THE OHIO STATE UNIVERSITY

Cognitive Radar Experiments At The Ohio State University

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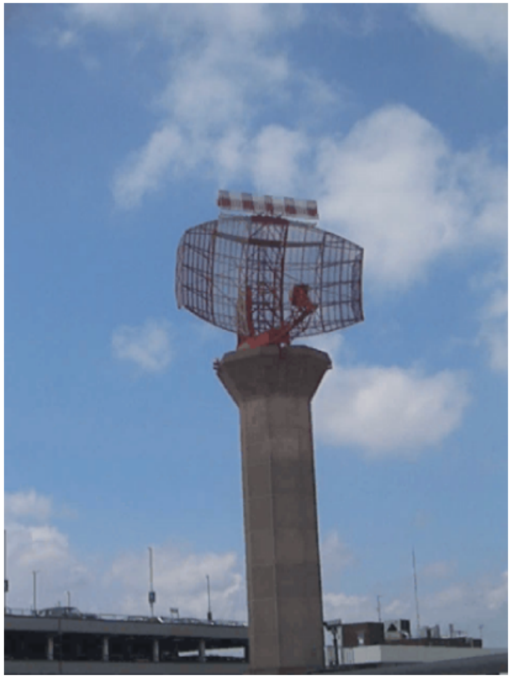
The OSU ElectroScience Lab

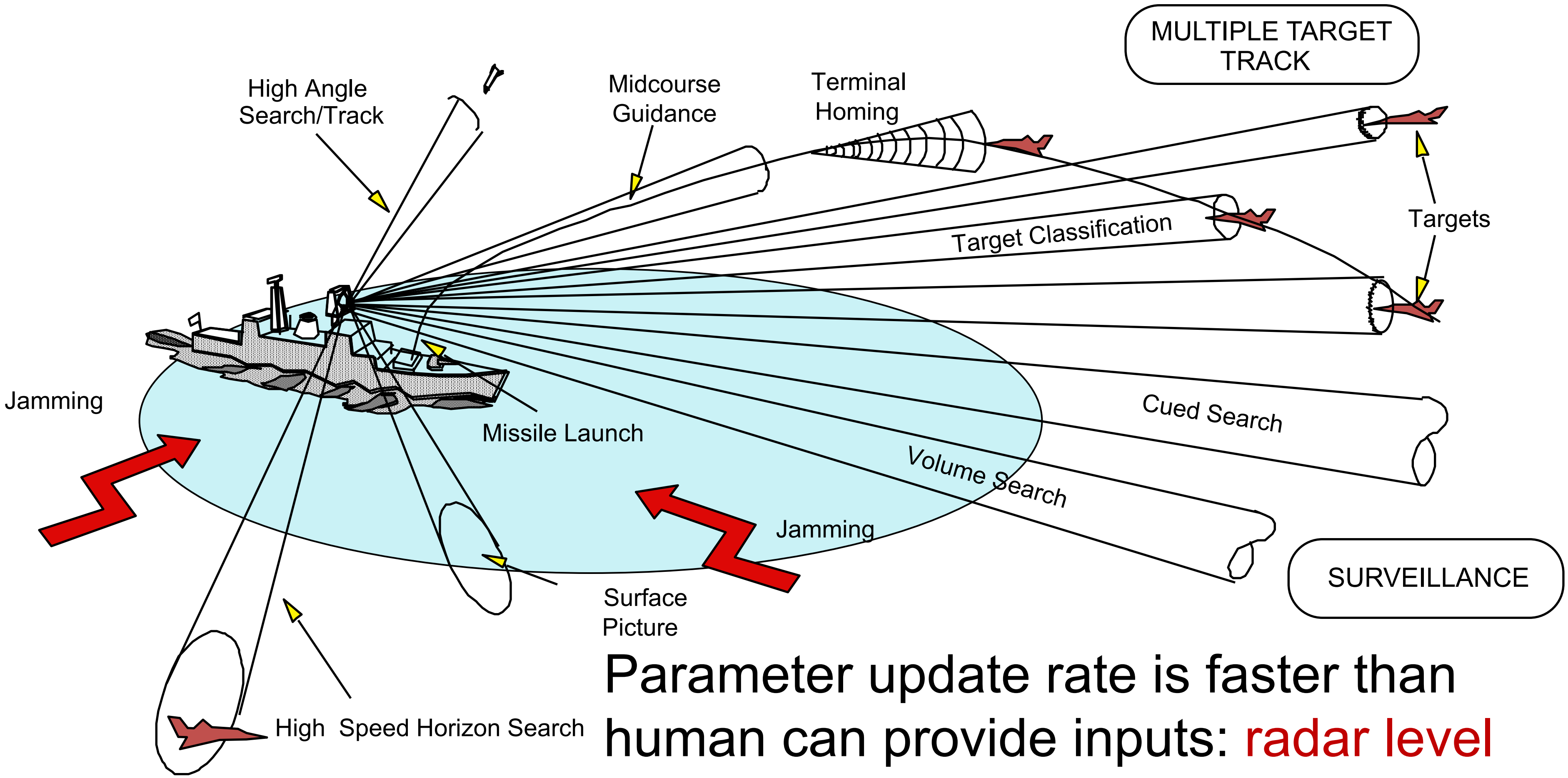
All Radar *Systems* Are Cognitive

- Consider an air traffic control radar



- The “turn-and-burn” sensor is not considered cognitive
- The overall air traffic control system is cognitive
- Air traffic controllers and pilots provide the cognition

Phase Array Radar Case



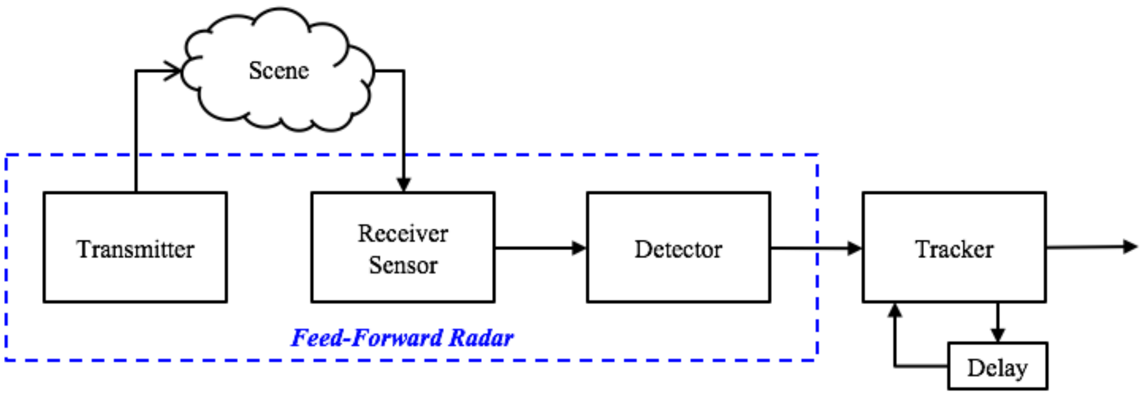
Parameter update rate is faster than human can provide inputs: radar level cognition needed for best performance

The Case For Cognition

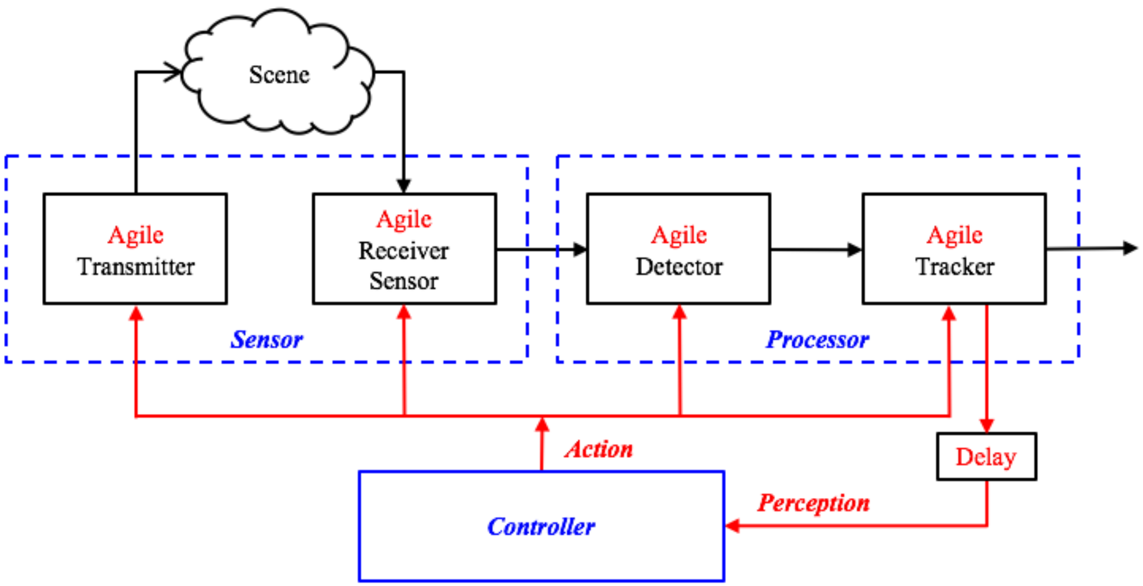
- A human operators currently provides cognition
- Humans operate on slow timescales
- Already there is latent capacity in radar system
  - Electronic scanning allows parameter changing each pulse
- Change role of operator to be editorial: operator sets goal, radar determines how to achieve it
- For next generation of radar we need cognition to achieve maximum capability

Cognitive Radar Concept

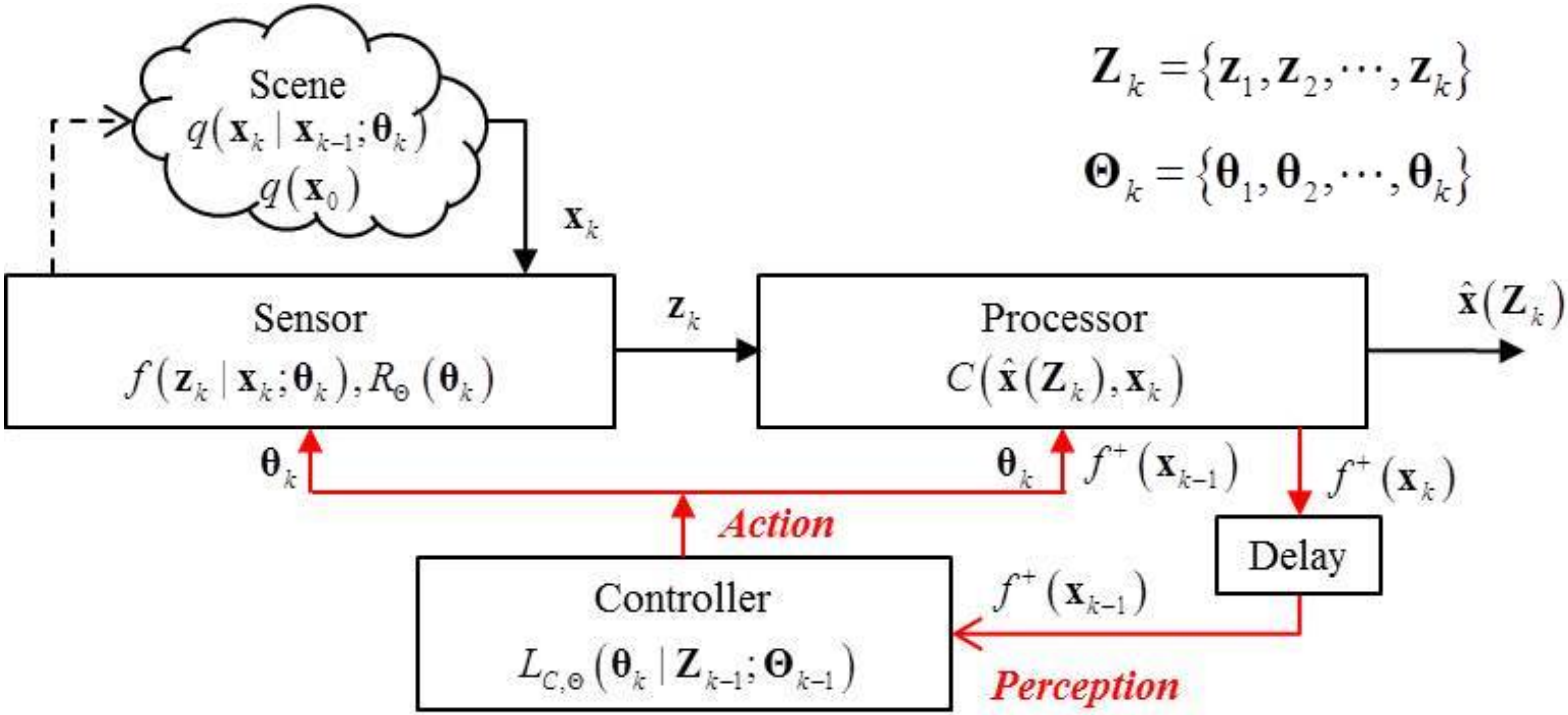
Standard feed-forward radar system performs detection to obtain sensor measurements that are passed on to a higher-level processor (tracker)



Cognitive radar system processor includes detector and tracker, feedback to sensor



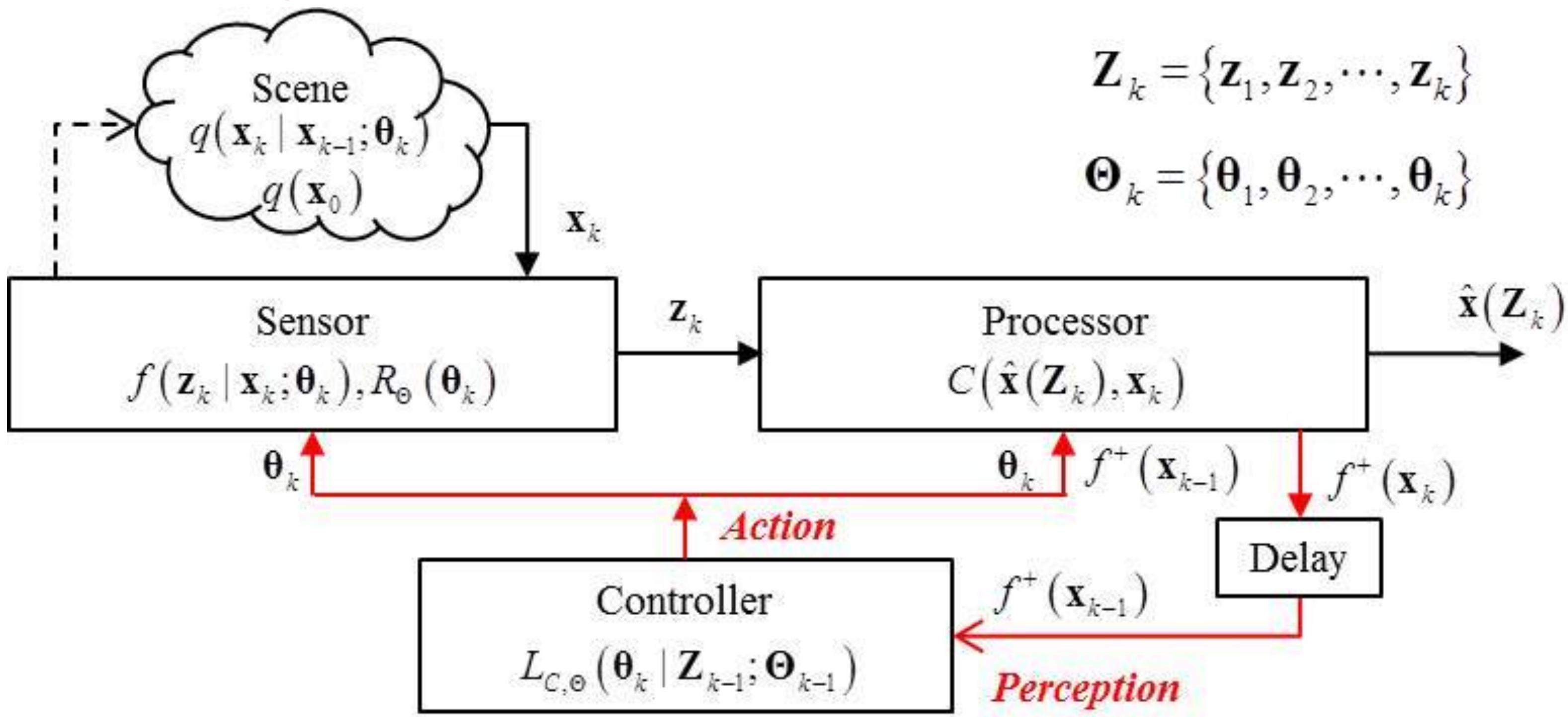
Cognitive Radar Framework



- Sensor model now includes adjustable sensor parameters $\boldsymbol{\theta}_k$ and sensor cost/constraint function $R_\Theta(\boldsymbol{\theta}_k)$
- Controller determines next sensor parameters by minimizing a loss function that balances state estimation cost and sensor cost

$$\boldsymbol{\theta}_k = \arg\min_{\boldsymbol{\theta}} L_{C,\Theta}(\boldsymbol{\theta} \mid \mathbf{Z}_{k-1};\boldsymbol{\Theta}_{k-1}) = \arg\min_{\boldsymbol{\theta}} L\left\{R_C^{\uparrow}(\boldsymbol{\theta} \mid \mathbf{Z}_{k-1};\boldsymbol{\Theta}_{k-1}), R_\Theta(\boldsymbol{\theta})\right\}$$

Cognitive Radar Framework



- State estimation cost characterized by predicted conditional Bayes risk: Bayes risk for next estimate given past data

$$R_C^{\uparrow}(\boldsymbol{\theta} \mid \mathbf{Z}_{k-1};\boldsymbol{\Theta}_{k-1}) = \int C\left(\hat{\mathbf{x}}(\mathbf{z}_k, \mathbf{Z}_{k-1}), \mathbf{x}_k\right) f(\mathbf{x}_k, \mathbf{z}_k \mid \mathbf{Z}_{k-1};\boldsymbol{\theta},\boldsymbol{\Theta}_{k-1})\, d\mathbf{x}_k d\mathbf{z}_k$$

$$f^{\uparrow}(\mathbf{x}_k, \mathbf{z}_k) \equiv f(\mathbf{x}_k, \mathbf{z}_k \mid \mathbf{Z}_{k-1};\Theta_k) = f(\mathbf{z}_k \mid \mathbf{x}_k;\boldsymbol{\theta}_k) f^-(\mathbf{x}_k)$$

Example: Single Target Tracker

- Initialization

$$f^{+}(\mathbf{x}_0) \equiv q(\mathbf{x}_0)$$

- Recursion

$$\mathbf{B}_k^{\uparrow}(\boldsymbol{\theta}_k \mid \mathbf{Z}_{k-1}; \boldsymbol{\Theta}_{k-1}) = -E^{\uparrow}\left\{\Delta_{\mathbf{x}_k}^{\mathbf{x}_k} \ln f^{\uparrow}(\mathbf{x}_k, \mathbf{z}_k)\right\}$$

PC-BIM

$$\boldsymbol{\theta}_k = \arg\min_{\boldsymbol{\theta}} \; L\left\{\mathrm{tr}\left\{\mathbf{B}_k(\boldsymbol{\theta}; \boldsymbol{\Theta}_{k-1}, \mathbf{Z}_{k-1})^{-1}\right\}, R_{\Theta}(\boldsymbol{\theta})\right\}$$

Controller Optimization

Obtain $\mathbf{z}_k$ using $\boldsymbol{\theta}_k$

Sensor measurement

$$f^{-}(\mathbf{x}_k) = f(\mathbf{x}_k \mid \mathbf{Z}_{k-1}) = \int q(\mathbf{x}_k \mid \mathbf{x}_{k-1}) f^{+}(\mathbf{x}_{k-1}) \, d\mathbf{x}_{k-1}$$

Motion update

$$f^{+}(\mathbf{x}_k) = f(\mathbf{x}_k \mid \mathbf{Z}_k) = \frac{f(\mathbf{z}_k \mid \mathbf{x}_k) f^{-}(\mathbf{x}_k)}{\int f(\mathbf{z}_k \mid \mathbf{x}_k) f^{-}(\mathbf{x}_k) \, d\mathbf{x}_k}$$

Information update

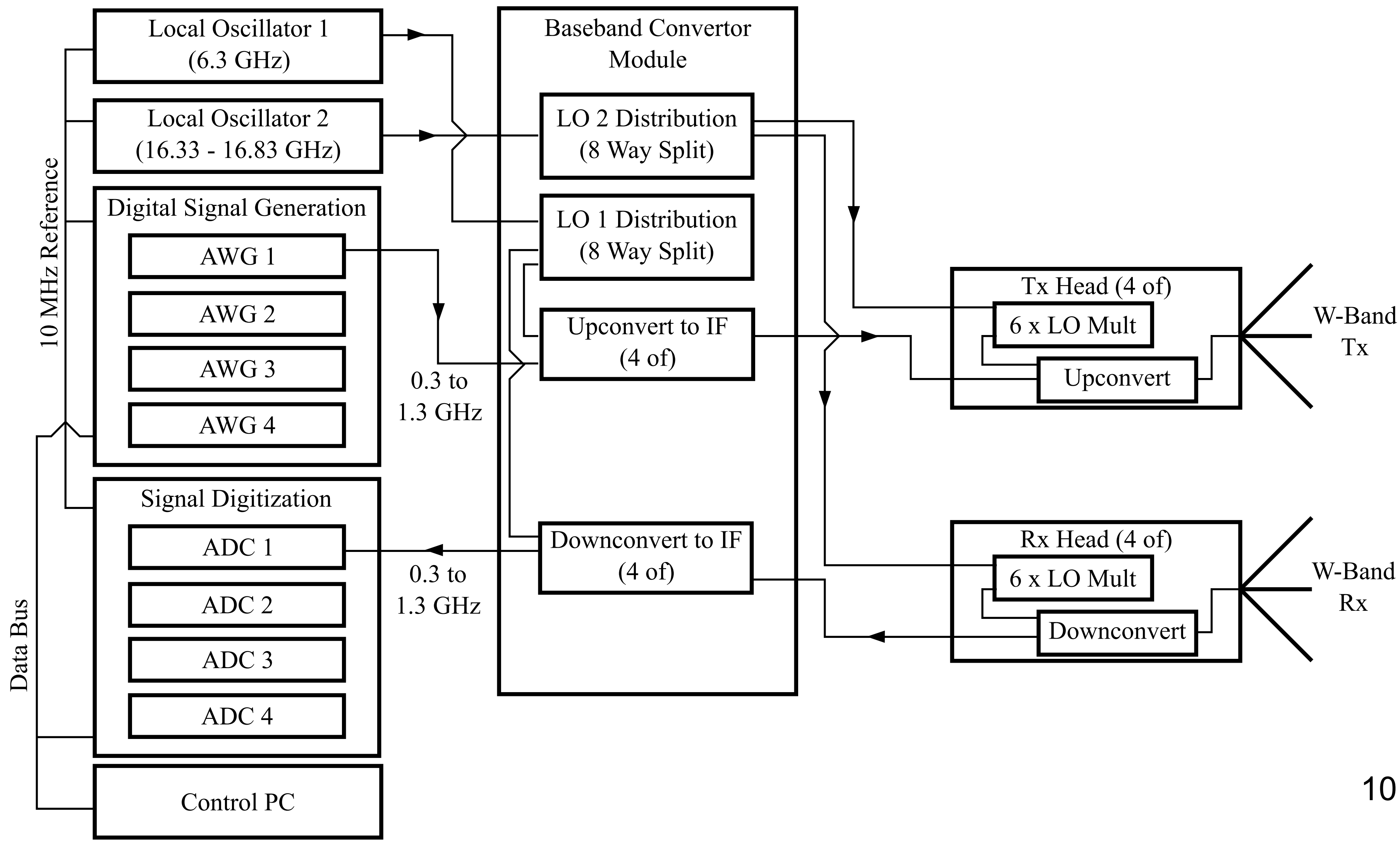
$$\hat{\mathbf{x}}(\mathbf{Z}_k) = \boldsymbol{\mu}_k^{+} = E^{+}\{\mathbf{x}_k\}$$

State estimation from posterior

The CREW Systems At OSU

- Cognitive Radar Engineering Workspace (CREW)
- Dedicated experimental system for cognitive radar research
  - Operates at W-band
  - Four transmit & four receive channels
  - Arbitrary waveform generation for each Tx channel
  - Independent digitization for each Rx channel
  - All channels coherent
  - Capable of real-time parameter adaption
- Funded from an AFOSR DURIP award (~$650k)
- System design came from Cognitive Sensing Lab
  - Digital hardware came from Keysight
  - RF hardware came from Millitech

System Block Diagram



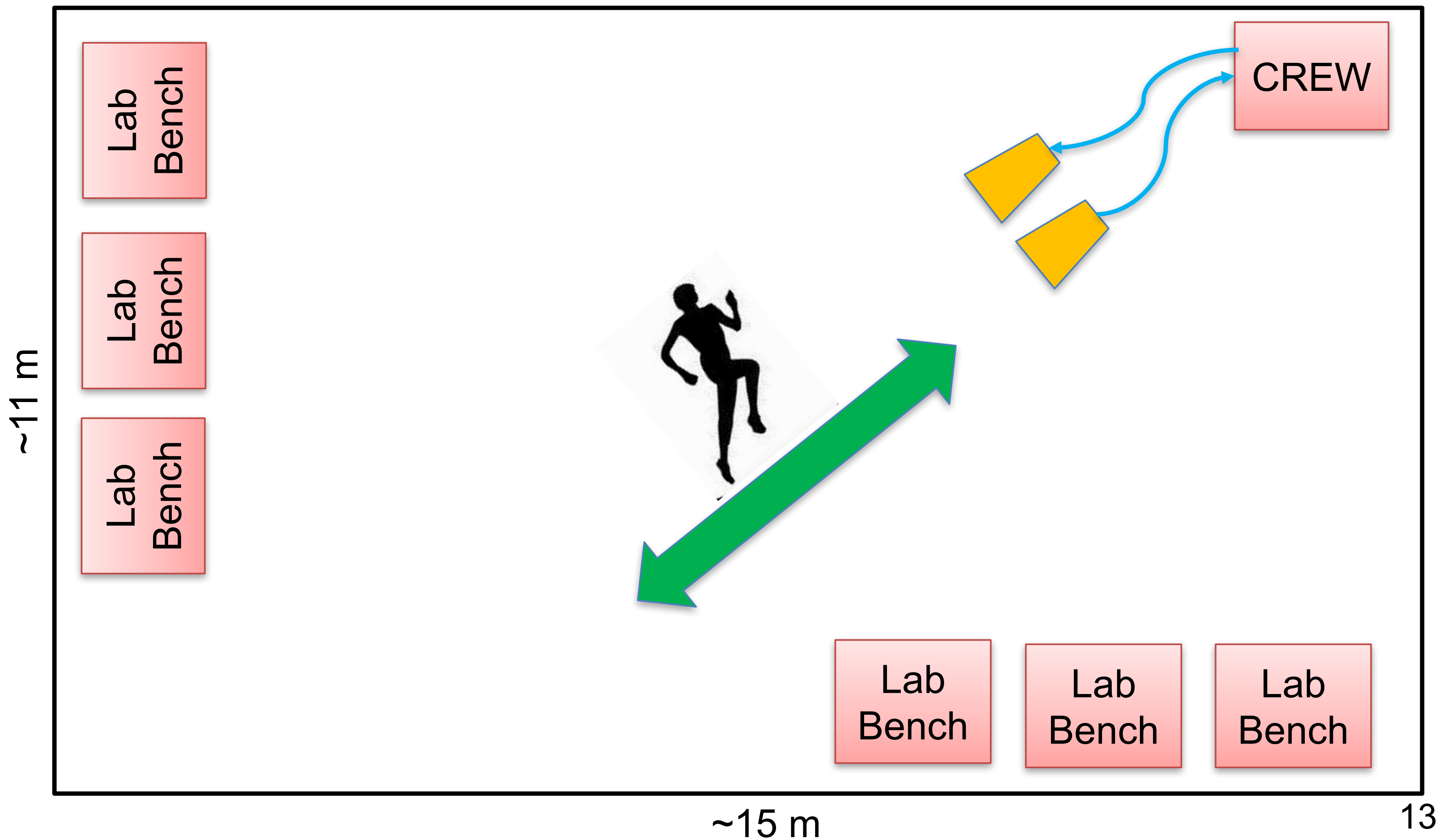
System Photographs

- Built by Agilent/Keysight and Millitech
- Solve clock & trigger challenges by centralized rack based solution
- Can position Tx/Rx heads around lab to achieve multistatic operation

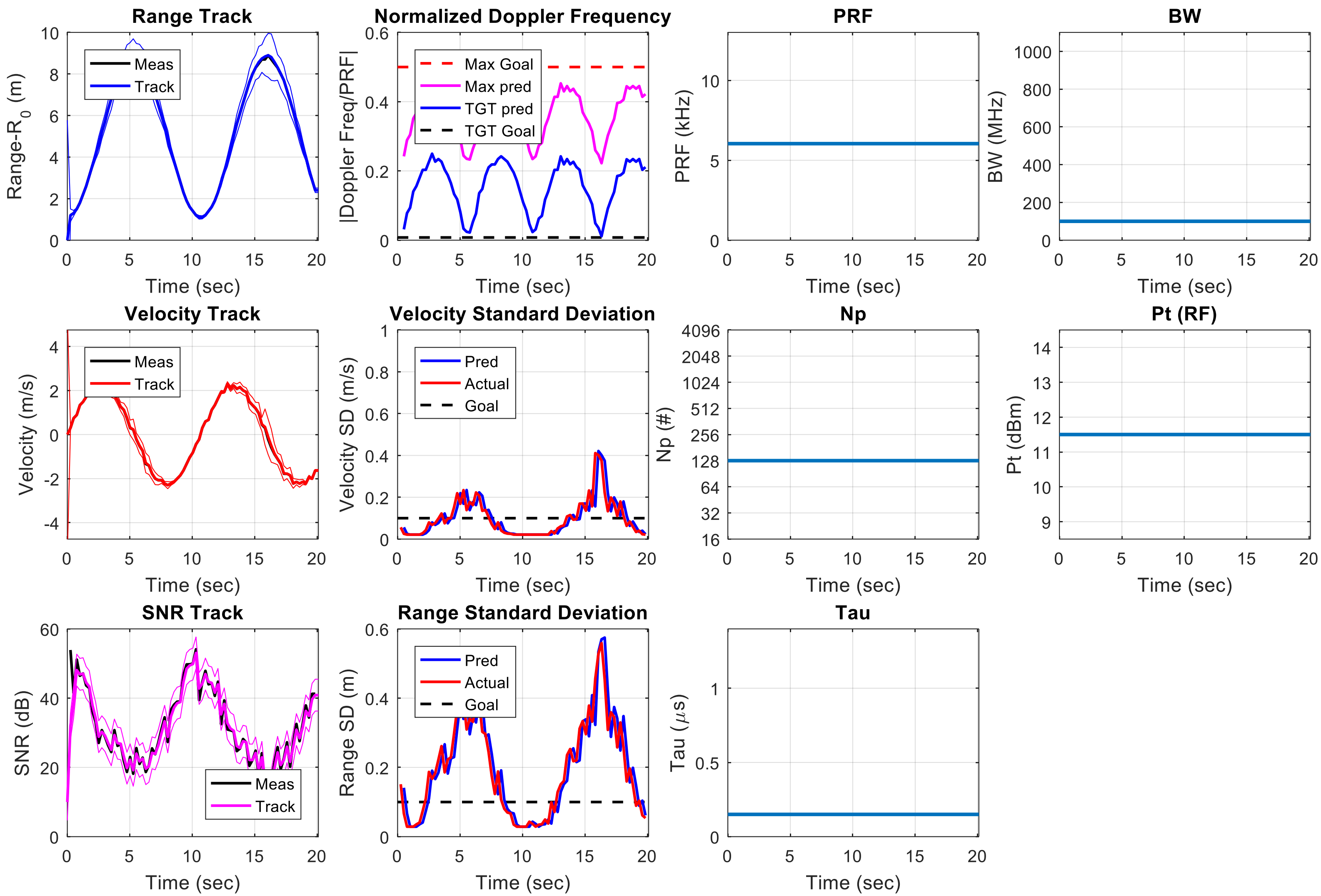
The FARMS Environment

- Fully Adaptive Radar Modelling & Simulation (FARMS)
- Needed to test algorithms before experiments
- Simplified environment simulation
- Same interface to radar data as the CREW
- Software switch to say experiment or simulation
- Same code used for simulation and experiments

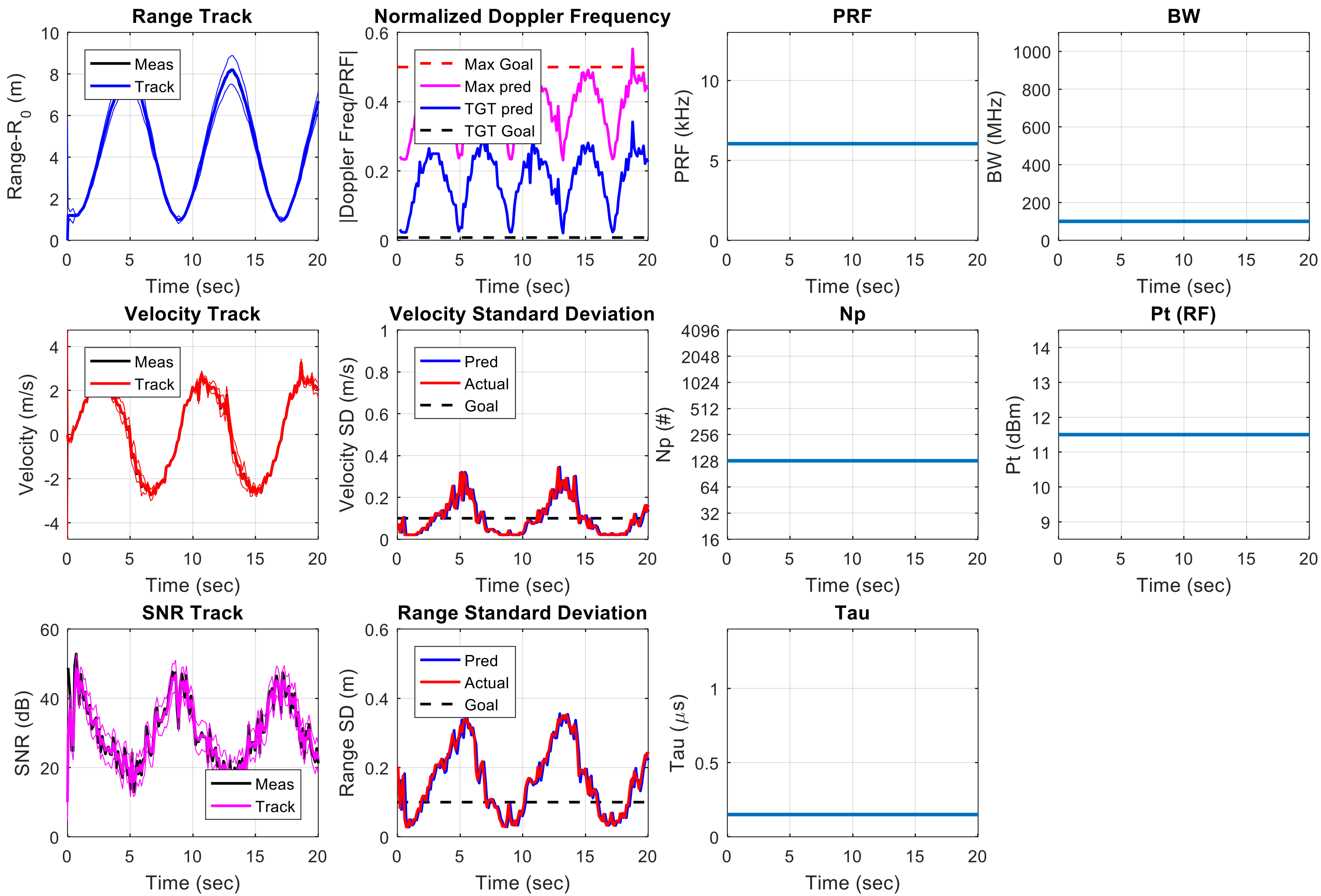
Cognitive Tracking Experiment



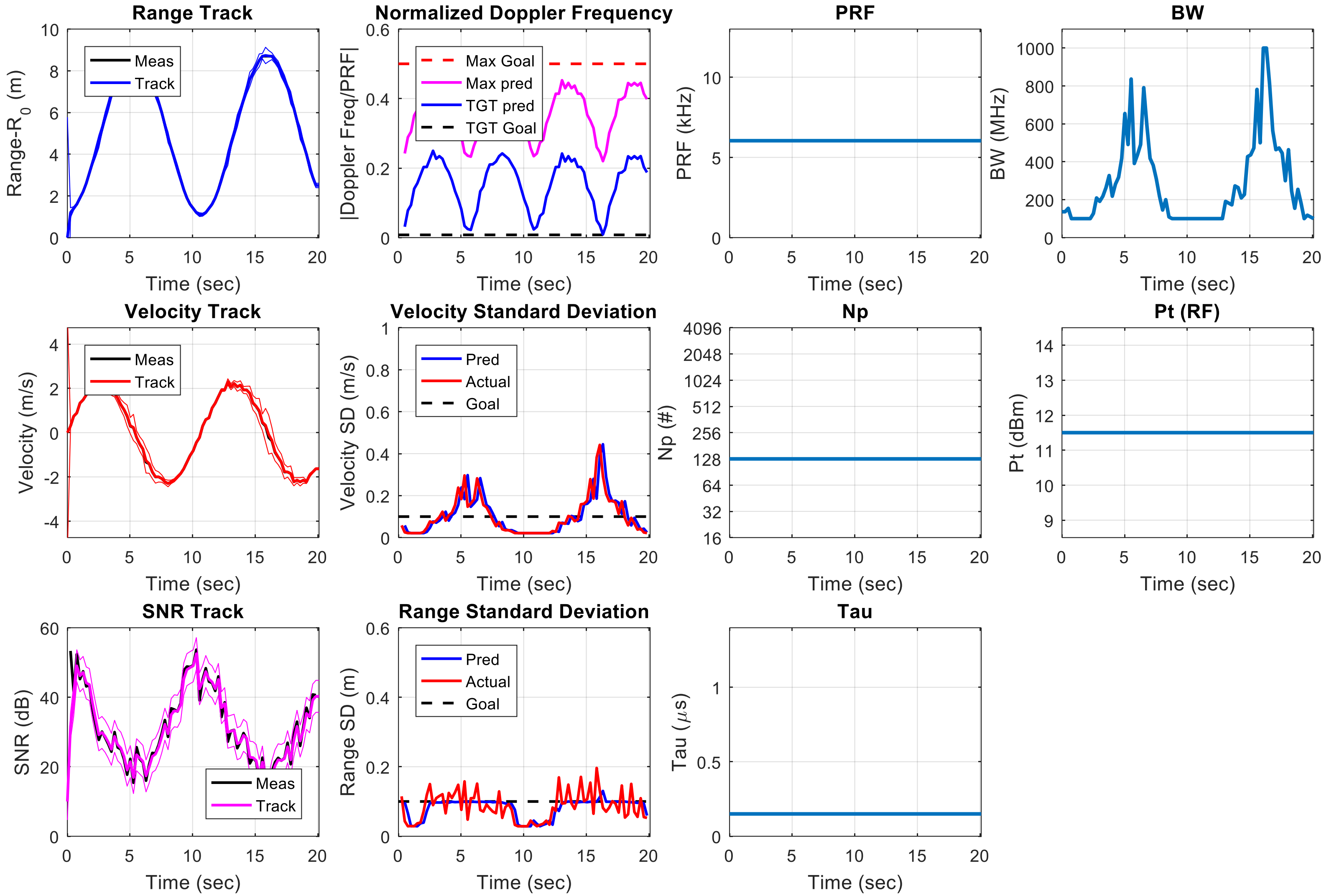
Fixed Param: Simulation



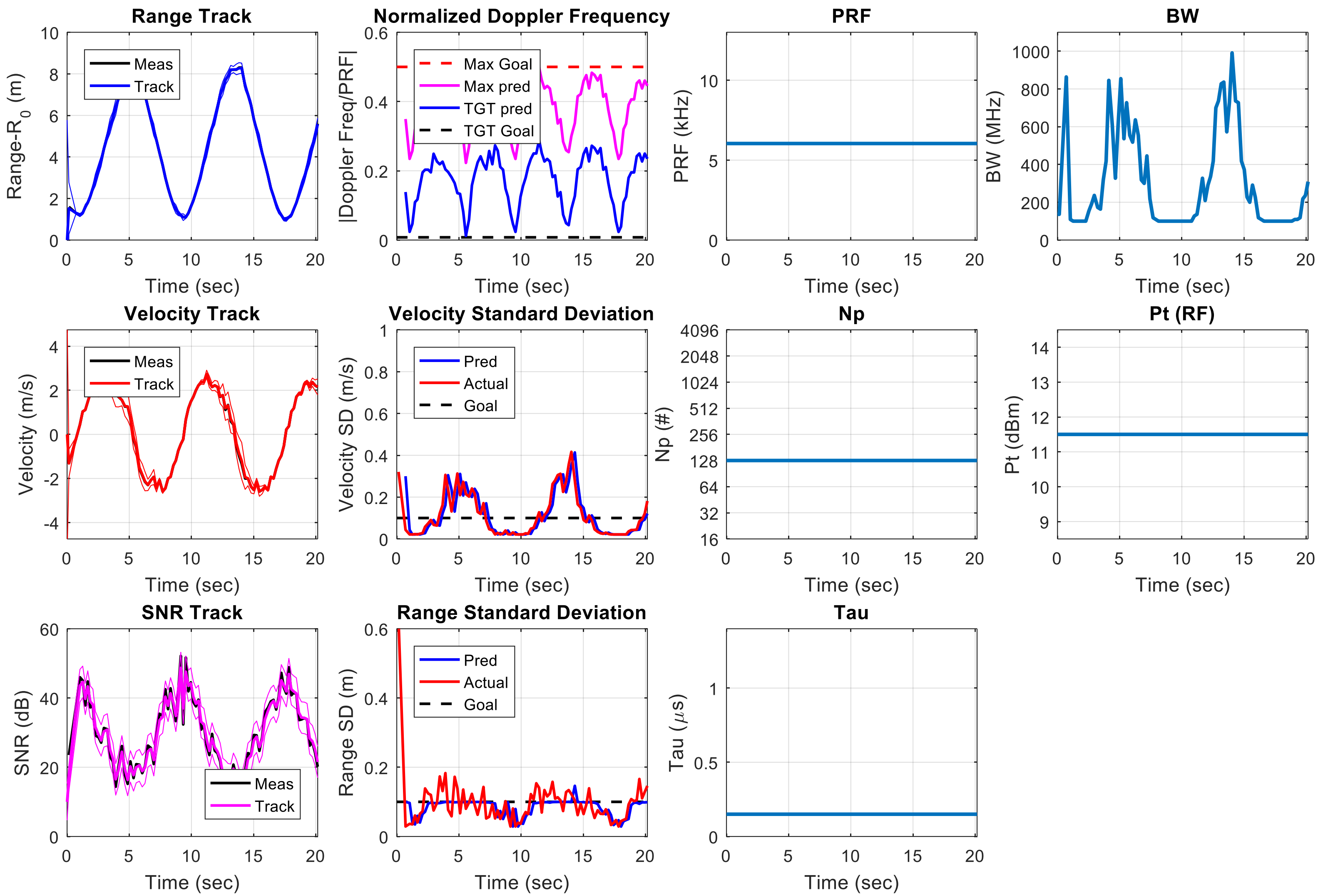
Fixed Param: Experiment



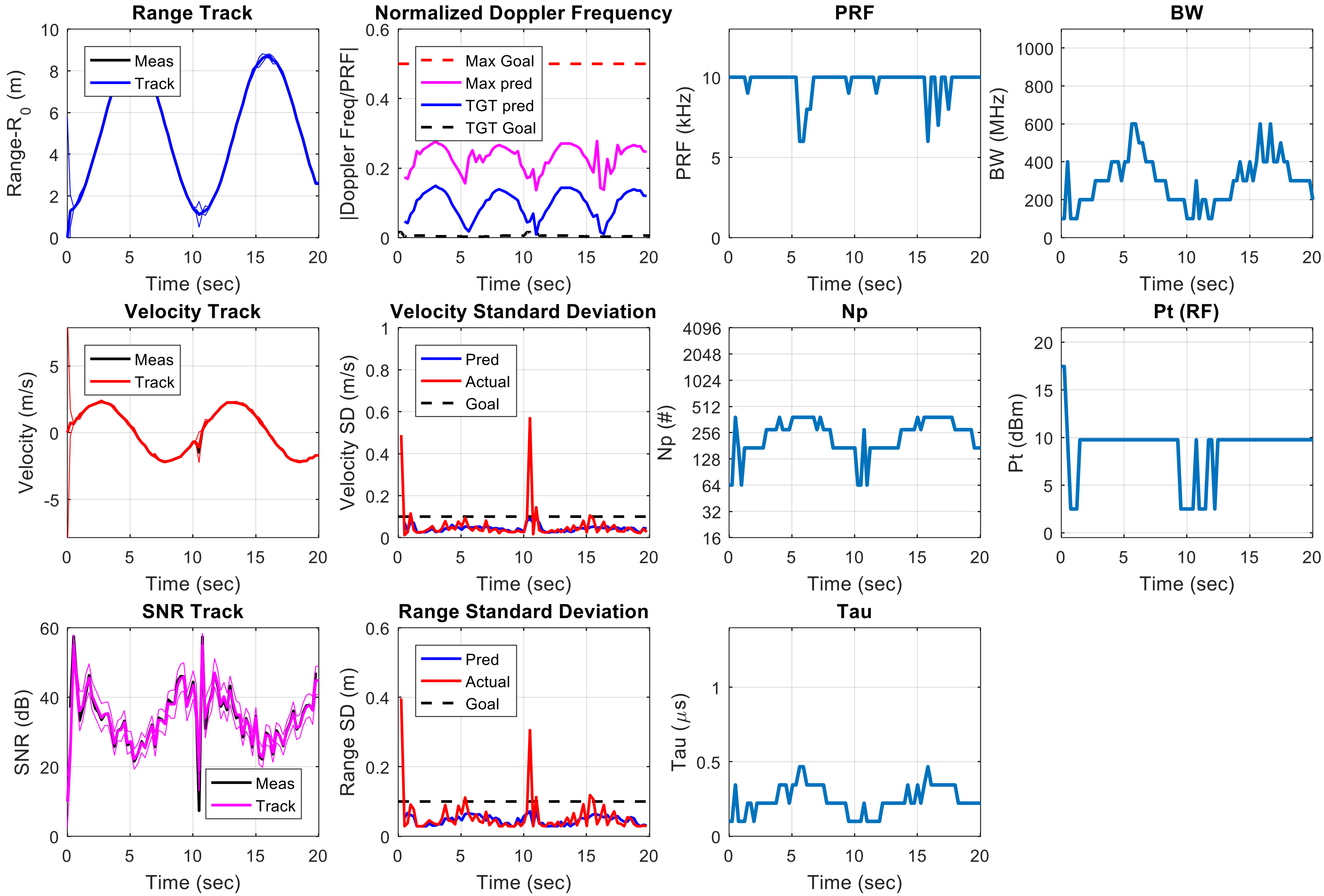
Bandwidth Adapt: Simulation



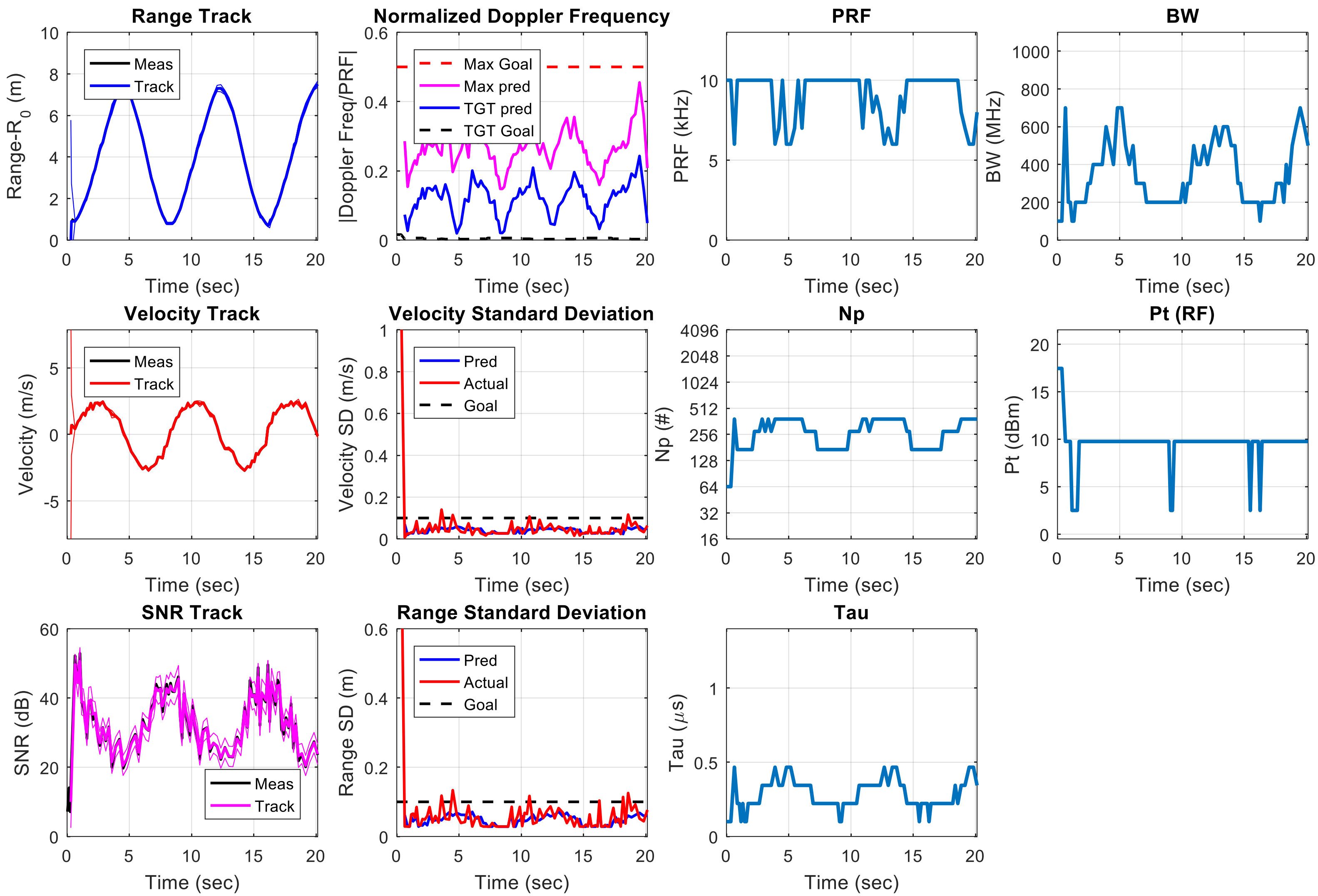
Bandwidth Adapt: Experiment



Adapt All Params: Simulation



Adapt All Params: Experiment



Summary

- Presented a case for needing cognition in radar
- Introduced the FAR framework
- Introduced the CREW at The Ohio State University
- Reported on results of experiments in cognitive radar
  - Tracking a single target
  - Can use adaption to optimize performance against set goals
  - Close match between simulation and experiment
  - Can adapt multiple parameters at once

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