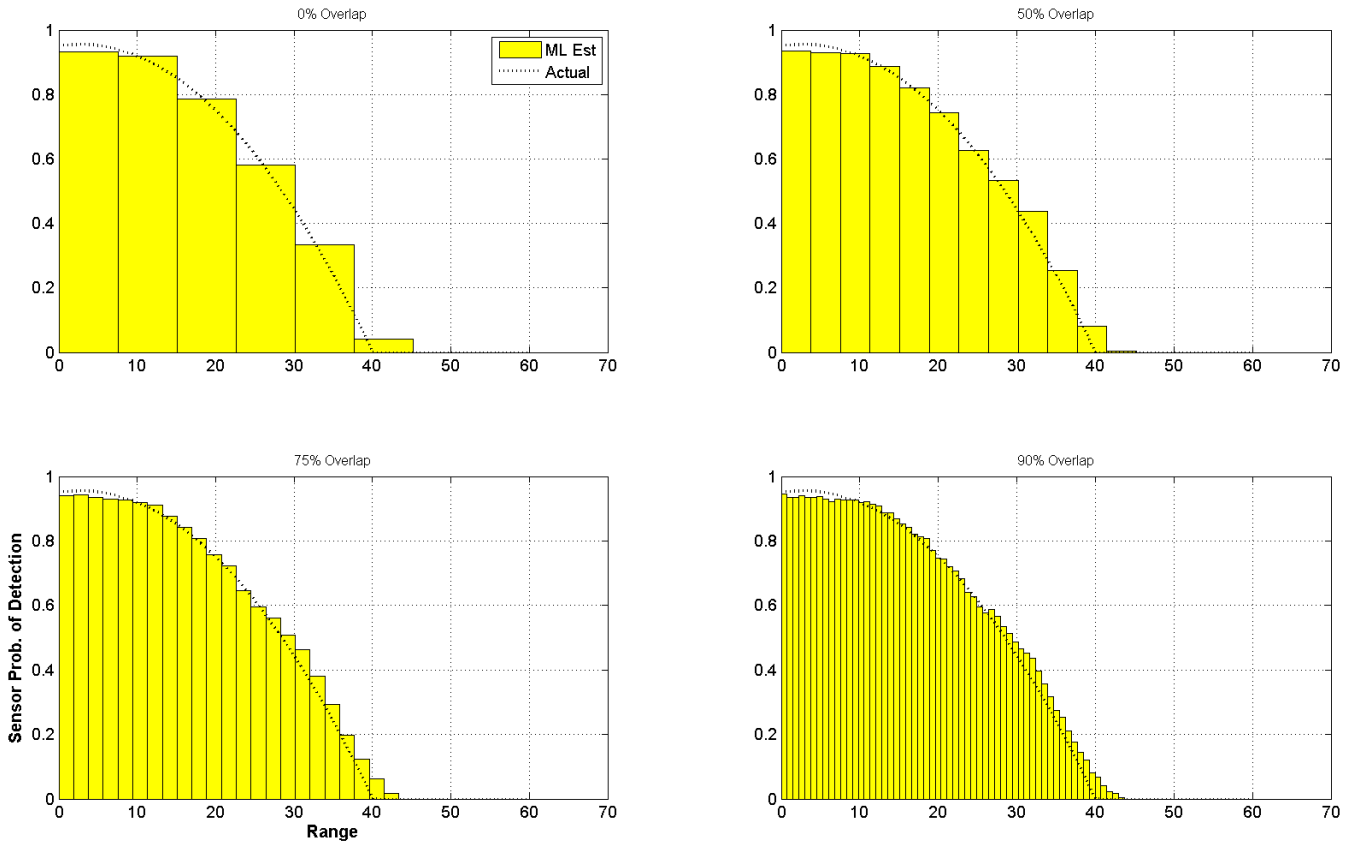
"Smoothing" an SPDF





- Keep bin size constant
- But allow bins to overlap

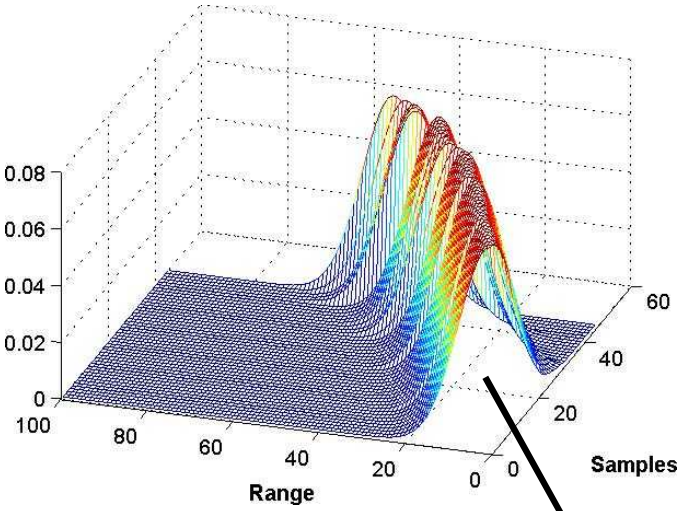
SPDF with Overlapping Bins



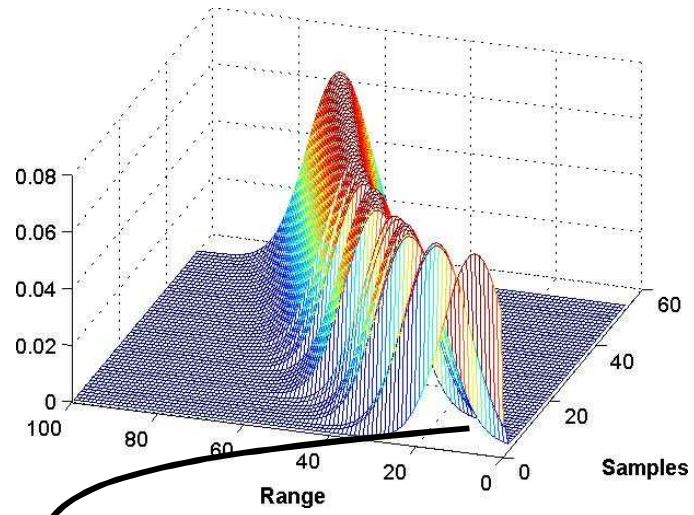
- **This is equivalent to a Parzen Estimator for estimating S_i and U_i with box kernels**

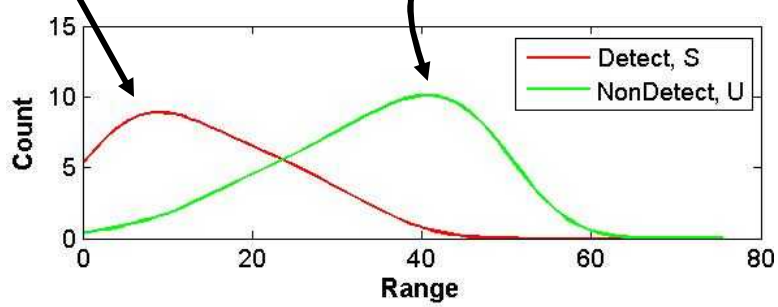
Parzen SPDF Estimation

Detections

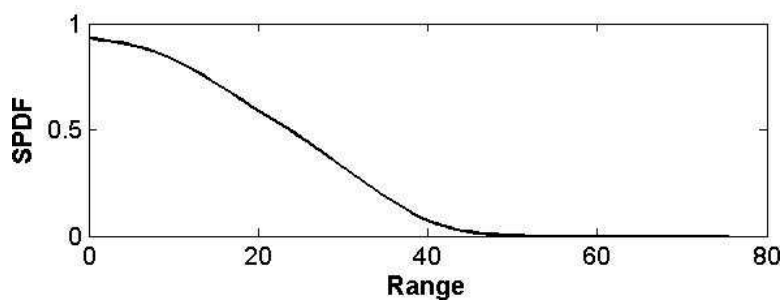


Nondetections





$$\hat{\theta}(r) = \frac{\hat{s}(r)}{\hat{s}(r) + \hat{u}(r)}$$



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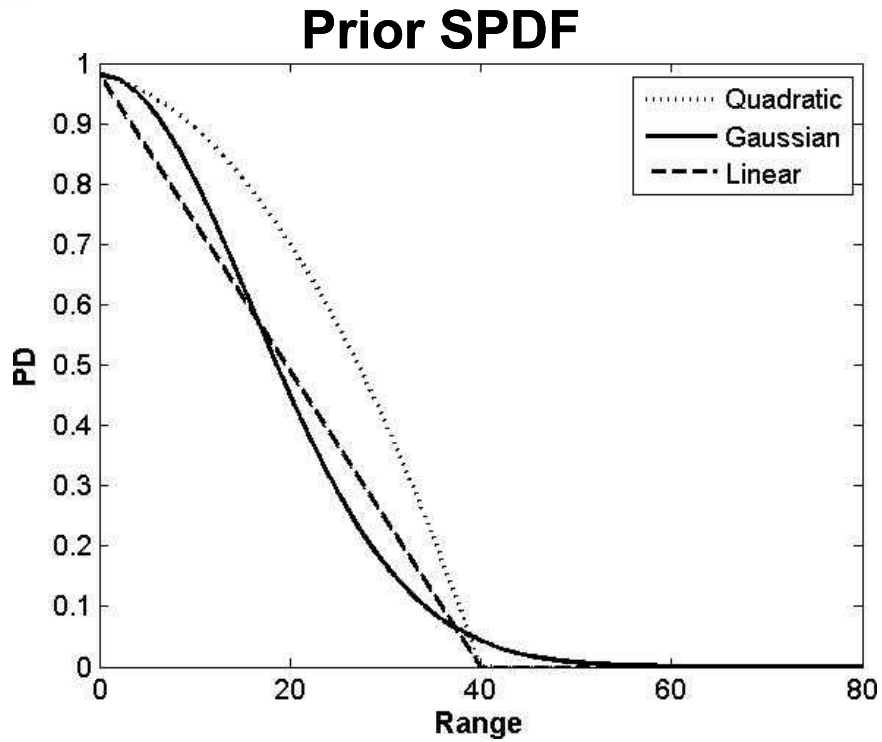
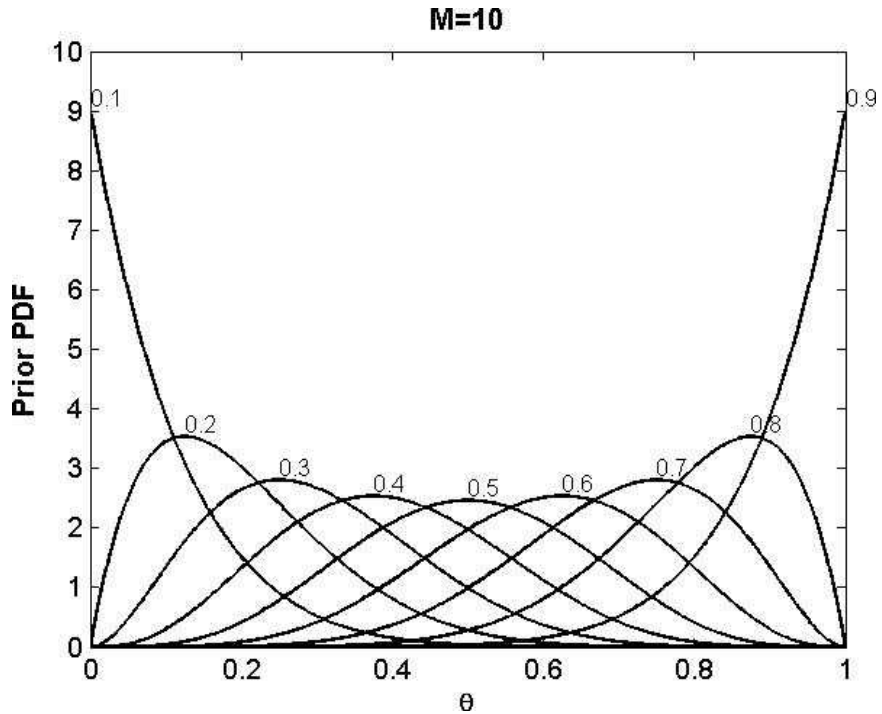
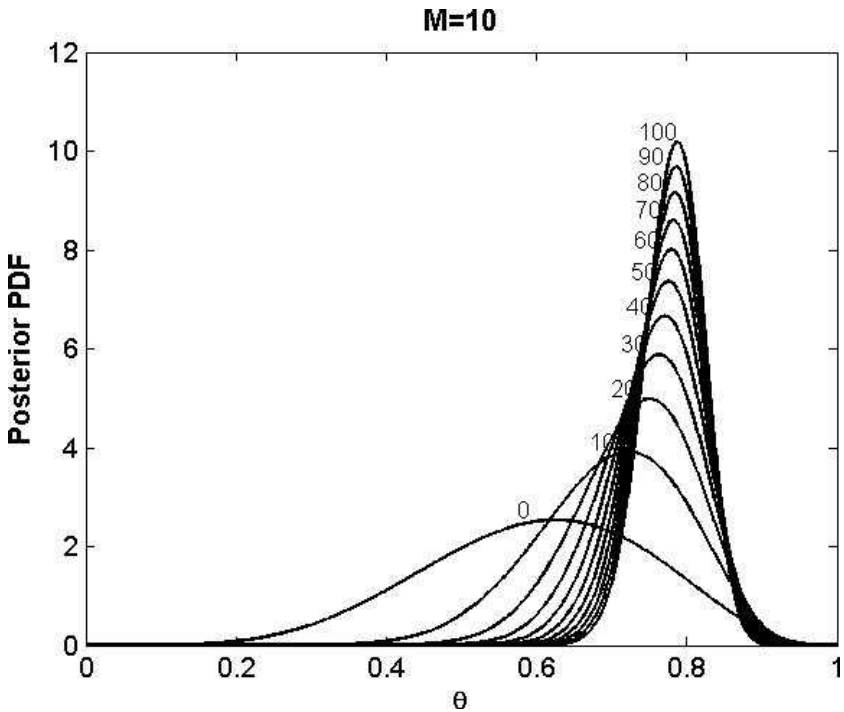
Bayesian Prior

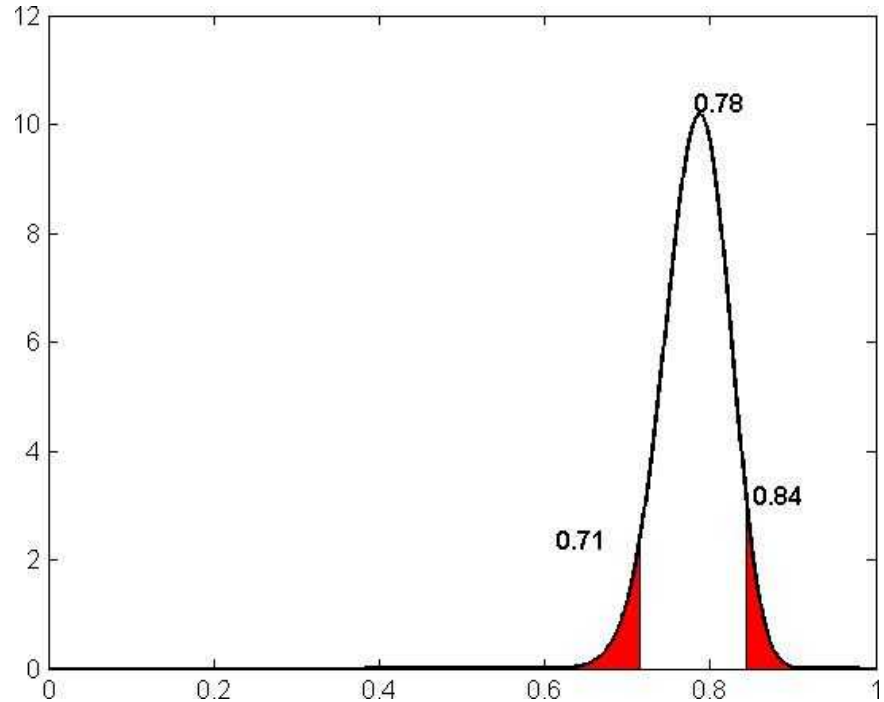




- **Prior**
  - **Beta(a,b), mean=a/(a+b)**
- **Weight of prior**
  - **M (samples)**
  - **M = a + b**

Bayes Posterior





- **Posterior mean is our best estimate 0.78**
- **90% Confidence interval [0.71, 0.84]**
- **Uncertianty u_b-l_b = 0.84 – 0.71**

Posterior Mean

$$\tilde{\theta}(r) = (1-\alpha(r))\hat{\theta}(r) + \alpha(r)\bar{\theta}(r)$$

$$\bar{\theta}(r) = \frac{a(r)}{a(r)+b(r)}$$

$$\alpha(r) = \frac{a(r)+b(r)}{a(r)+b(r)+s(r)+u(r)}$$

$\tilde{\theta}(r)$ – Bayes Posterior

$\hat{\theta}(r)$ – Parzen

$\bar{\theta}(r)$ – Prior

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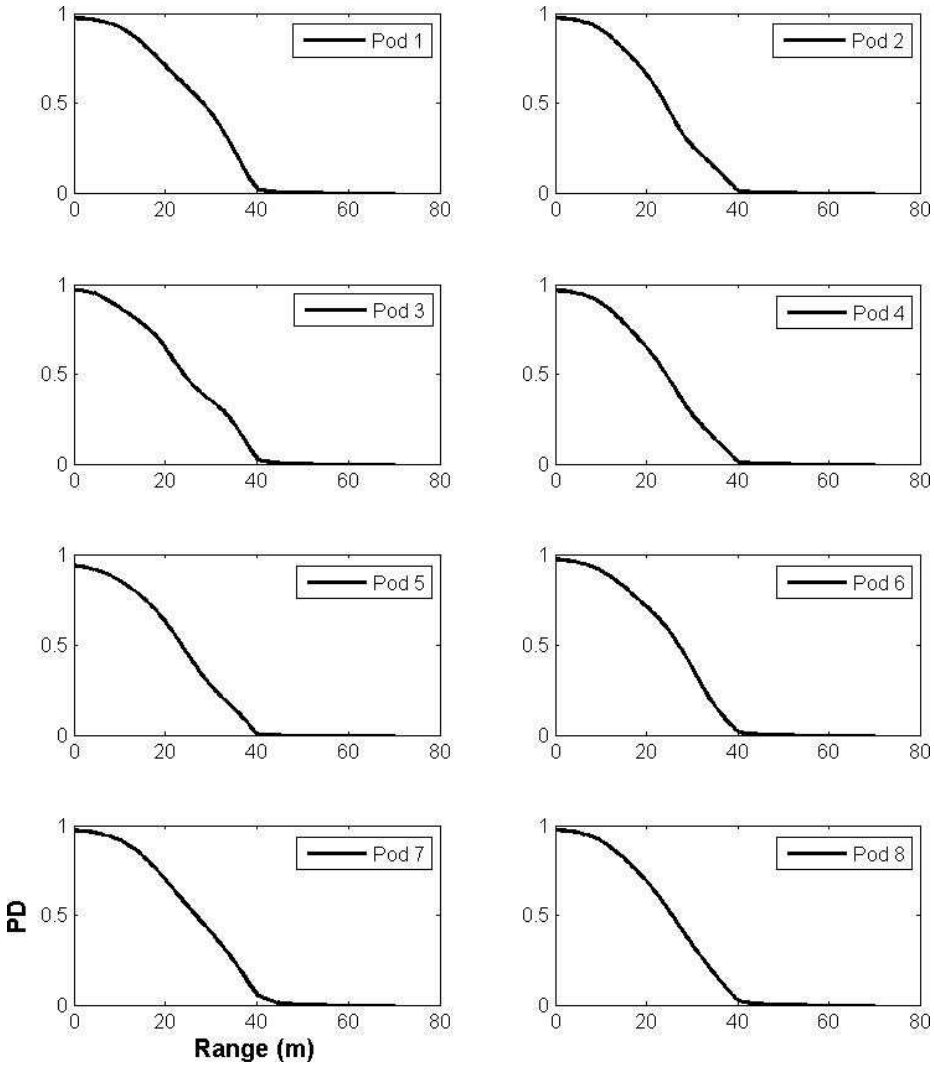
SPDF Results



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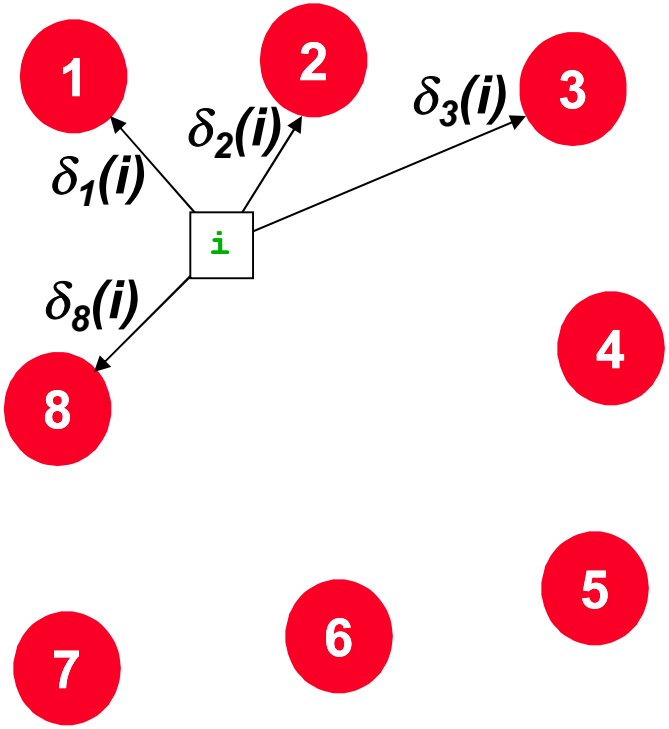
Creating a Detection Map

$$\pi_i = 1 - \prod_{j=1}^{P} \left[1 - \theta_j^*(\delta_j(i)) \right]$$



- π_i – probability of detection at pixel *i*
- $\delta_j(i)$ – distance of the ith pixel from the jth sensors
- ***P*** – number of sensors

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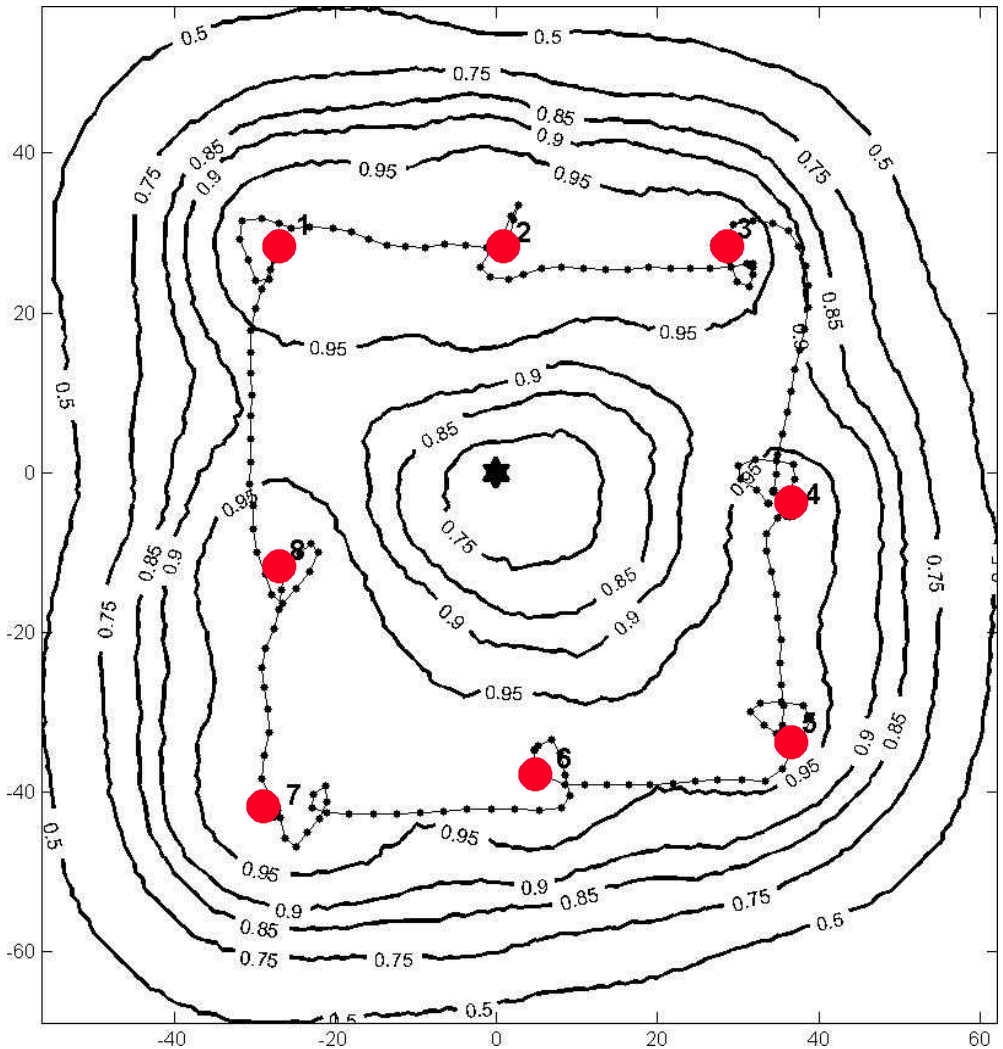
Detection Map Results



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Conclusion & Future Work

- Developed alogrithms to learn a sensor probability of detection function (SPDF)
- Use Parzen estimator to create a smooth SPDF
  - Incorporates evidence from nearby locations
  - With enough samples converges to true result
- Put Parzen estimator in a Bayesian framework to incorporate prior information and estimate confidence intervals
- Combine multiple SPDF's to create a detection map
- Collect data in complex terrain and test algorithms
  - Arroyos / ravines
  - Hill sides
  - Forests
- Extend to other perimeter security systems
  - Ground based radar
- Nonisotropic SPDF
- Multiple MDU
- Incorporate uncertainty into visualization of the detection map
- Automatically request MDU to walk/run in certain areas to reduce uncertainty
- Compare algorithm results to manual approach

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