New Sensor Signal Processor Paradigms: When One Pass Isn’t Enough

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Outline

• Simplified evolution of signal processing
  – Stream processing vs. multi-hypothesis processing

• Multi-hypothesis example: model-based processing
  – DARPA VisiBuilding & Multipath Exploitation Radar Programs

• Impact on embedded computing architectures

• Conclusions
Simplistic Evolution of Signal Processing

Stream signal processing can be impeded by smarter use of processed data

1. Filtering
2. Adaptive processing
3. Knowledge-aided processing (e.g., DARPA KASSPER program)
Digression: Model Interpretation Affects How You Process Data

“Seeing Double”, J. Richard Block (Routledge, 2002)
Model-based approaches might require many iterations on both the data stream and model-hypothesis generation.
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VisiBuilding Program

• Objective: Develop innovative sensing and exploitation architectures to see inside buildings
  – Find personnel inside of buildings
  – Provide building layouts (walls, rooms, stairs, doorways)
  – Identify weapons caches, shielded rooms, etc.

• Ideal approaches should:
  – Provide actionable information (e.g., model-based, not radar blurs)
  – Support range of CONOPS
  – Provide robustness to urban environment
**SAR-Based Building Imaging**

- Current imaging assumes that sensing is a separable function of sensor position $p$ and structure $x$.
- Algorithms imply that inverse function can be approximated:

$$x = \{G(p)H(p,x)\} = H^{-1}(p)H(p,x) \approx x$$

- Fatal flaws:
  - $H(p,x)$ is a highly nonlinear mapping with no direct inversion.
  - Approach cannot easily exploit known constraints on $x$.

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Open-loop imaging doomed to fail in complicated environments!
VisiBuilding Approach

General approach:
1. Use baseline $p_0$ to maximize initial information
2. Determine dominant features
3. Update model with new features
4. (optional) Modify sensor state $p$
5. Predict output due to model and compare with data
6. Stop if converged; otherwise, iterate to step 2

$y = H(p, x)$

$GH(p, x)$

Building constraints; material properties
Model-based reasoning requires forward prediction and iterative refinements of the model.
LAYOUT INITIALIZATION

a) Extracted Features

b) Hypothesized Layouts
Multipath Exploitation Radar for Urban Tracking

- Multipath Exploitation Radar can provide persistent wide area tracking of vehicles in a metropolitan area like Baghdad using only three UAVs at 15 kft altitude
  - Track high value targets through dense city streets without direct line-of-sight
  - Provide long-term track history of all targets for post-event forensics
- Enabling technology uses specular multipath off buildings to see into urban shadows and canyons
  - Provides six-fold increase in sensor coverage area over physical line-of-sight limit

Multipath Exploitation Radar can cover entire Baghdad metropolitan area with three multipath exploiting airborne sensors!
Line of Sight vs. Multipath Coverage

Example: Surveillance of a typical urban scene (two to four story buildings) as seen by 15 kft UAV
- Top down view of typical city block shown
- Line-of-sight shadows dramatically reduce visibility of roads between buildings
- Multipath fills in the shadows

Urban shadows are fatal for line-of-sight systems

Specular reflections from buildings fill urban shadows and increase road visibility

Specular reflection allows detection within urban canyons
Multipath Hypothesis Tracking: “RF Hall of Mirrors”

- Range-Doppler returns from multipath reflection structures are unique “fingerprints” for different tracks

Target tracks overlaid on urban layout:

Multipath returns provide fingerprint identifiable to urban location
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Impact on Embedded Computing Architectures

- Many future applications will not yield to conventional stream processing approaches
- Model-based approaches will require physics-based computation and inferencing ideally suited for dedicated co-processors (e.g., GPUs and FPGAs)

Physics-Based Architectures

- Teraflop computations for hypothesis modeling
- Physical modeling can exploit 3-D graphics engines for phenomenology and hypothesis testing
Summary

• Signal processing will migrate from stream signal processing approaches to physics-based multi-hypothesis processing

• Several DARPA programs (VisiBuilding and Multipath Exploitation Radar) are already pushing algorithm development in these areas

• Unique convergence with GPU processing technology is ideally suited for physics-based approaches