Distributed Sensing and Inference

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• Who am I?
• Why am I here?
• Now that I’m here, what should I do?
My Research Interests

Statistical Signal Processing
modeling, parameter estimation, hypothesis testing

• Radar imaging
  – Tomography for radar
  – Multistatic: multiple transmitters and receivers
  – Physics-based modeling for low-dimensional feature sets
    • Discovery, estimation, evaluation
  – Automatic Target Recognition (ATR)

• Sensor Networks
  – Self-calibration (location; orientation)
  – Multi-modal sensor fusion
  – Communication-constrained distributed inference
Radar Feature Modeling and Estimation

\[ E(f, \phi) = \sum_{k=1}^{n} A_k \left( \frac{j f}{f_c} \right)^{\alpha_k} e^{-2\pi f y_k \sin \phi} \sin \left( \frac{2\pi f}{c} L_k \sin (\phi - \phi_k) \right) \exp \left( -j \frac{4\pi f}{c} [x_k \cos \phi + y_k \sin \phi] \right) \]

**Frequency Dependence**

**Aspect Dependence**

**Location Dependence**

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**Scattering Attributes**

- \( A_k \): amplitude [H, V, X]
- \( x_k, y_k \): location
- \( f_k \): frequency type
- \( L_k \): length
- \( \phi_k \): pose angle
- \( \phi \): angle response

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**Extract**

\( x=35.2 \text{ m} \)
\( y=46.3 \text{ m} \)
\( A=9.43 \text{ dB} \)
\( L=1.33 \text{ m} \)

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**T72-sn132**

AZ=249.79, EL=17.18

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WISP, November 11-12, 2004
XpatchF synthetic backscatter data

- Publicly released
- 7-13 GHz frequency band
- 0-360° az, 0-90° elev
- 0.07° angle spacing
- 1” x 1” x 1” resolution
- Full polarization
- ~300 Gbytes of data
3D Radar Tomography Example

Is there more to signal processing than pretty pictures?

Color encodes radar look angle.
Sensor Network Self-Localization

- Location estimation for nodes in a large ad-hoc network.
- Measurements:
  - Distance
  - Signal time (difference) of arrival
  - Received signal strength
  - Direction of arrival
- Investigate location error as a function of:
  - Node density
  - Number of beacons
  - Network size

Red: beacon nodes
Blue: nodes w/unknown location
Distributed Inference for Sensor Networks

Collaboration in

Sensing

Communications

Decision-Making by People

Targets of Interest

Sensed Phenomena

Statistical Model for Sensed Variables and Information Fusion

Graphical Model for Ad-hoc Communication

Event Likelihoods for Human Decision-Making

Measurements dependent across time and space
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• Identifiability of models
• Inference quality vs. measurements
  – What measurements do we take to produce ‘best’ estimates or inferences?
• Robust parametric/nonparametric inference
  – Use models where you can
  – Use nonparametric statistical methods on ‘residual’ for robustness
• Automatic inference to support human decisions
  – Explore human machine inference interface
  – SP must generate outputs with higher information rate
Now that I’m here, what should I do?

How do we build SP network 'bipartite graphs'
Epistemology

- [Craig Q2] What can SP tell us about the network?
- [Craig Q3] What should the input signals be?
  - What do we want to know?
  - What can we measure, and why do we think those measurements will be useful?

Jointly define/hypothesize/test a model

model  measurements  inferences
What are the research questions?

- What can SP tell us about the network?
- What's happening in my network?
- How do I detect/identify/quantify (unusual) activity
  - DoS; equipment failures; routing changes
- What can I infer from xxx measurements?
- What other measurements would make the inference task (much) easier?
- How do I present inference outputs to decision-makers?
- How do I automate the inference/decision/response process?
Data Thoughts

• Some high-fidelity data is useful, even if it is synthetic
  – Model development; model robustness; new insights

• Range of data sets: controlled realistic
  – Identify questions that can/cannot be answered with each set

• Choose measured data sets carefully
  – Goal-oriented
  – Minimize ‘noise’ that detracts from research

• Staged data collections with refinement

• Challenge problems:
  – "If you measure something, it will improve."
ATR: MSTAR Data Set

MSTAR Public Targets:
10 targets x ~275 aspects = 2747 image chips
• Problems before tools
• A signal processing ‘resource bank’?
  – Triage of research questions?
If you were to design the next internet, what measurements would you build in?

The answer guides:
• the compelling research questions
• the initial data needs
• a scientific framework for collaboration at the next level