Sensing & Effecting

Sensor & Data Fusion

U.S.ARMY

ARL

Distributed Change Detection of a Radioactive Source

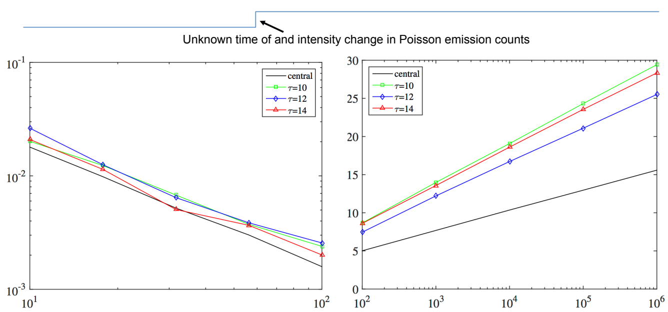
POC: Mr. Gene Whipps
Electronics Engineer
gene.t.whipps.civ@mail.mil

SE-11

Funding: 6.1
1/3 Man Year
Execution: 2015

Objectives

- Detect a hazardous radioactive point source using a network of particle emission count sensors.
- Detect the source with minimal detection delay with constraints on communication bandwidth and the false alarm rate.
- Develop a distributed algorithm that is robust to communication errors and scalable with network size.
- Develop analytic performance metric.



False alarm rate versus decision threshold for the centralized and distributed detectors.

Detection latency versus decision threshold for the centralized and distributed detectors.

Challenges

- Current, centralized and distributed approaches are not robust to node or communication link outages.
- Radiation source parameters, such as location and intensity, are typically unknown requiring increased algorithm complexity.
- Batch processing methods (fixed-length sequence of samples) are not designed to minimize detection latency and assume a known source arrival time.

Approach

- Develop a distributed change-point detector to quickly detect the arrival of a point source.
- The design objective is to minimized average detection delay for a maximum false alarm rate.
- State-of-the art methods employ batch (NP) [1], sequential (SPRT) [2], or change-point methods (CUSUM) [3] at each sensor node and not at a fusion center. Fusion performed by majority voting or LRT-based methods to make a final decision. Unknown source and background parameters are estimated in isolation instead of jointly across the network.
- Our approach is similar to the general-purpose change-point detection algorithm reported in [4]; we have extended this method to multi-sensor cases and with quantization. Unknown source parameters treated as random resulting in a composite rule.
- Local emission counts are quantized before communicating to a fusion node to reduce bandwidth requirements.

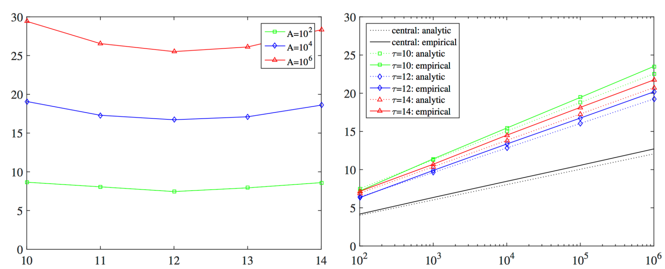
[1] A. H. Liu, J. J. Bunn, and K. M. Chandy, "An analysis of data fusion for radiation detection and localization." in *FUSION*, 2010, pp. 1–8.
[2] N. S. Rao, C. W. Glover, M. Shankar, J.-C. Chin, D. K. Yau, C. Y. Ma, Y. Yang, and S. Sahni, "Improved sprt detection using localization with application to radiation sources," in *FUSION*, 2009, pp. 633–640.
[3] L. Qian, J. Fuller *et al.*, "Quickest detection of nuclear radiation using a sensor network," in *Homeland Security (HST), 2012 IEEE Conference on Technologies for*, 2012, pp. 648–653.
[4] M. Pollak, "Optimal detection of a change in distribution," *The Annals of Statistics*, vol. 13, no. 1, pp. 206–227, Mar. 1985.

Results

- Developed a distributed change-point detector that quickly detects the arrival of a radioactive point source.
- The detector incorporates quantization of local detection statistics to limit network bandwidth requirements.
- Developed a multi-sensor analytic performance metric.
- Empirical performance from simulations agrees with analytical performance predictions.
- Algorithms require data storage that scales linearly with measurements and sensor nodes. A sliding window limits the computation complexity.

Change-point Rule

$$N = \inf \left\{ n : \max_{1 \le k \le n} \int_{\Theta} \prod_{i=1}^{M} \prod_{j=k}^{n} \frac{p_i^{\theta}(x_{i,j})}{p_i^{0}(x_{i,j})} \mathrm{d}F_{\theta} \ge A \right\}$$



Detection latency versus quantization threshold for the centralized and distributed detectors.

Empirical and analytical detection latency versus decision threshold for a given source.

Discussion & Conclusions

- Algorithms that are scalable and robust to node and link failures are critical features for Army ISR missions.
- Principled approach to detector design with fundamental understanding of detector performance and complexity.
- Distributed detection architecture applies to other applications where count statistics are collected by a network of sensors; for example, events in social media.

Path Forward

- Incorporate direct optimization of local quantizers via a proxy such as Kullback-Leibler divergence.
- Present findings at an international technical conference.

Publications

- This work to appear in Fusion 2015, July 6-9.
- Whipps, G, Ertin, E, Moses, R, "Distributed Detection of Binary Decisions with Collisions in a Large, Random Network", Signal Processing, IEEE Trans. on, Vol 63, No 6, Mar 2015.
- Whipps, G, Ertin, E, Moses, R, "A Consensus-based Decentralized EM for a Mixture of Factor Analyzers", MLSP 2014, Sep 2014.
- Whipps, G, Ertin, E, Moses, R, "Distributed Detection with Collisions in a Random, Single-hop Wireless Sensor Network", ICASSP 2013, May 2013.