WPI Precision Personnel Locator: Inverse Synthetic Array Reconciliation Tomography Performance

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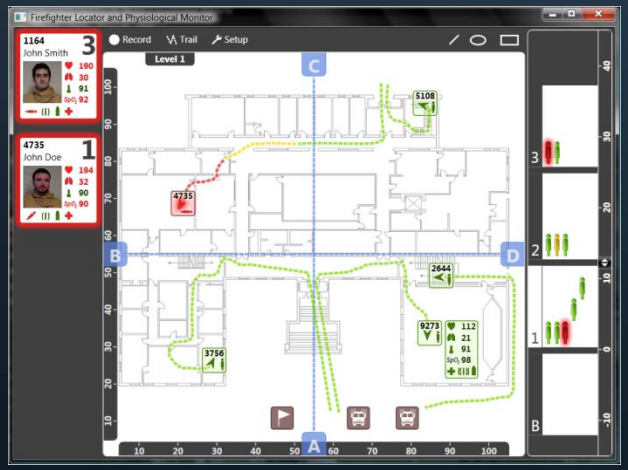
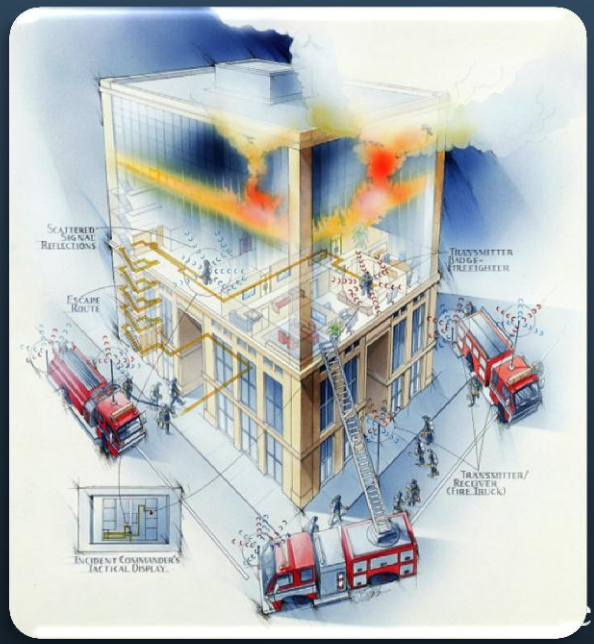
Introduction

PPL Project Goals

- To locate first responders indoors
- With sub-meter 3D accuracy
- Requiring no preinstalled infrastructure
  - Rapidly deployable
  - Ad-hoc mode





ISART Concept

- ISART Exploits the strengths of both RF and inertial based navigation systems

Inertial Navigation
- Error growth with time
- Requires frame of reference initialization (tedious)
- Agnostic of RF conditions

RF Navigation
- No error growth with time
- Provides a static frame of reference
- Hampered by multipath

ISART
- Uses inertial data over short time intervals to form synthetic aperture
- Fuses RF samples at the signal level

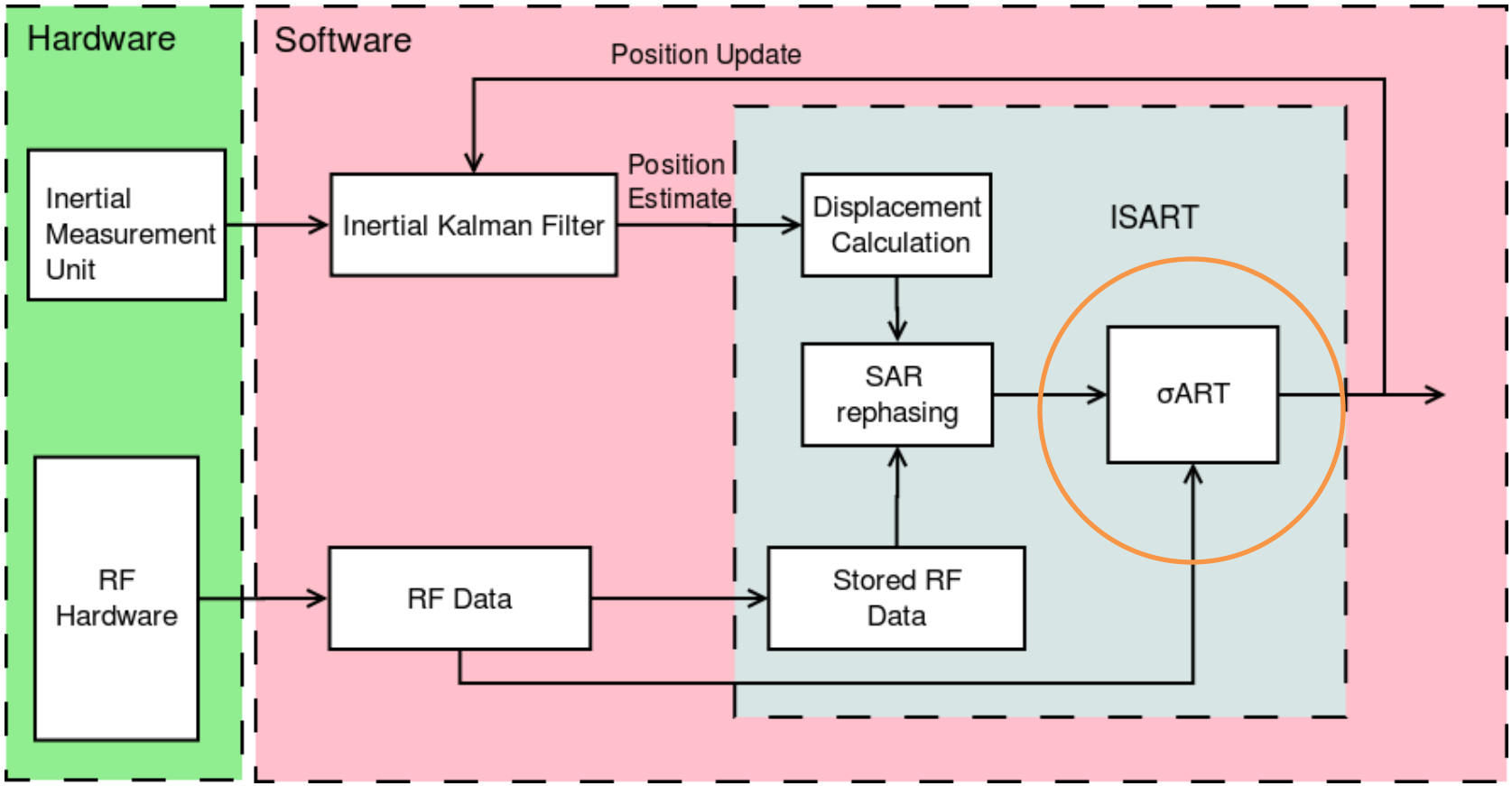
ISART Validation

- We will be comparing the accuracy of the ISART algorithm to an RF-only algorithm (σART) on the same data set
- We will also show INS-only results
- The INS processing for both the INS-only cases and the ISART cases are based on the same INS filter:
  - OpenShoe project, www.openshoe.org [1]

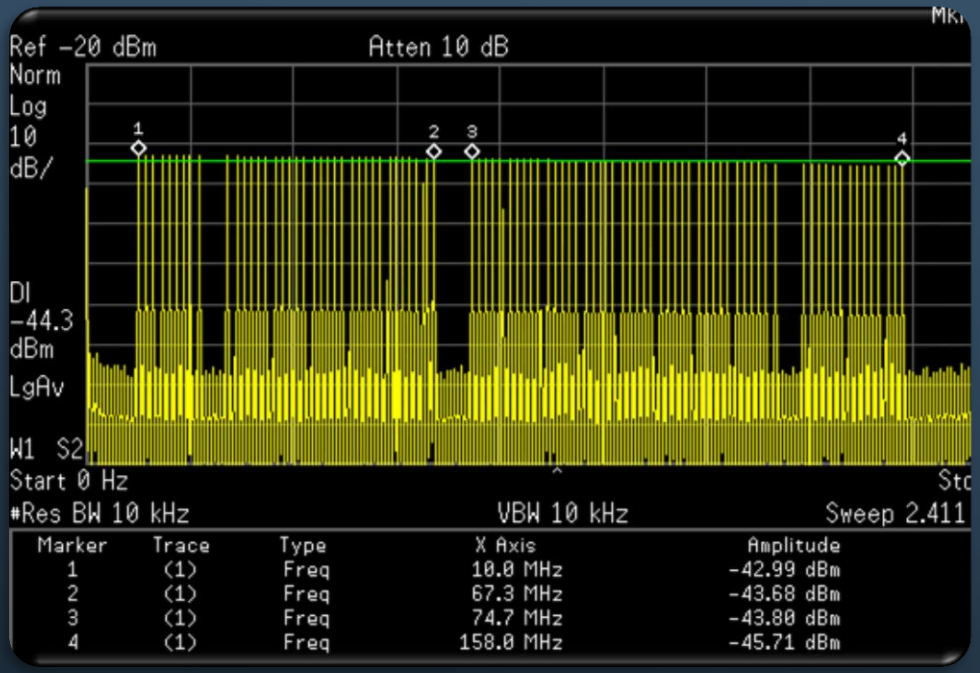
[1] Nilsson J.-O., Skok I., Handel P., Haris K. V. S., "Foot-mounted INS for Everybody An Open-source Embedded Implementation" in IEEE/ION Position Location and Navigation Symposium (PLANS) Conference, April 2012.

ISART Theory

ISART System



σART Signal Structure



Spectrum analyzer capture of MCWB signal
550-700 MHz. 100 carriers

- Developed by WPI PPL project in 2006 [2]
- Multicarrier Wide Band (MCWB) signal (1)
- Asynchronous mobile unit (Transmitter)
- Operates on entire set of received signals

$$X(\omega)=\sum_{n=0}^{m-1}\delta(\omega-(\omega_0+n\Delta\omega)) \quad (1)$$

[2] Duckworth, J., Cyganski, D., et al. "WPI precision personnel locator system: Evaluation by first responders. In Proceedings of ION GNSS, 2007.

σART: Hardware Artifacts

The asynchronous transmitter introduces:

- An unknown time offset: τ
- An unknown mixer phase: θ

When we take these parameters into consideration (1) becomes:

$$X'(\omega) = \sum_{n=0}^{m-1} \delta(\omega - (\omega_0 + n\Delta\omega))\, e^{-j(\omega\tau - \theta)} \qquad (2)$$

The received signal on the p^{th} antenna is therefore:

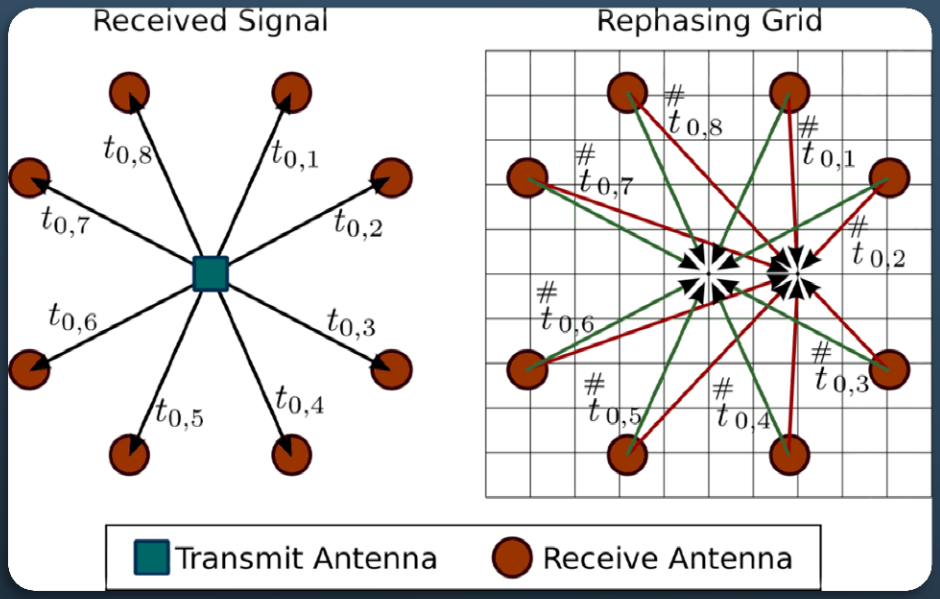
$$R_p(\omega) = X(\omega) H_p(\omega) e^{-j(\omega\tau - \theta)} \qquad (3)$$

Which can be represented by a complex vector of DFT coefficients: $\boldsymbol{r}_p$

σART Algorithm

- The received signals, $\boldsymbol{r}_p$, are stored in a received data matrix, $\boldsymbol{R} \in \mathbb{C}_{N \times P}$, where N is the number of carriers and P is the number of reference antennas
- The inputs to the σART algorithm are:
  - The received data matrix, $\boldsymbol{R}$
  - A point in space, (x, y, z)
  - The locations of the p reference antennas
- From this information a metric is computed at every point in a discretized search space

σART: Re-phasing



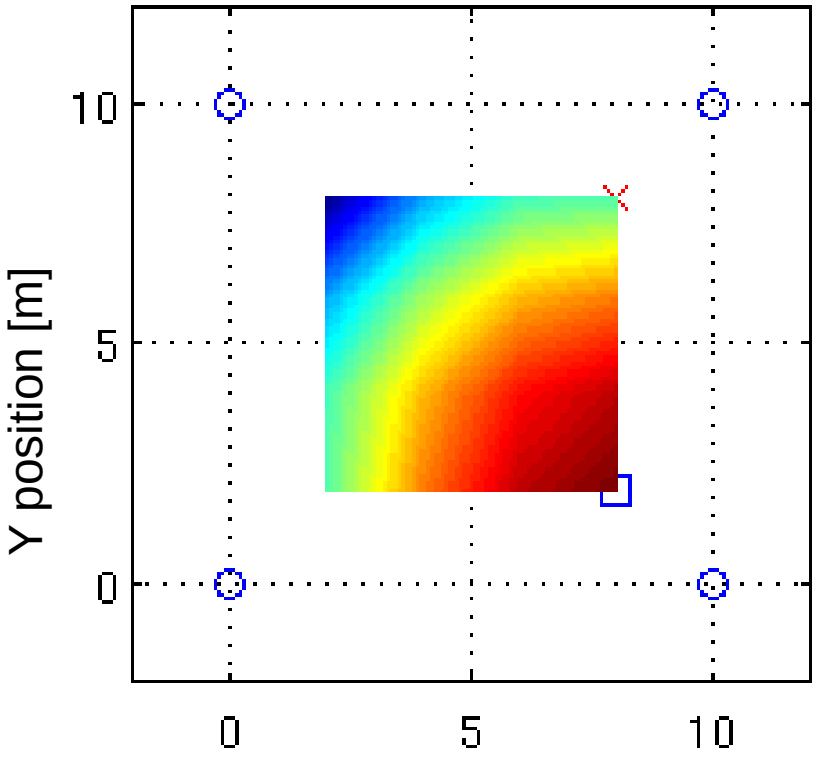
Example of re-phasing at a point near the truth location

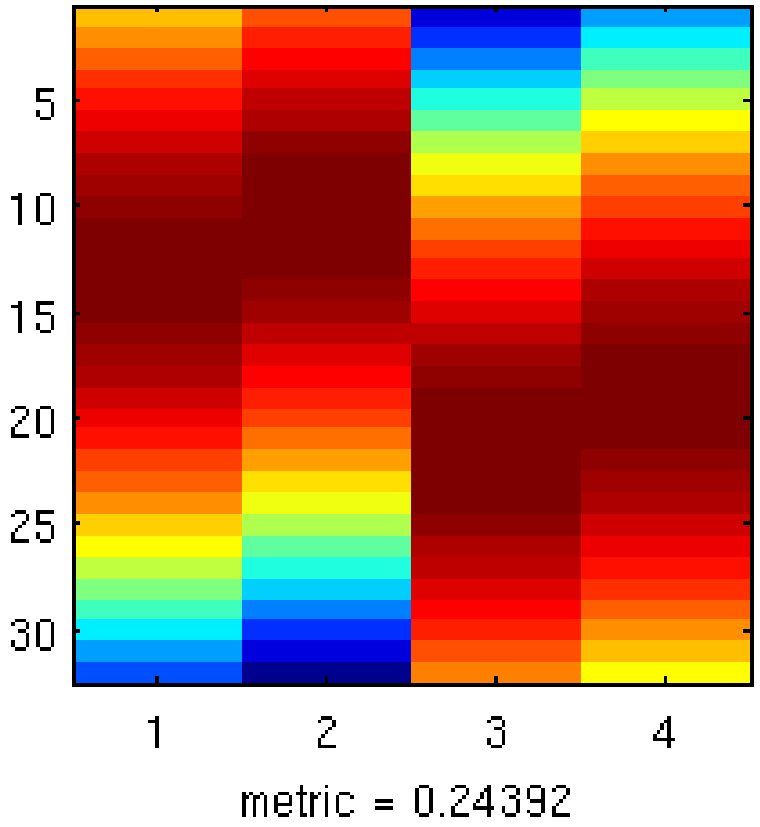
$$R \rightarrow R'$$

- For each point in the scan grid compute the distance to each of the reference antennas
- Apply propagation delays to R

σART: Re-phasing

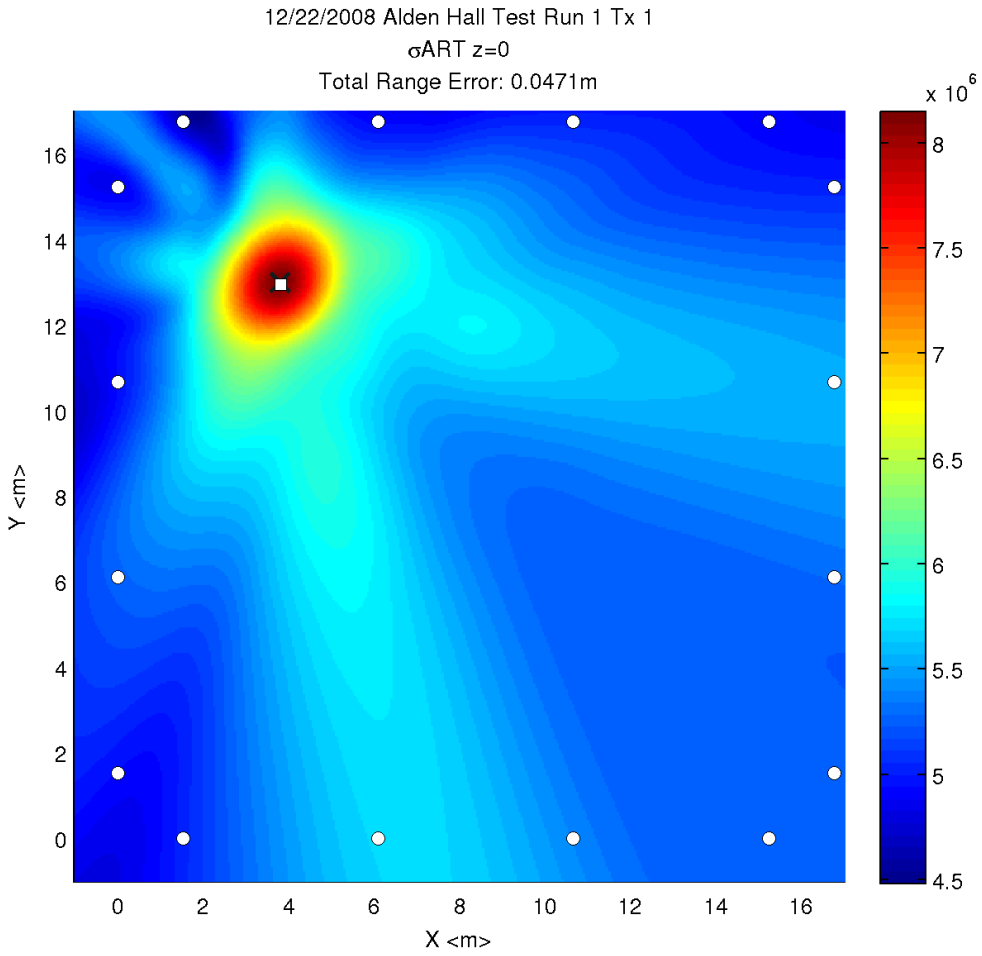
$$\boldsymbol{R}' = \left[\boldsymbol{r}_1 e^{j\omega_t^{\#}{}_{k,1}} \; \boldsymbol{r}_2 e^{j\omega_t^{\#}{}_{k,2}} \; \boldsymbol{r}_3 e^{j\omega_t^{\#}{}_{k,3}} \; \boldsymbol{r}_4 e^{j\omega_t^{\#}{}_{k,4}}\right] \quad (4)$$



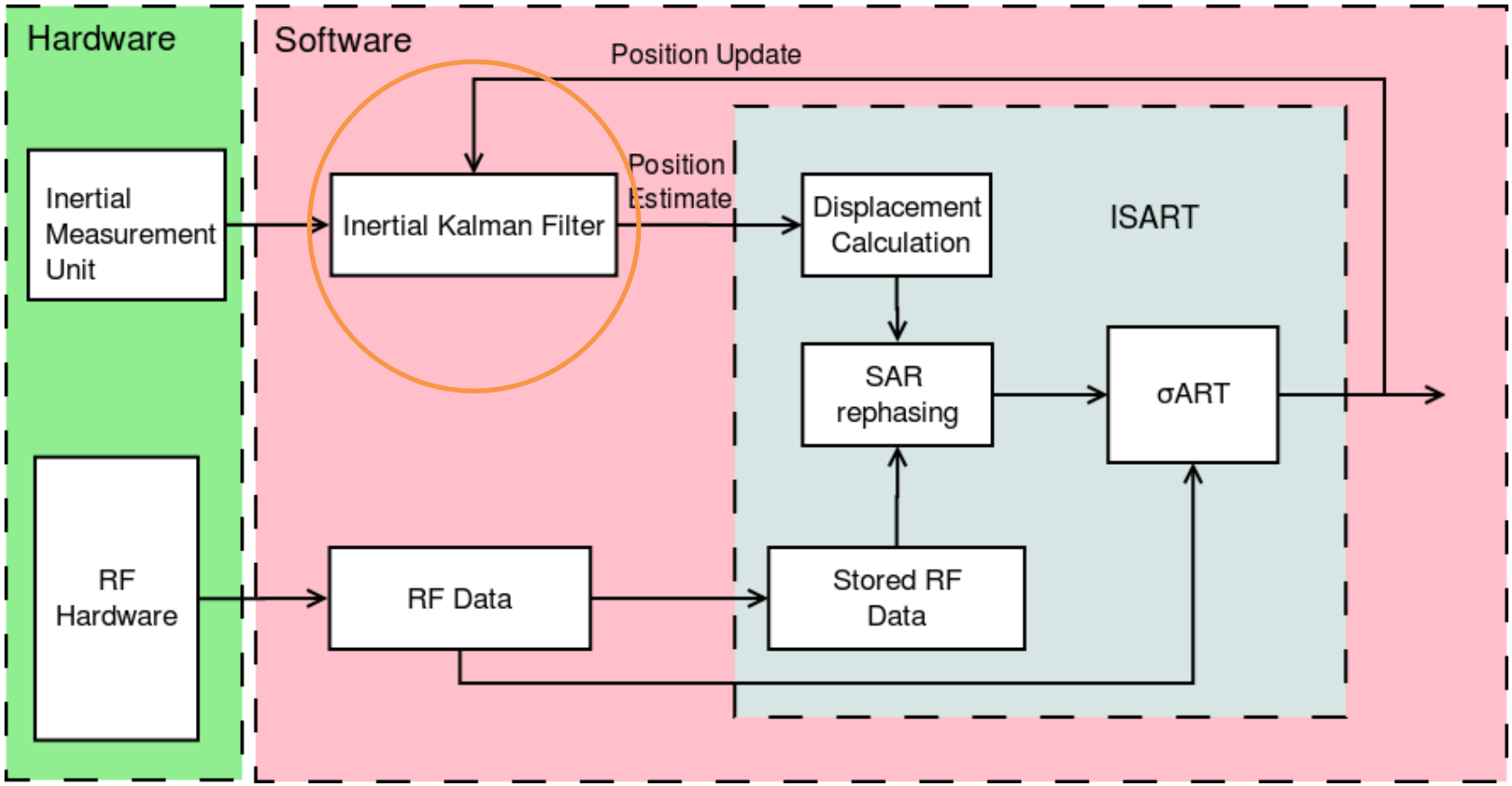


k^{th} Scan Location: ✕ Actual Location: □ Reference Antenna: ○

σART: Metric Function



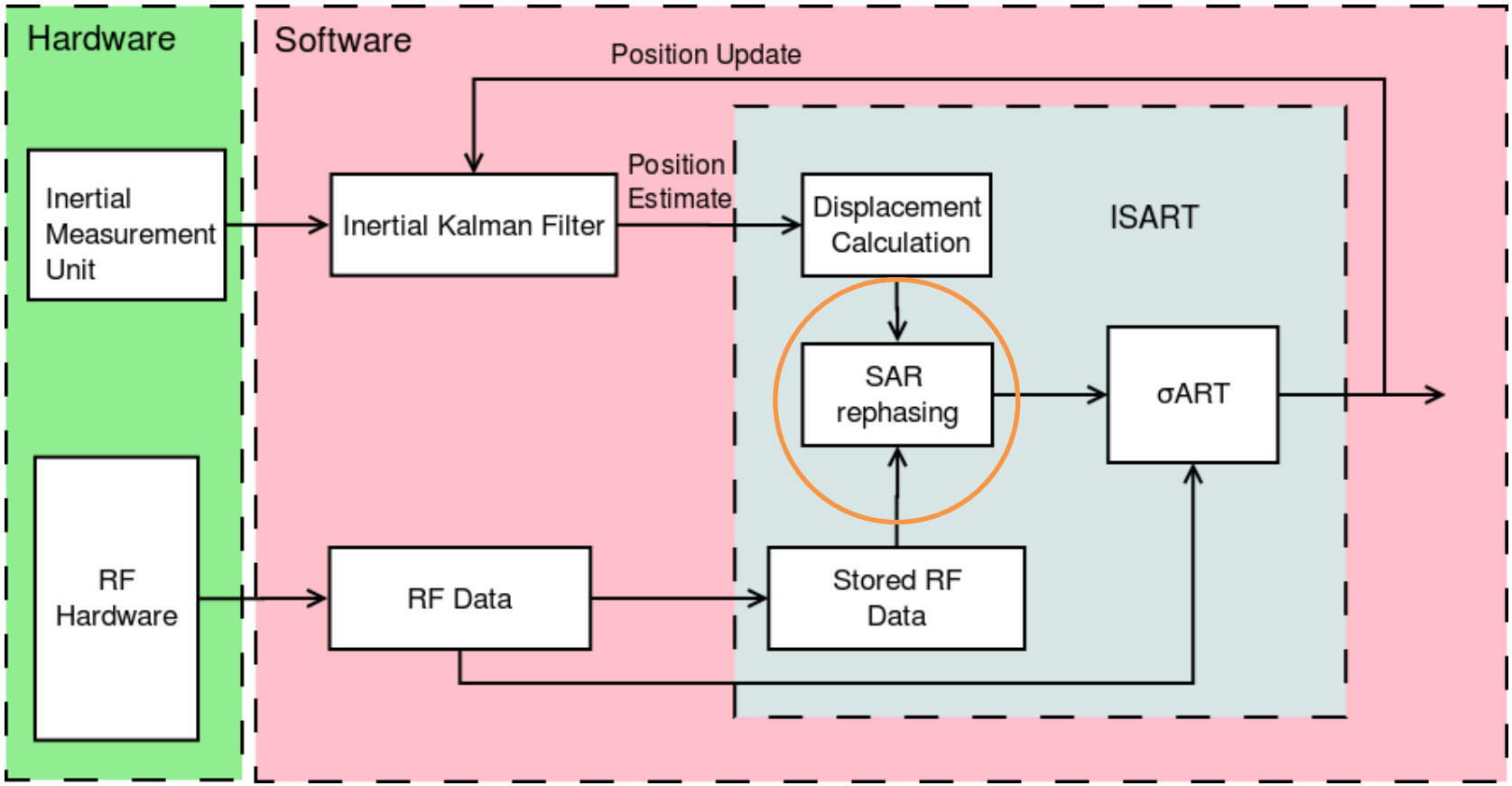
ISART System



INS EKF

- In order to correct for sensor drift, most INS EKFs make use of zero velocity updates (zupts)
- If the inertial sensor is known to be stationary, then a high quality observation of the velocity states can be used to correct the position and acceleration states
- Mounting inertial measurement units (IMUs) on the foot allows for frequent zupts

ISART System

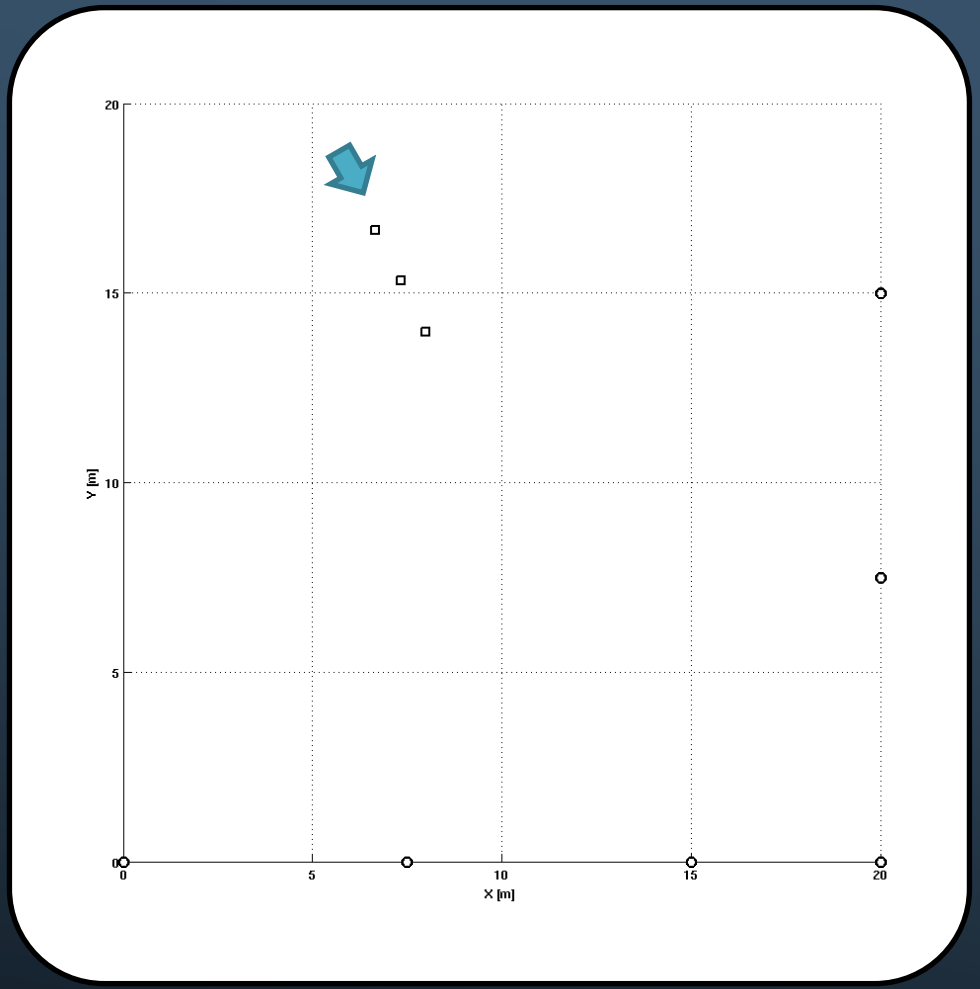


SAR Rephasing

- Inertial displacement estimates are used to rephase RF data from multiple locations so that their direct path signals should appear to originate at the same locations
- The direct path components should be linearly dependent
- The multipath components from multiple locations should be uncorrelated

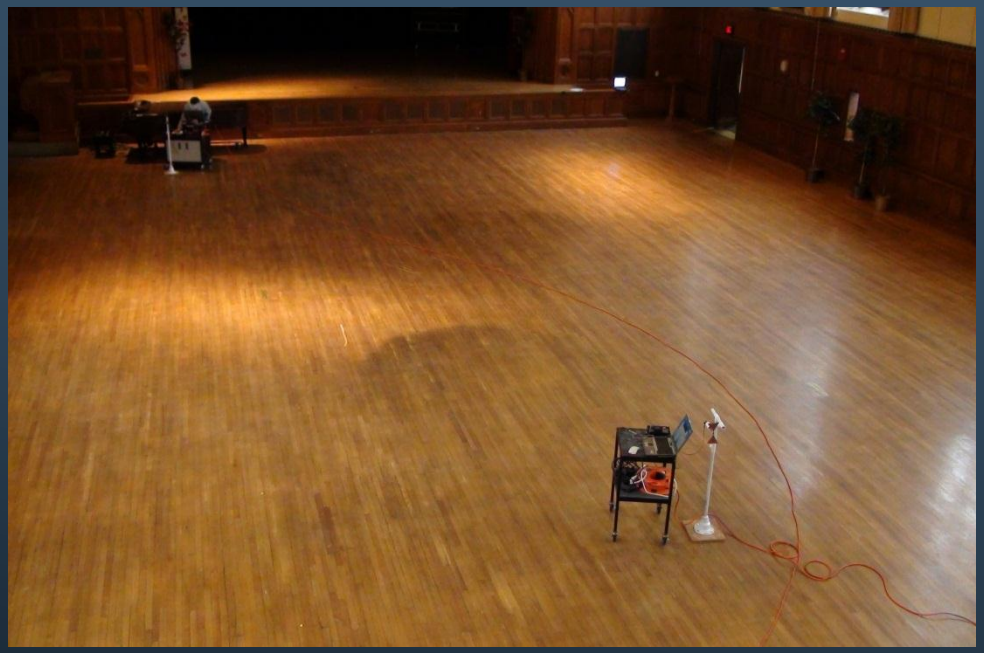
ISART: Array Synthesis

- RF data from multiple transmitter positions are fused
- Virtual antennas (determined from inertial displacements) represent additional data



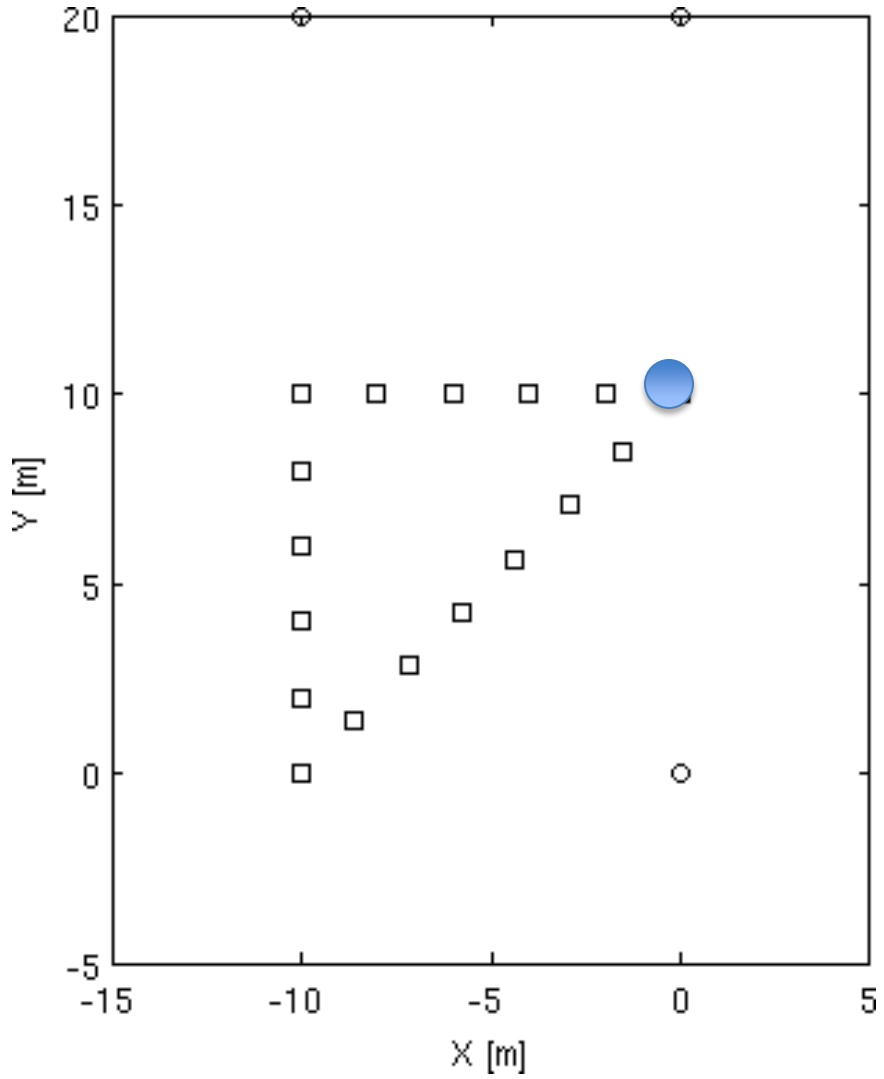
Experimental Results

Auditorium Test

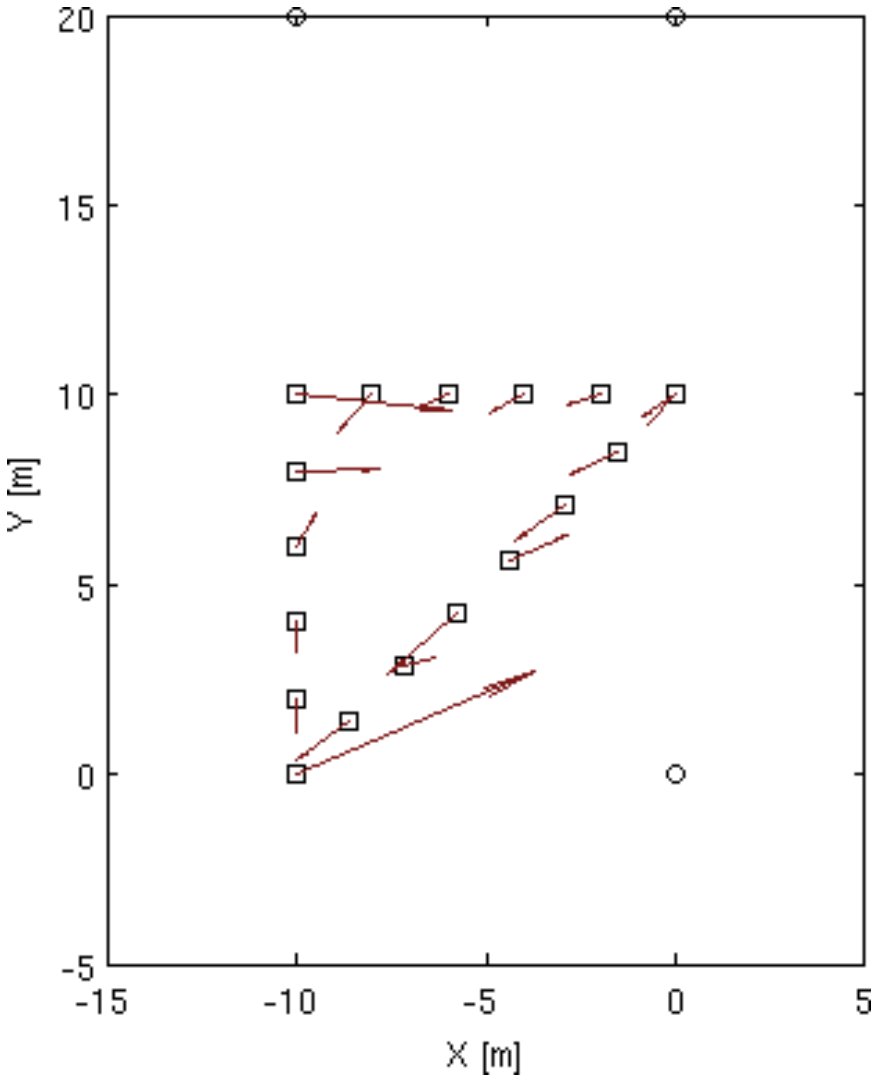


- Most basic test configuration
  - 4 Reference antennas
  - Indoor line of sight
  - Small search area
- Analog Devices ADIS16133BMLZ IMU
- Walking prescribed path with foot zupts occurring on truth points

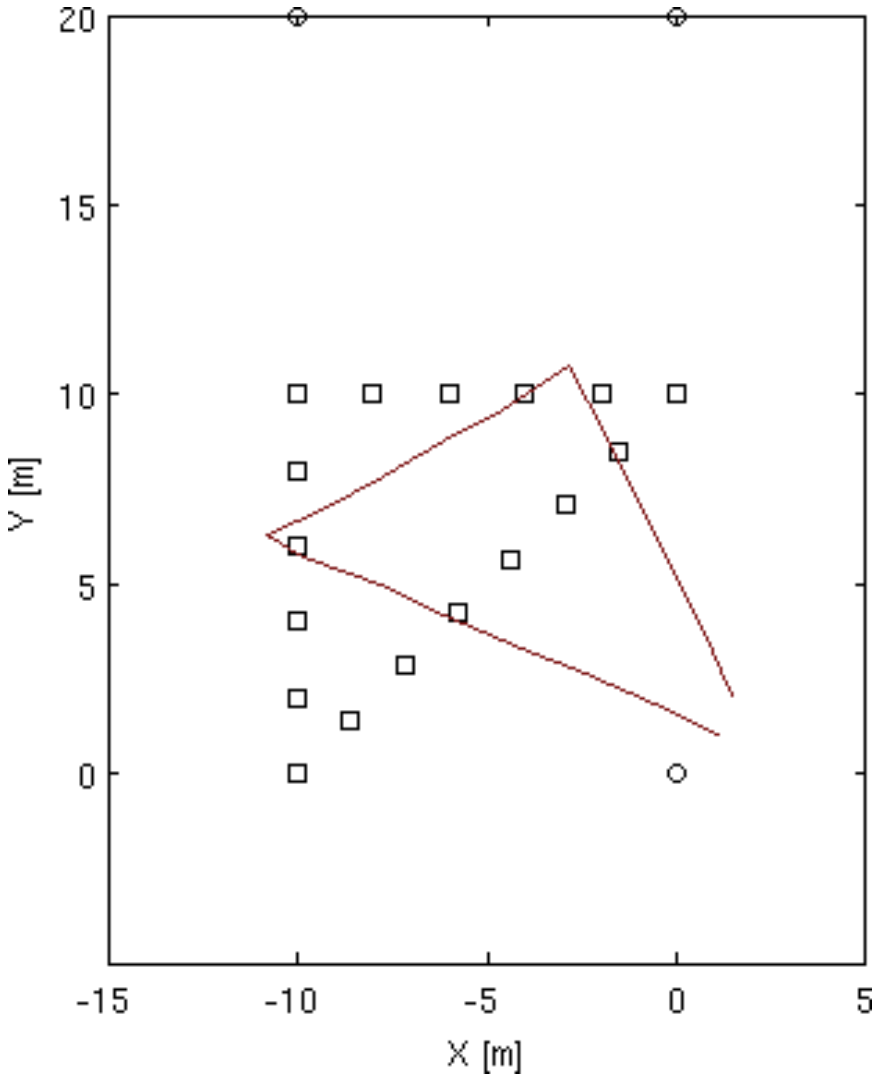
Test Configuration



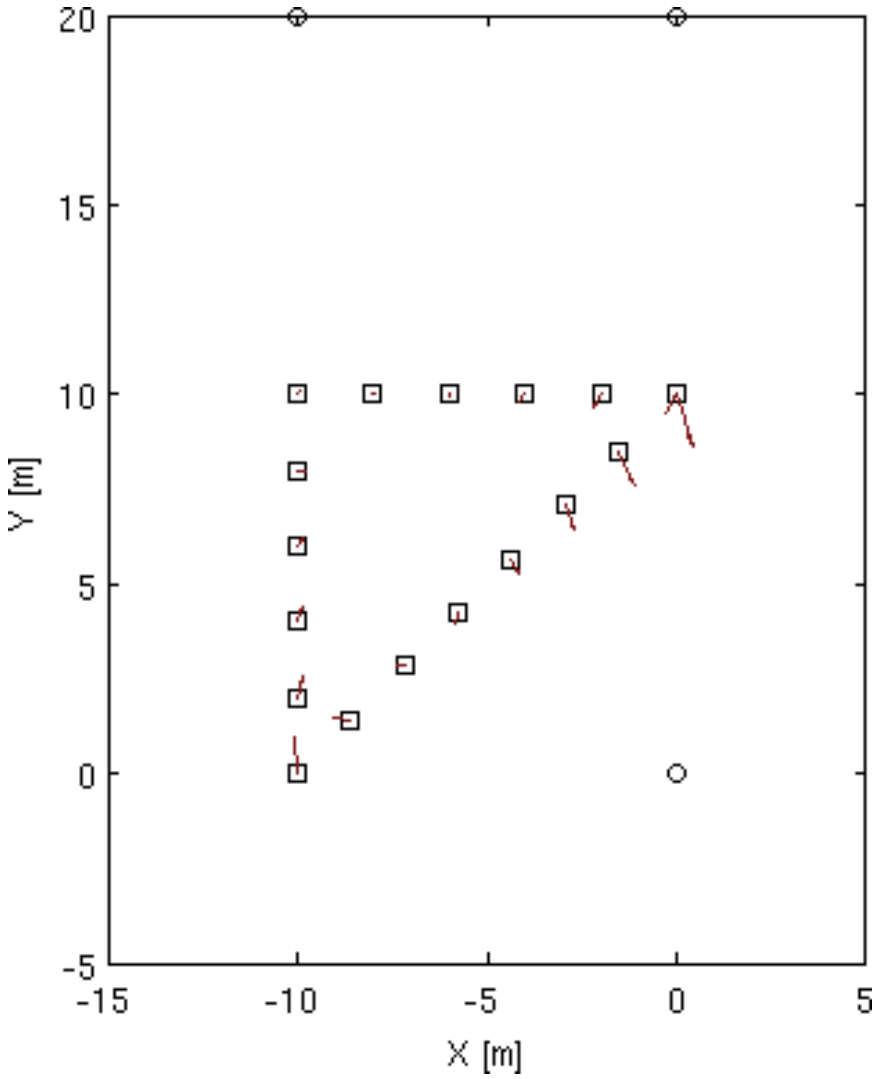
σART (RF-Only): 2.30 m RMS error



Inertial-Only Results



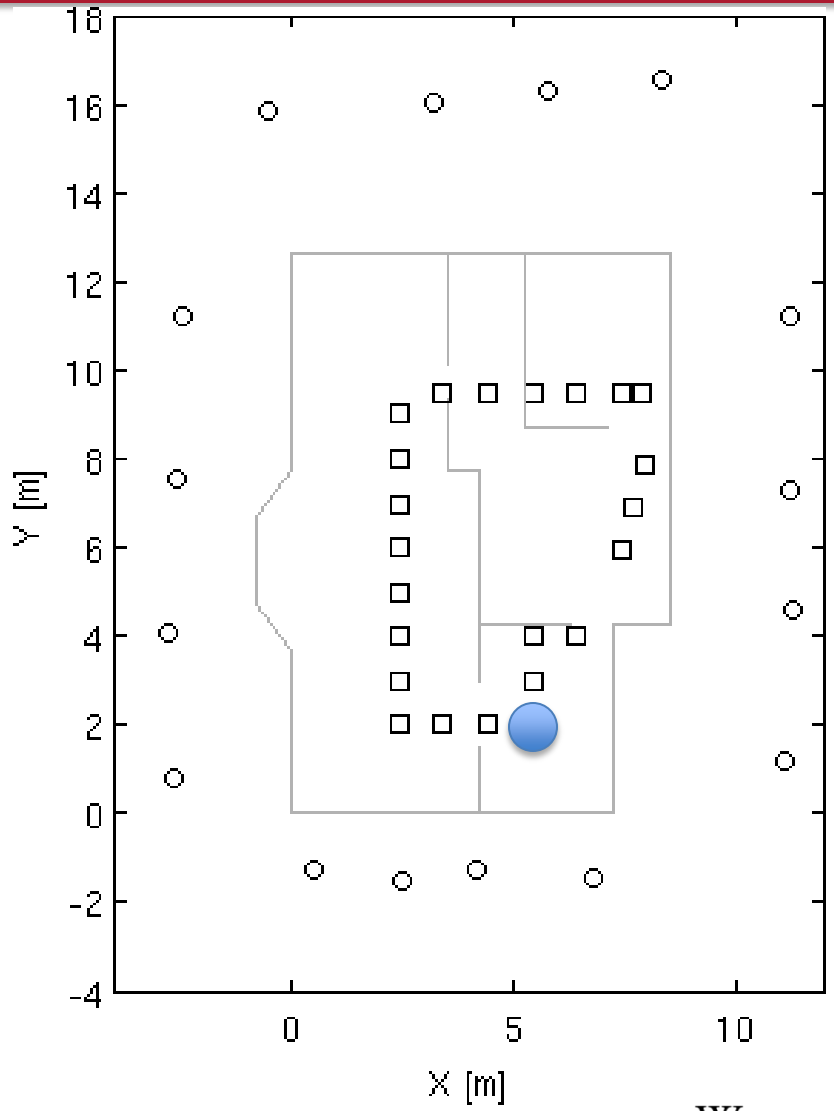
ISART: 0.58 m RMS error



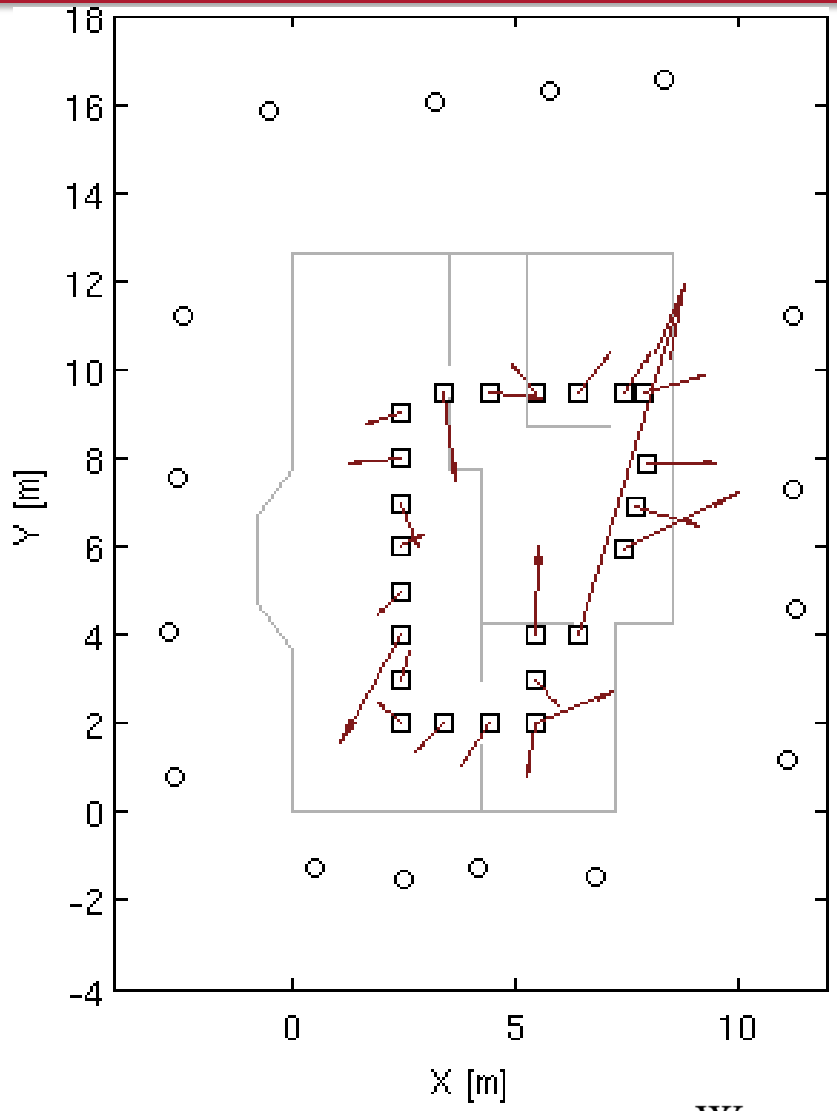
Wooden House Test

- More complicated scenario
  - 16 Reference antennas (outdoor)
  - Indoor transmitter, no line of sight
  - Medium sized search area
- Intersense NavChip IMU
- Walking prescribed path with foot zupts occurring on truth points (no acute angles)

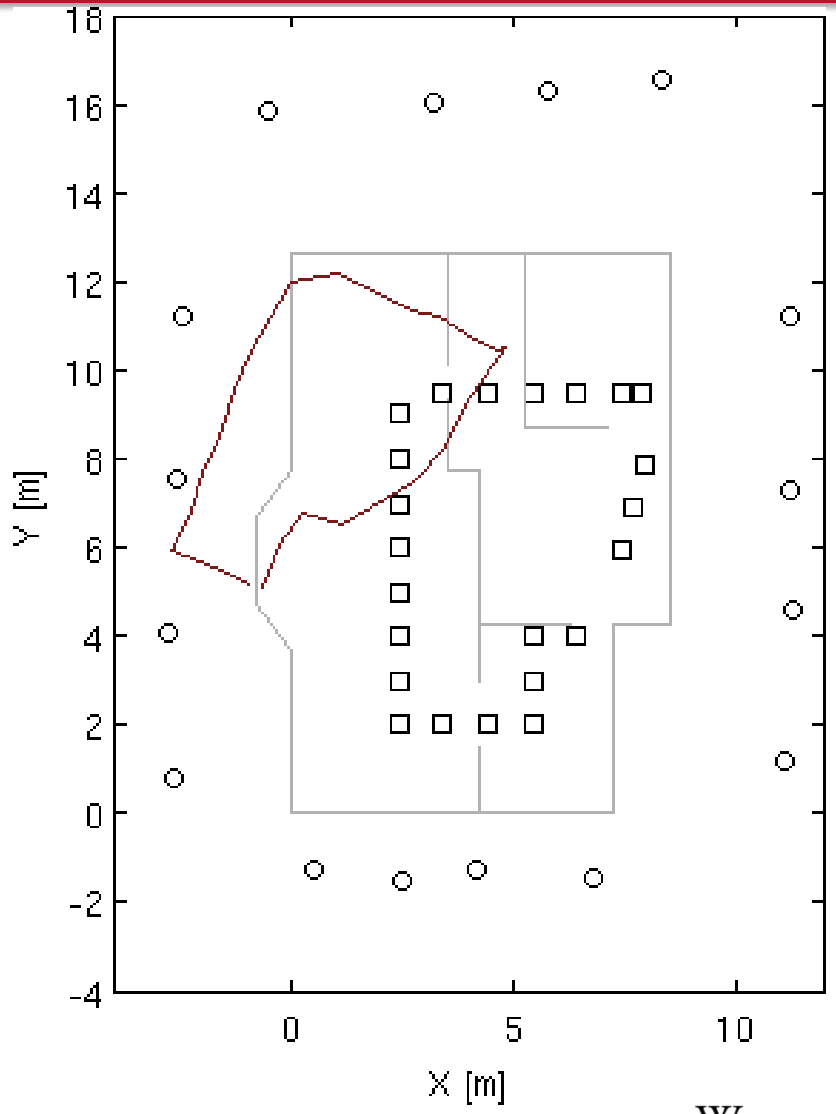
Test Configuration



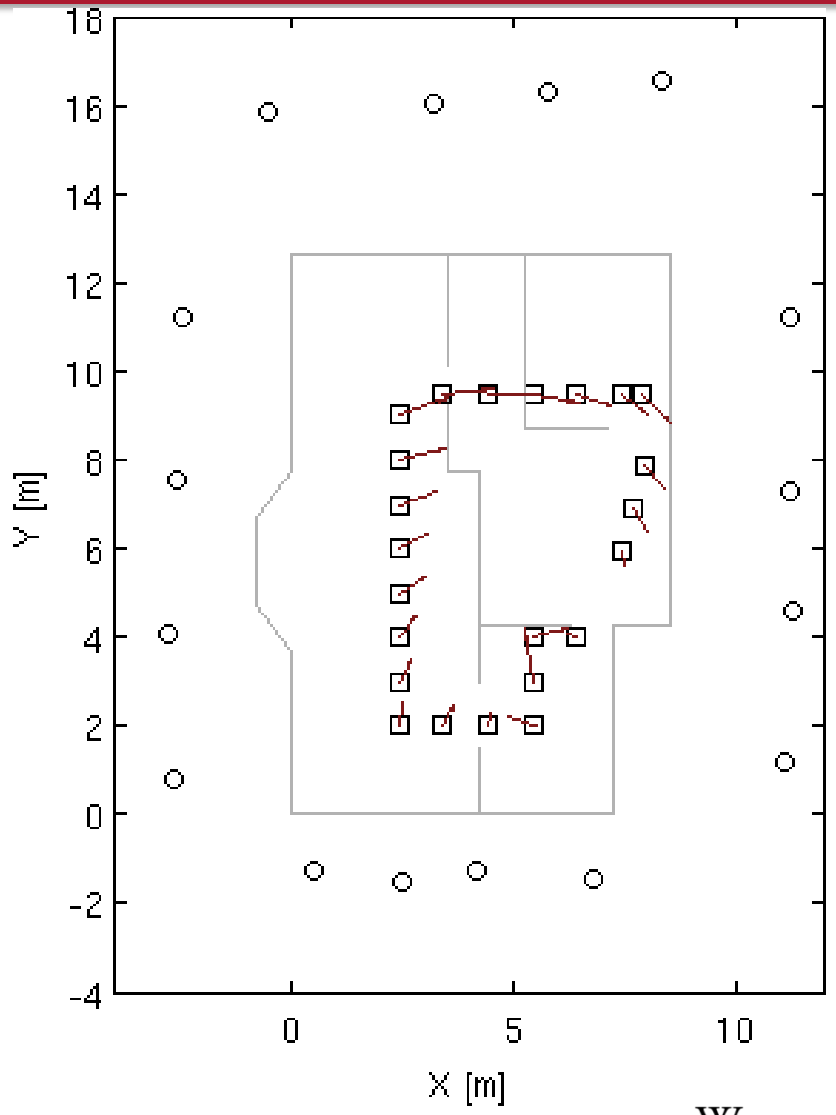
σART (RF-Only): 2.20 m RMS error



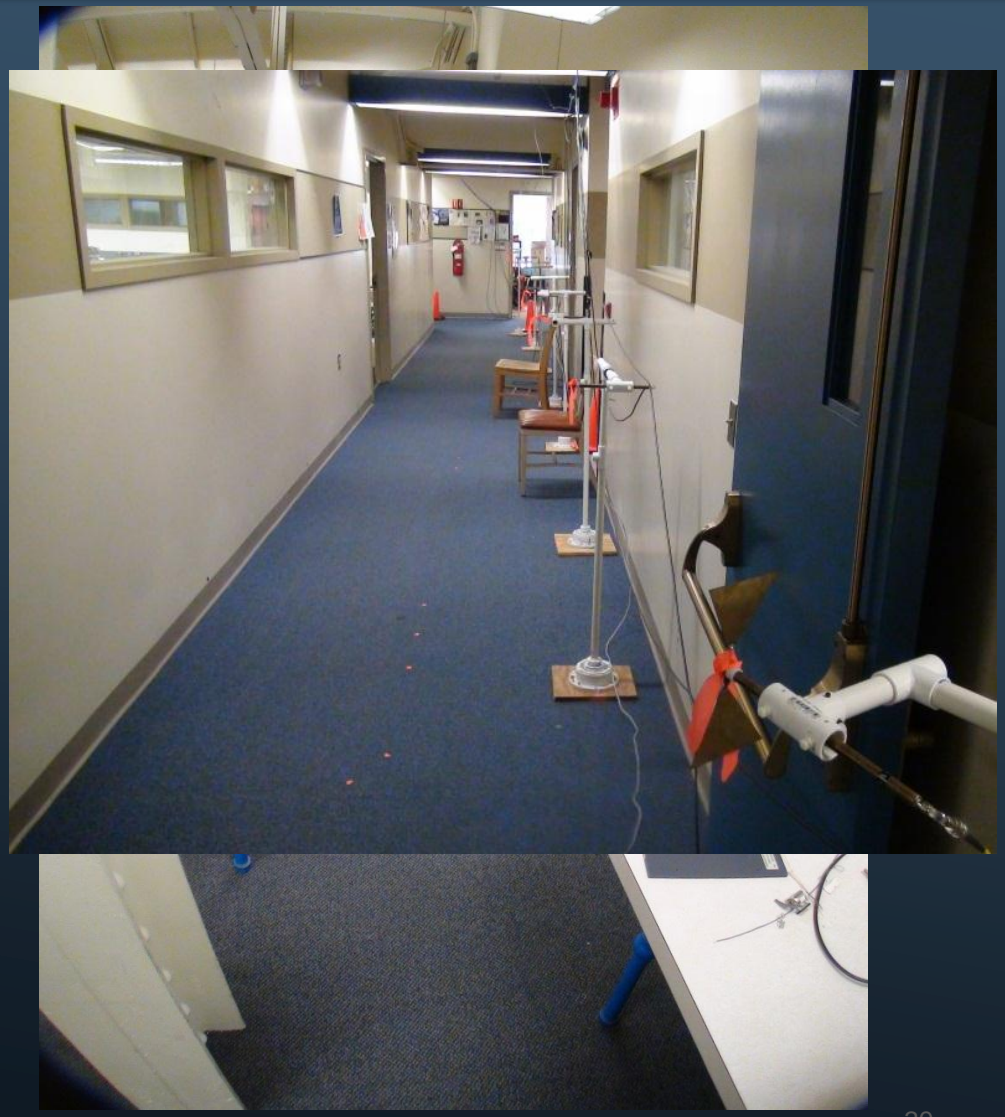
Inertial-Only Results



ISART: 0.77 m RMS error

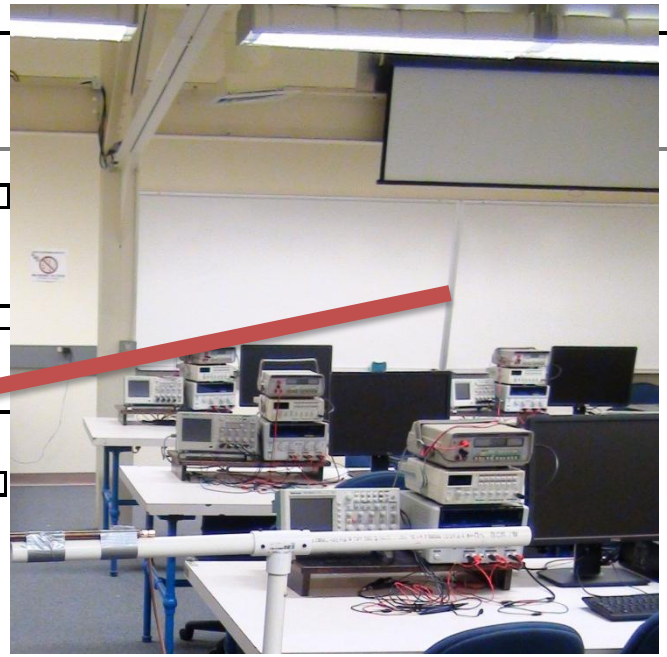


Lab Test

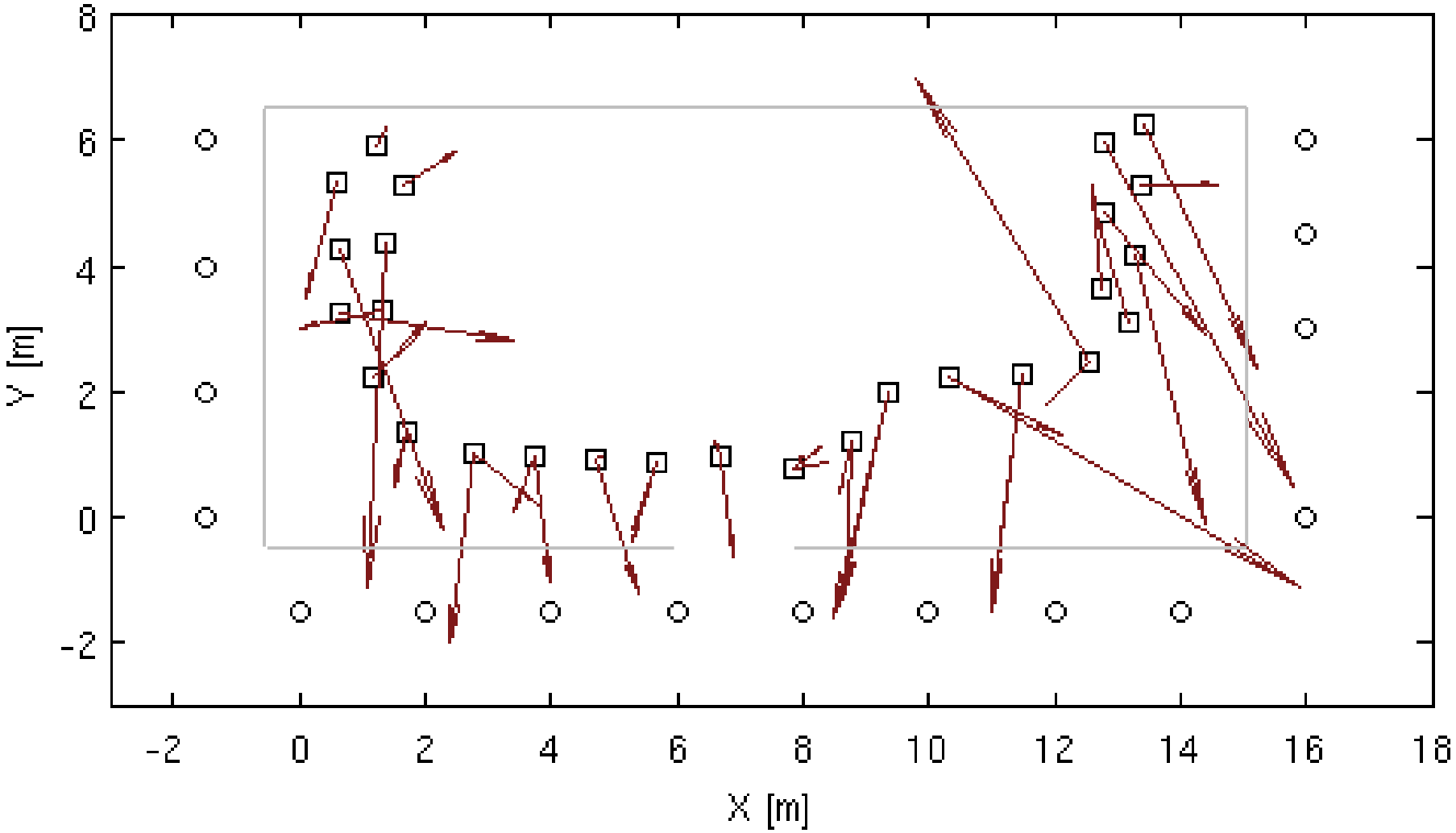


- More complicated scenario
  - 16 Reference antennas
  - Indoor transmitter, no line of sight
  - Largest search area
  - Extreme multipath / blocked direct path
- Intersense NavChip IMU
- Walking natural path with truth points post-surveyed at footfall locations

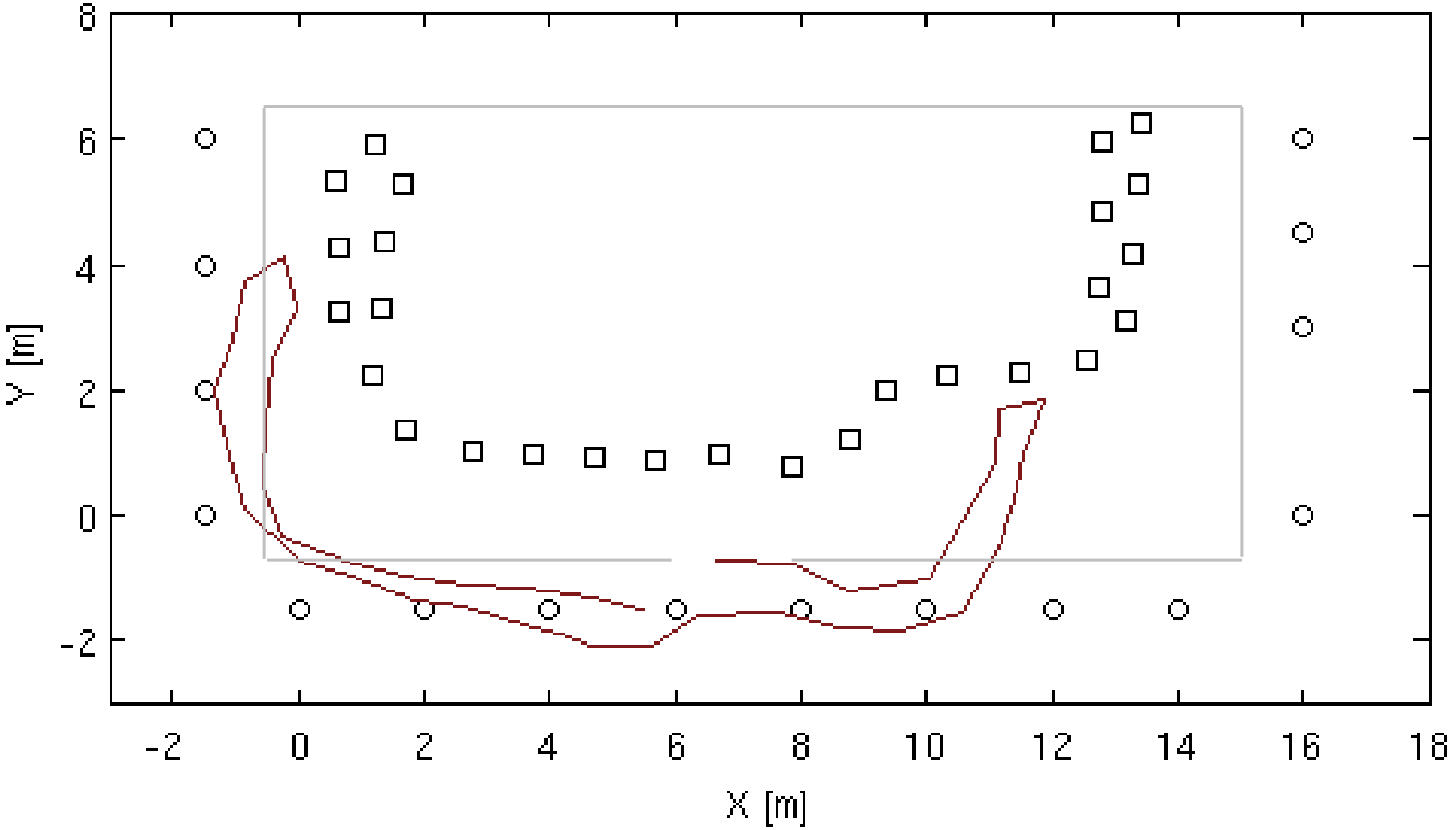
Test Configuration



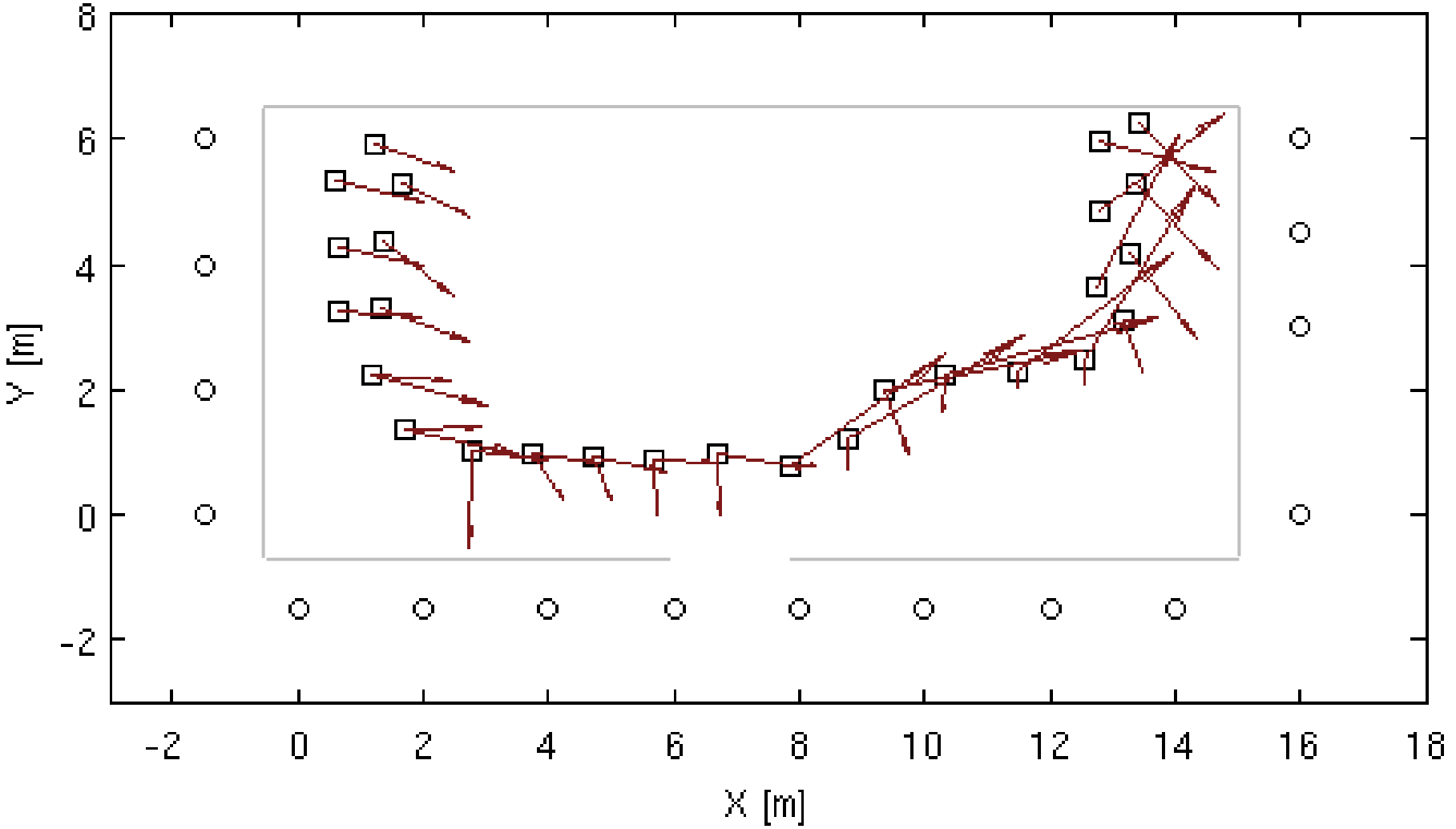
σART (RF-Only): 2.82 m RMS error



Inertial-Only Results



ISART: 1.77 m RMS error



Conclusions

- Created new framework for RF-INS sensor fusion
- Performed multiple experiments to validate this new approach
- Differs significantly from other fusion techniques
  - Fuses RF data at signal level
  - Leverages array processing gains
- ISART shows improved performance over the RF-only σART algorithm

Next Steps

- TOA like synchronization could improve performance in presence of large reflectors
- Real time implementation needed
  - Fortunately ISART is highly parallelizable

Thank You

Questions?