Systems Simulation
ECE 597/697 S

CASA System Overview

Prof. Michael Zink
Overview

- Societal need
- State of the art
- Collaborative Adaptive Sensing
- Test bed
  - Radars
  - Communication
  - Distribution Infrastructure
- Meteorological Command & Control
- End user integration
- CASA future
ERC Overview

• A guiding strategic vision for transforming engineered systems and the development of a diverse and globally competitive engineering workforce

• A systems-motivated interdisciplinary research program that runs from discovery to engineered systems and is enabled by test beds

• A set of cross-disciplinary, systems-focused education programs from pre-college to practitioners designed to produce graduates who can advance technology and speed technology transfer

• Cross-institutional commitment to facilitate and foster the interdisciplinary, innovation focused culture and the diversity of the ERC
Societal Need

*Observe, understand, detect, predict hazardous weather*

- Tornadoes
- Floods (3000 flash floods annually)
- Land-falling hurricanes
- Thunderstorms
- Boundary-layer winds for particle transport

- 300 lives, $13B damage
Today's Weather Radar Network

gap - earth curvature prevents 72% of the troposphere below 1 km from being observed.
Concept of Operations

- Multi-Doppler scan
- Closest radar
- Surveillance scan

NEXRAD = 5 min between updates
CASA = 1 min between updates
Collaborative Adaptive

- Allocate sensing collaboratively and adaptively in response to target dynamics (spatial+temporal), user data product need, and data quality
- Improved resolution, sensitivity, accuracy, and ability to support multiple users and multiple applications simultaneously.
Organizational Structure

- Sensing
- Distributing
- Prediction
- End User

Technical Integration
How can we optimize system operation for the best response?
Test Bed Location
Test Bed Location cont’d
### IP1 Node Component Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>$8,000</td>
</tr>
<tr>
<td>Radome</td>
<td>$20,000</td>
</tr>
<tr>
<td>Tower (8m)</td>
<td>$15,000</td>
</tr>
<tr>
<td>Data Acq.</td>
<td>$20,000</td>
</tr>
<tr>
<td>Transceiver</td>
<td>$30,000</td>
</tr>
<tr>
<td>EL Positioner</td>
<td>$10,000</td>
</tr>
<tr>
<td>Az Positioner</td>
<td>$90,000</td>
</tr>
<tr>
<td>Platform, frames</td>
<td>$10,000</td>
</tr>
<tr>
<td>Computers, storage</td>
<td>$20,000</td>
</tr>
<tr>
<td>HVAC</td>
<td>$6,000</td>
</tr>
<tr>
<td>Power line</td>
<td>$500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$229,500</td>
</tr>
</tbody>
</table>

Note: 20 m towers cost $120,000

### IP1 Node Yearly O&M Costs

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric power</td>
<td>$2,000</td>
</tr>
<tr>
<td>Spare parts/repairs</td>
<td>$7,500</td>
</tr>
<tr>
<td>Networking</td>
<td>$16,500</td>
</tr>
<tr>
<td>Land Lease</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total Annual</strong></td>
<td>$26,000</td>
</tr>
</tbody>
</table>

Note that these are parts costs only.
Communications: Redundancy

KCYR $\Rightarrow$ KRSP

KCYR $\Rightarrow$ KLWE
Distribution Infrastructure

Wireless link DS-3 (45 Mbit) or Canopy radio* (7.5 Mbit)

*Canopy radio is used on the Cyril-Lawton and Cyril-Rush Springs links

Detection algorithms

SOCC

LB

LB

ECE Department
MC&C Overview

1 Mbps (moment) 100 Mbps (raw)

End users: NWS, emergency response

20 + 40 sec. “heartbeat”
Detection

- Identify weather features in radar data:
  - **RT Threshold**
    - Operates on single radar data, in polar coordinate system
    - Uses a relative threshold
    - Will detect lower levels of reflectivity
  - **CASA SCIT**
    - Operates on merged data
    - Produces more detections in areas of high and widespread reflectivity

![Detections](image)
Task Generation

- Forms scanning tasks by clustering similar weather features
  - Scanning tasks have type
    - Reflectivity Tasks
    - Storm Tasks
    - Rotation Tasks
  - Scanning tasks have area
    - Polygons

Detections Tasks
Optimization

- Chooses the set of sector scans to maximize end-user satisfaction.

- 60 second heartbeat
  - First 20 seconds – each radar does a 360 surveillance scan.
  - Remaining 40 seconds – radars to DCAS sector scanning.

- All sector scans are PPI sector scans.
  - Sweep horizontally, tilt up in elevation, sweep horizontally, tilt up in elevation, repeat...

- Sector size determines number of tilts scanned
  - Minimum sector size = 60 degrees.
  - Maximum sector size = 360 degrees.
  - Radars start at lowest tilt and work up for as many tilts as possible in 40 seconds.
MC&C: What to Scan?

\[ J(C) = \sum_t \left[ U(t, \Delta k) Q(t, C) \right] \]

\[ U(t, \Delta k) = \sum_g w_g U_g(t, \Delta k) \]

\( w_g \) sets user importance/priority.

\( U_g \) sets task importance/priority. Value depends on time since the task was last scanned.

Tasks (t) (blue) Scans (C) (green)

End User Policy Control

End User Rules

<table>
<thead>
<tr>
<th>Rule ID</th>
<th>Rule trigger</th>
<th>Sector Selection</th>
<th>Elevations</th>
<th># Radars</th>
<th>Contiguous</th>
<th>Sampling interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>Reflectivity</td>
<td>task size</td>
<td>All</td>
<td>1</td>
<td>yes</td>
<td>1/180 sec.</td>
</tr>
<tr>
<td>T1</td>
<td>Reflectivity</td>
<td>Task size</td>
<td>All</td>
<td>1</td>
<td>yes</td>
<td>1/120 sec.</td>
</tr>
<tr>
<td>T2</td>
<td>Storm Cell (SCIT CASA)</td>
<td>Task size</td>
<td>All</td>
<td>2</td>
<td>yes</td>
<td>1/180 sec.</td>
</tr>
<tr>
<td>T3</td>
<td>Rotation</td>
<td>Task size</td>
<td>All</td>
<td>2</td>
<td>yes</td>
<td>1/60 sec.</td>
</tr>
<tr>
<td>P1</td>
<td>Reflectivity</td>
<td>Task size</td>
<td>All</td>
<td>1</td>
<td>no</td>
<td>1/600 sec.</td>
</tr>
<tr>
<td>R1</td>
<td>Reflectivity</td>
<td>Task size</td>
<td>All</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>Storm Cell</td>
<td>Task size</td>
<td>All</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>Reflectivity</td>
<td>Task size</td>
<td>Lowest two</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td>Rotation</td>
<td>Task size</td>
<td>Lowest two</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O1</td>
<td>time</td>
<td>360</td>
<td>degrees</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MC&C: How to Scan?

\[ J(C) = \sum_i U(t, \Delta k) Q(t, C) \]

Determines the “quality” of a scan configuration C:
- How well is the task covered by a sector?
- How many radars cover the task?
- How many elevations will each such sector scan?
Example I
Example II
End User Integration

### Public (Streets)
- Understanding, believing, confirming, personalizing, action necessary, action feasible
- Protective Action/No Action
- Impact

### Emergency Mgrs (Towns/Streets)
- Spotter, Responder Resource Assessment
- Spotter, Responder Alert
- Spotter/Resp Deployment
- Public Notification
- Emerg. Response

### Spotters (Counties/Towns)
- Monitoring forecasts
- Pre-deployment
- Deployment/Reporting

### Media (Counties/Towns)
- Forecasts during regular programming
- Icons on screen
- Commercial Interruption Crew Deployment
- Wall-to-Wall Coverage

### NWS Forecasters (Counties/Towns)
- Hazardous Weather Outlook
- Short Term Forecast Special WX Statement
- Sht. Term Forecast WX Statement
- WARNING

### CASA Researchers
- DCAS: Ensemble Forecasts Clear-Air Sensing
- DCAS: NWP, Boundary Sensing
- DCAS: Feature Detection, Multi-Doppler views, Analysis Nowcasting

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Start

- Pre storm Environment: 3 days
- Watch: 2 days
- Warning: 24 hrs
- Event/False Alarm: 4 hrs.
- Event: 1 hr.
- ~18 min.

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Emergency Managers Product Usage

- CASA radar
- Spotter reports
- NEXRAD WSR-88D
- Local TV Weather Report
- Internet Weather Provider
- NOAA Weather Radio
- NWS Severe Weather Watch
- Mesonet products
- OK First Weather Briefing
- NWS Graphicast
- NWS Haz. Weather Graphics
- NWS Warning Decision Update
- NWS Severe Weather Warning
- NWS Zone Forecast
- Other
- SPC Convective Outlook
- NWS River Forecast Products
- National TV Weather Report

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Tornado Warnings

- 73% of EMs directly warn the public.
- 97% of those use sirens.
- 51% can warn by sub-region, many do not because they are risk averse or too busy

Diagram showing percentages of different warning methods used:

- Sirens: 100%
- NOAA Wx: 80%
- Radio: 60%
- Local Radio: 40%
- Reverse Call out system: 20%
- TV: 10%
- Cable: 10%
- Interrupt: 10%
- EAS: 10%
- Social Network: 5%
CASA Future: Distributed Negotiation Model

- Multi-attribute MC&Cs share information regarding tasks in boundaries and initial configurations.
- Each MC&C has a deadline while waiting for other MC&Cs’ strategy update or strategy change proposals.
- Main stages of negotiation
  - proposing: compute new configuration, share marginal utility.
  - agreement selection: MC&C changes its configuration if its marginal utility is higher than all neighbors whose proposals are in conflict with this MC&C’s proposal.
  - informing of changes: MC&Cs share new scanning configurations.
  - cancel proposal if the proposal cannot bring positive marginal utility based on its neighbor MC&Cs’ new strategies.
Resource Challenged Environments

**DCAS**
- Eliminates earth curvature problem
- Closed-loop architecture
- Introduces end-user driven adaptation

**Off The Grid Radar**

**Wireless Sensor Network**
- Ease of deployment
- Wireless networking
- Energy generation
- Limited reliance on existing infrastructure

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MA & PR Test Beds

- 3 - node test bed in MA
- 3 - node test bed in PR
- Long-distance wireless links
- Proof-of-concept for Virtual Private Sensor Networks
OTG Test Bed Example
Wireless Link Configuration

Link 1
- Node 1
- Wireless 802.11g link, Distance: 157 meters, ESSID="pair1"

Link 2
- Distance: 172 meters
- 2 meters distance between antennas
- 90°
- 45°
- Node 4

Link 3
- Distance: 197 meters
- Node 4

Link 4
- Distance: 265 meters
- ESSID="pair2"

Node 2
Node 3
Antenna Orientation

- 10 Mbps increase depending on antenna orientation
- Almost full channel capacity with fully separated channels
- The answer lies in the antenna gain pattern
Interference between Long-distance Links

Channel 1

Wireless links
A pair of directed antennas
Distance: 10.3 km

Channel 5

Distance: 2.4 km

Alpha
Beta
Mt Toby
CS

100°
Summary

- Engineering Research Center
- CASA
- Distributed Collaborative Adaptive Sensing
- Test bed and its components
- End user integration
- CASA’s future
Homework

- Read:
  - “MANET Simulation Studies: The Incredibles”, S. Kurkowski, T. Camp, M. Colagrosso