

WPI Precision Personnel Location System: Rapid Deployment Antenna System and Sensor Fusion for 3D Precision Location

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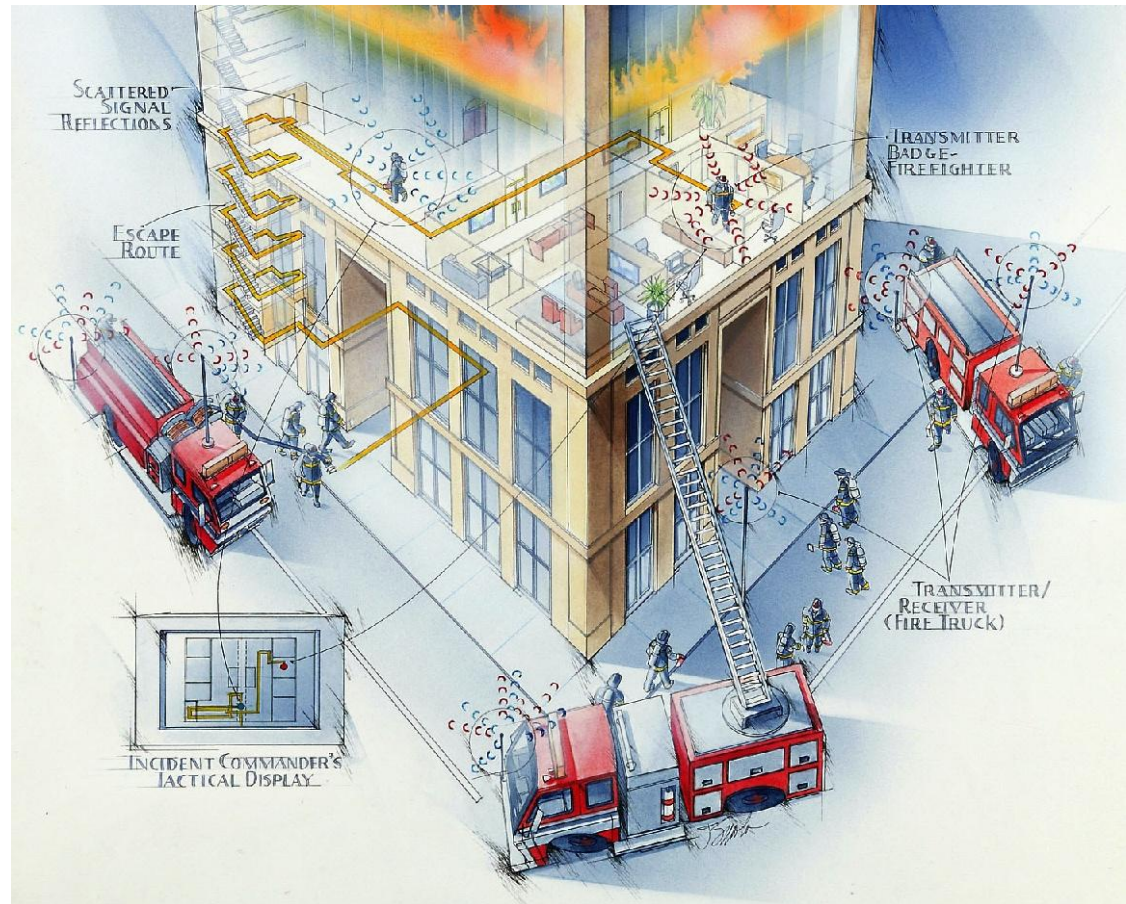
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PPL System Overview

- Primarily RF Approach
- Transmitter on personnel
- Receivers outside
- Position based on received signals
- No error from accumulation/drift



WPI PPL Goal

- Based on work with fire fighters, we need:
 - locations and paths displayed
 - floor level height accuracy with
 - < 1 meter x,y error
 - for multiple responders
 - requiring no pre-installed infrastructure
 - physiological / environmental monitoring
 - minimal set-up

1164
John Smith **2**



❤️ 190
 🩹 30
 📏 91
 SpO₂ 92

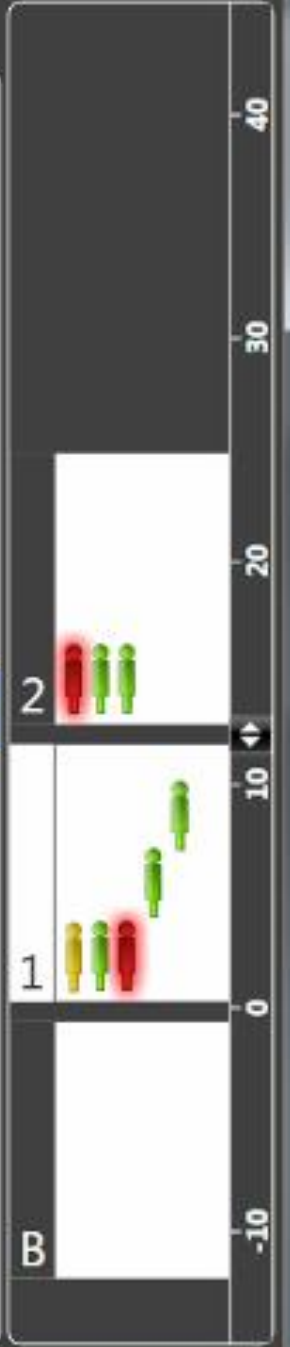
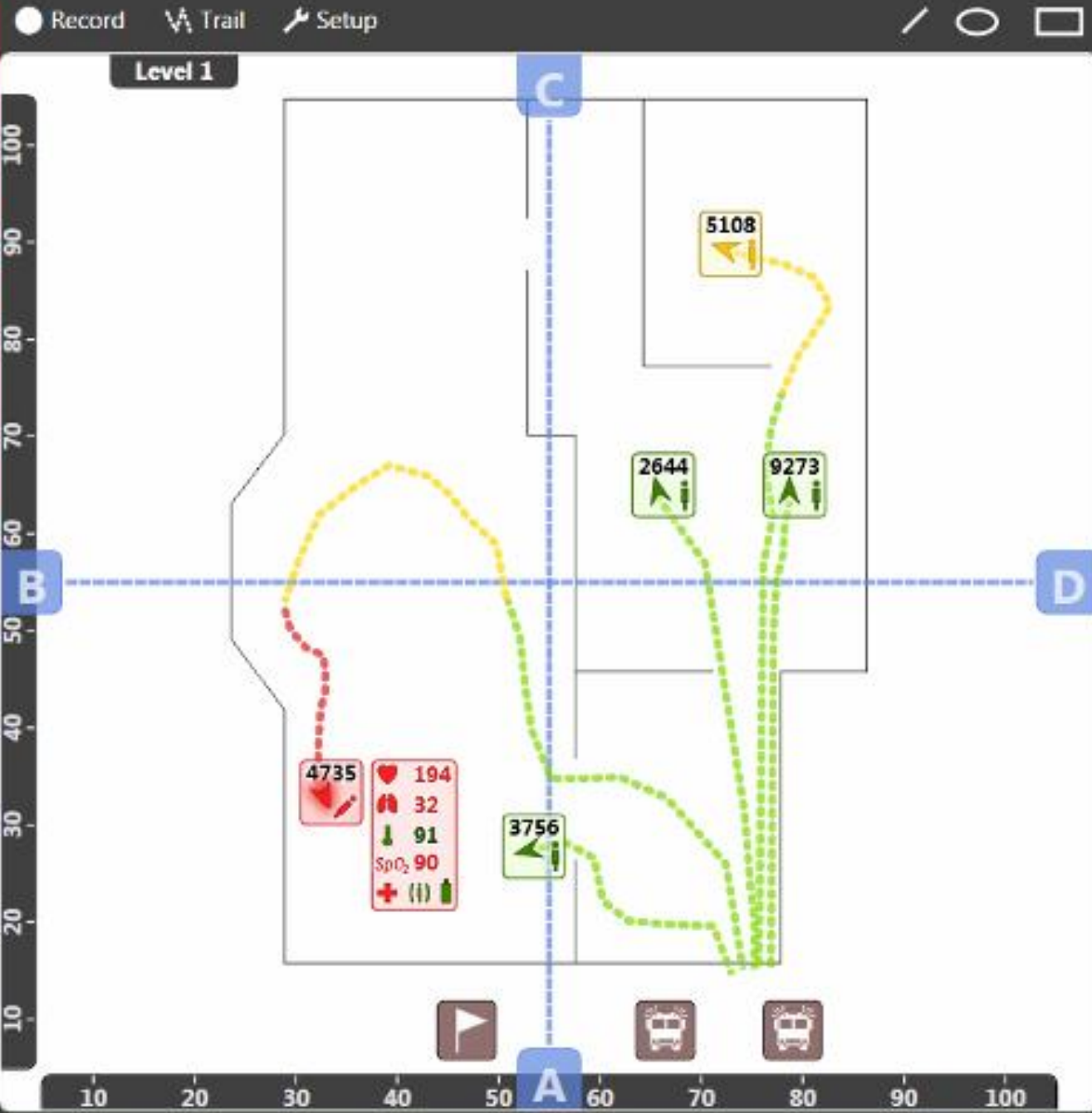
➔ (|) 📏 +

4735
John Doe **1**



❤️ 194
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System Hardware



Transmitter and power modules

Data channel and Physiological Monitoring

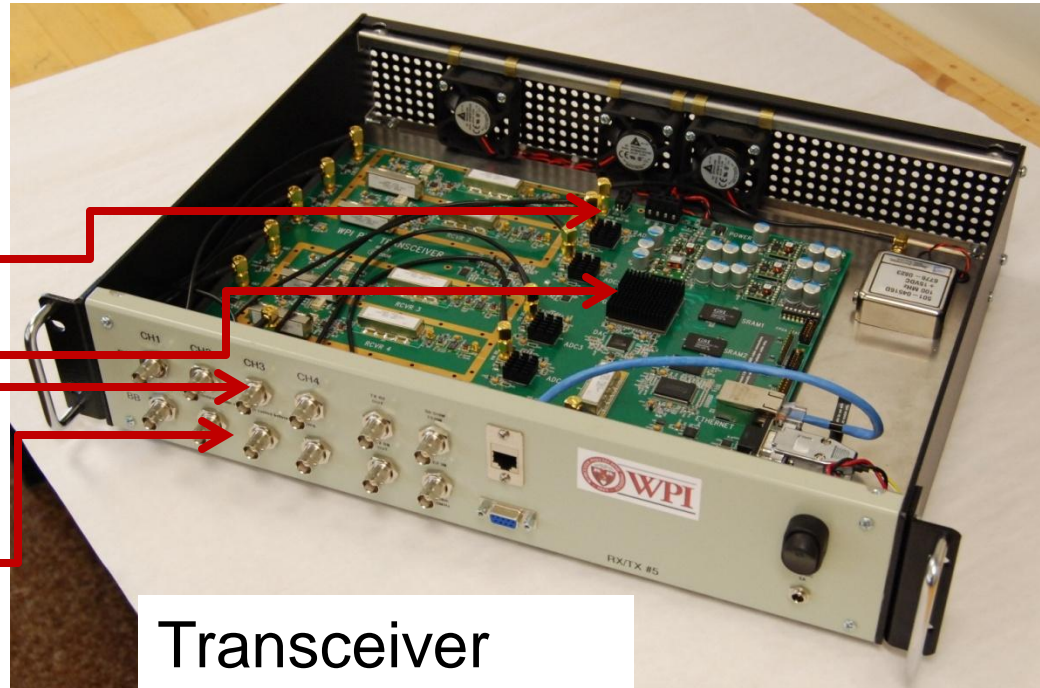
Locator

ADCs

Xilinx Virtex 4 FPGA

RF Inputs

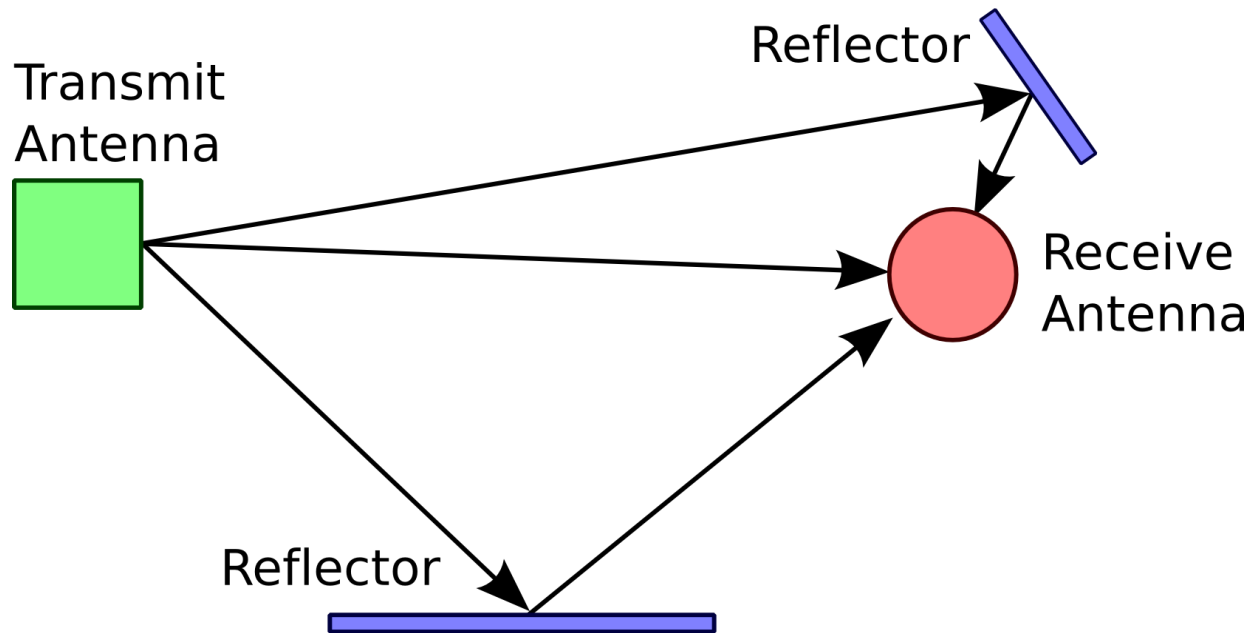
Baseband Inputs



Transceiver

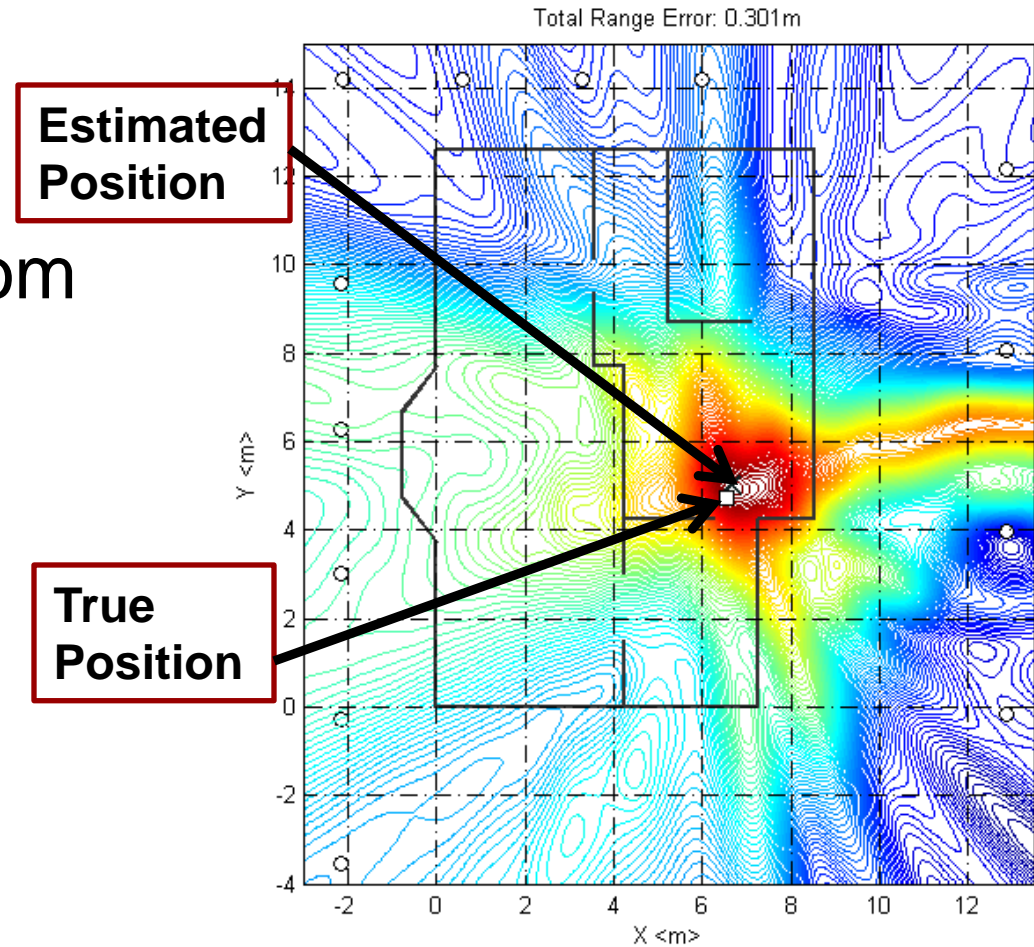
Multipath Problem

- Indoor positioning with RF is very challenging due to multipath
- Metal objects act as reflectors



Singular Value Array Reconciliation Tomography (σ ART)

- Unique algorithm developed at WPI
- Estimates positions from TDOA like information
- Not based upon 1D ranging and multi-lateralization like most approaches
- See reference



• <http://www.ece.wpi.edu/Research/PPL/Publications/>

The Need for Rapid Deployment

- Every minute counts
- A building may only be accessible from one side
- Floor information is critical
- Enhancing our RF system with additional sensors allows us to maintain a high level of accuracy



“The United States has the 5th highest fire death rate of all industrialized countries, most from residential fires.”

http://www.ihs.gov/MedicalPrograms/PortlandInjury/intop_firebrn.cfm

Original Deployment: Test Setup



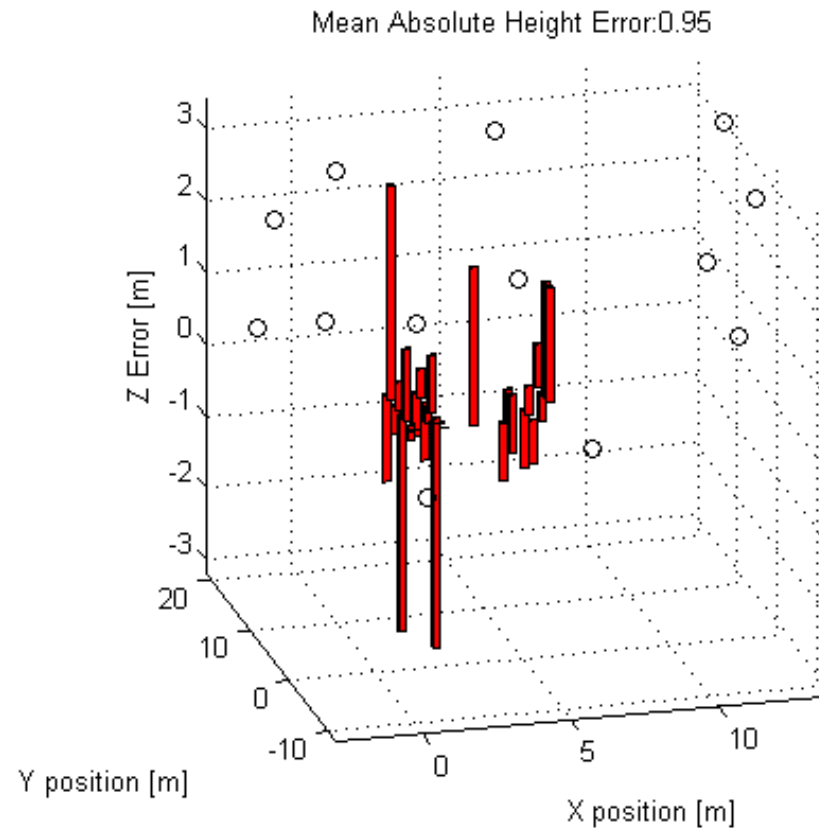
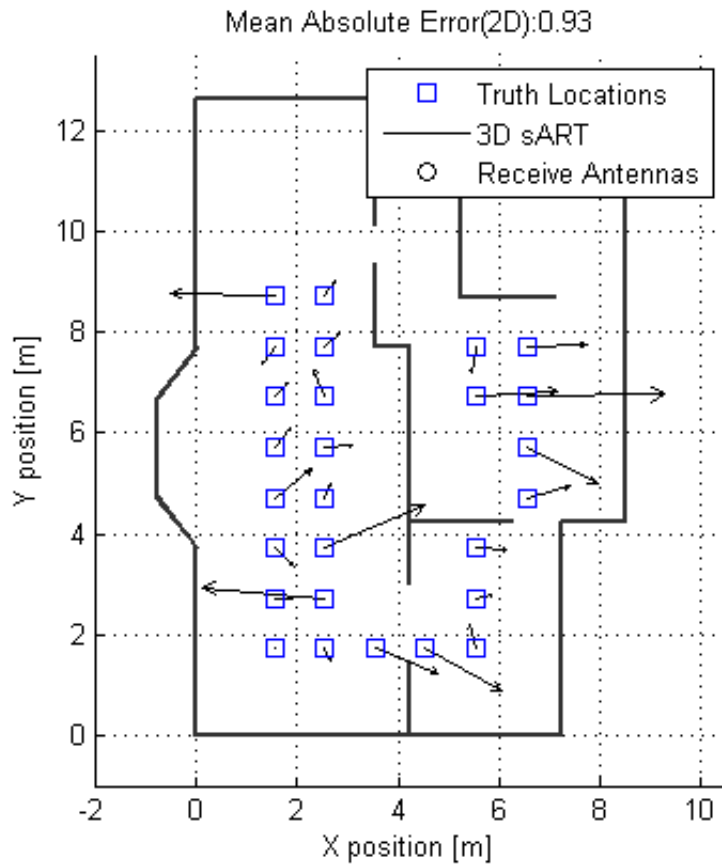
Mobile Locator Unit

Rapid Deployment: Test Setup



Performance – Original Deployment

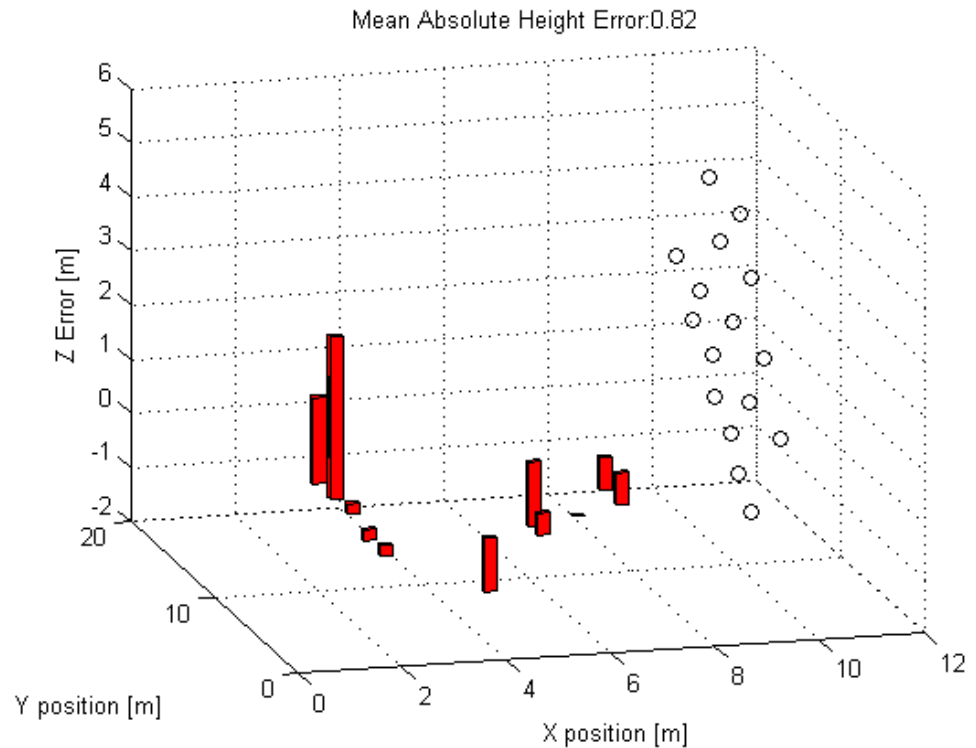
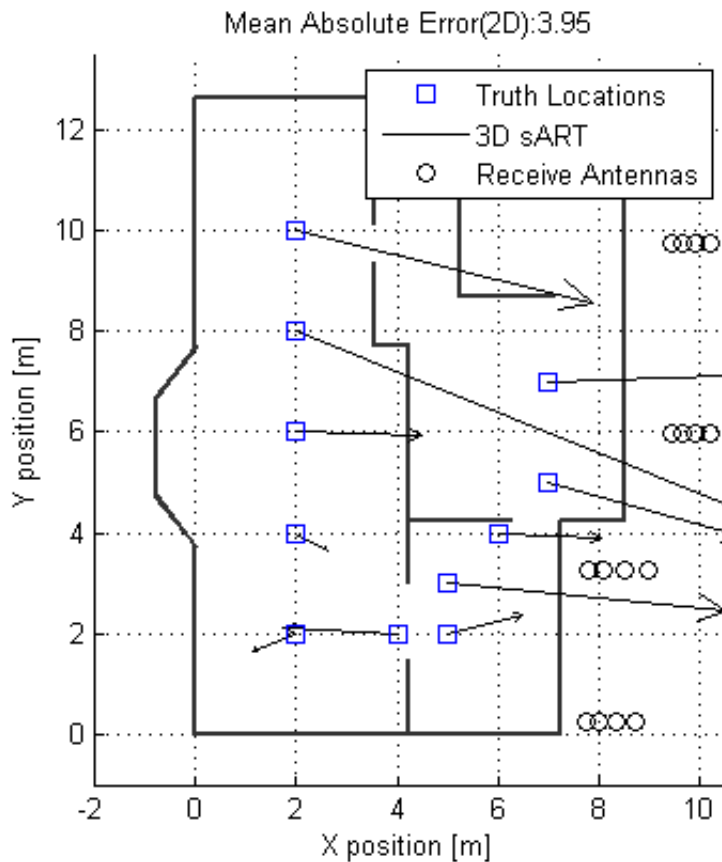
Original Deployment X,Y error: **0.93m** Z error: **0.95m**



Performance – Rapid 4 Ladder

Rapid Deployment/ σ ART

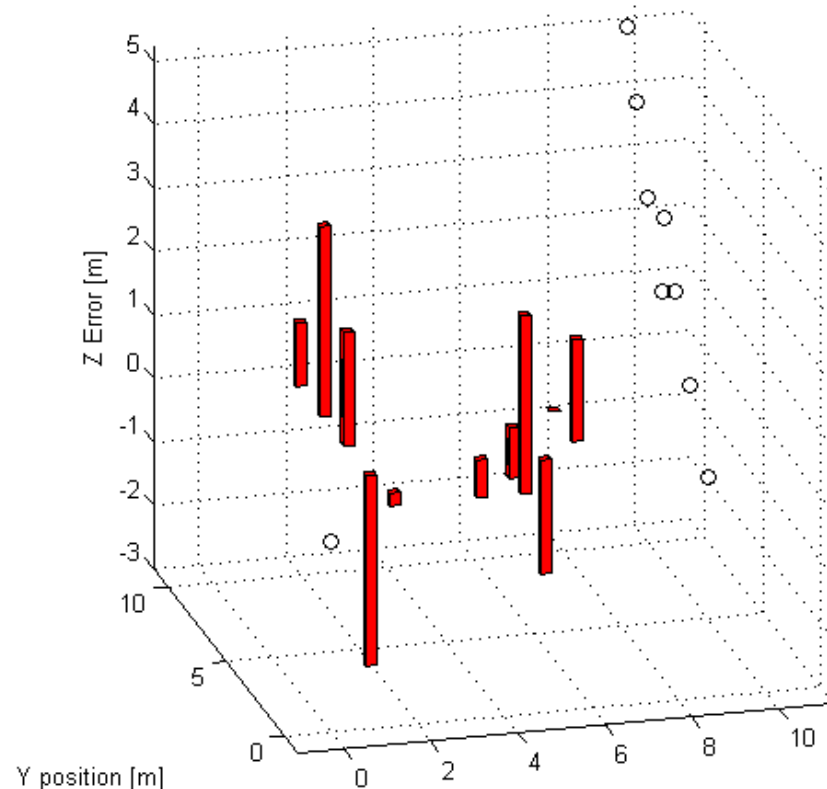
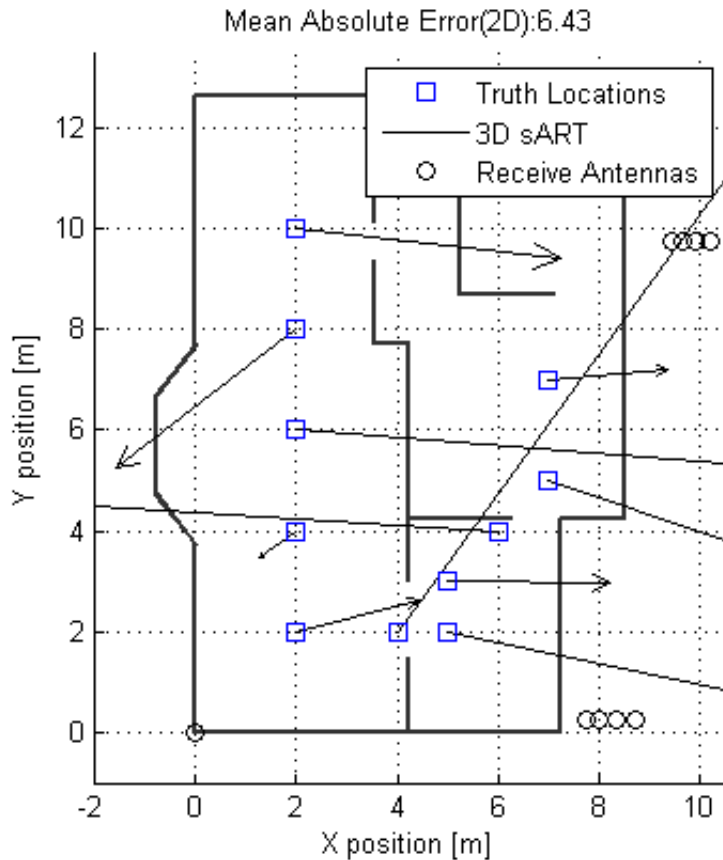
X,Y error: **3.95m** Z error: **0.82m**



Significant Geometric Dilution of Precision

Performance – Rapid 2 Ladder

Rapid Deployment/ σ ART X,Y error: **6.43m** Z error: **1.51m**

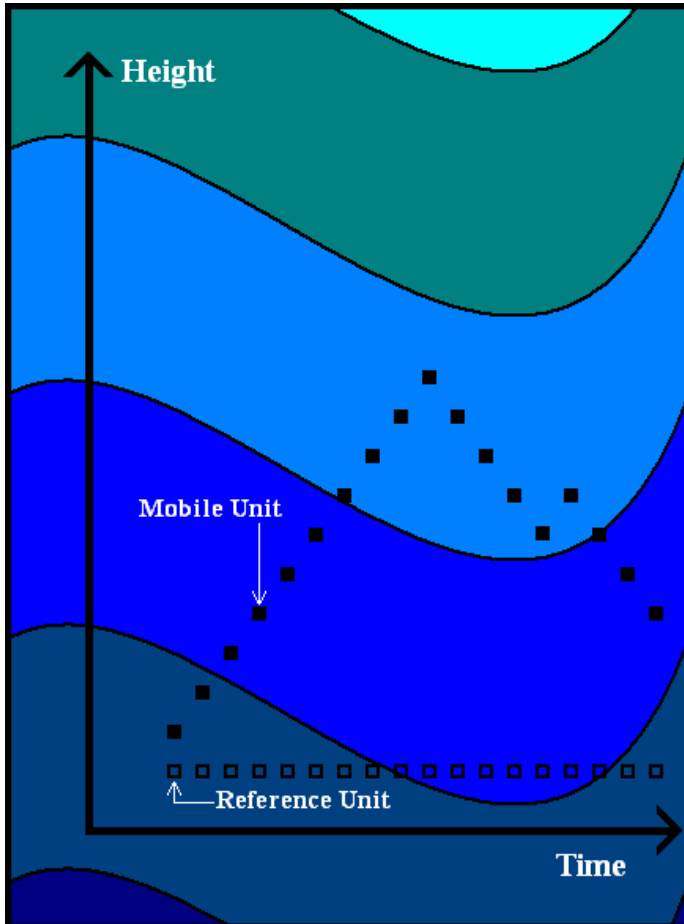


Further Increase in Geometric Dilution of Precision

Enhancement through Sensor Fusion

- The σ ART solution has a large geometric dilution of precision in the X direction with the new configuration
 - Direction perpendicular to plane of antennas
- For better X information we use RF based TOA 1D ranging
- Correct building floor estimates are critical
 - Fusing Barometric data will enhance height estimates
- Fusing TOA data can further enhance the overall solution

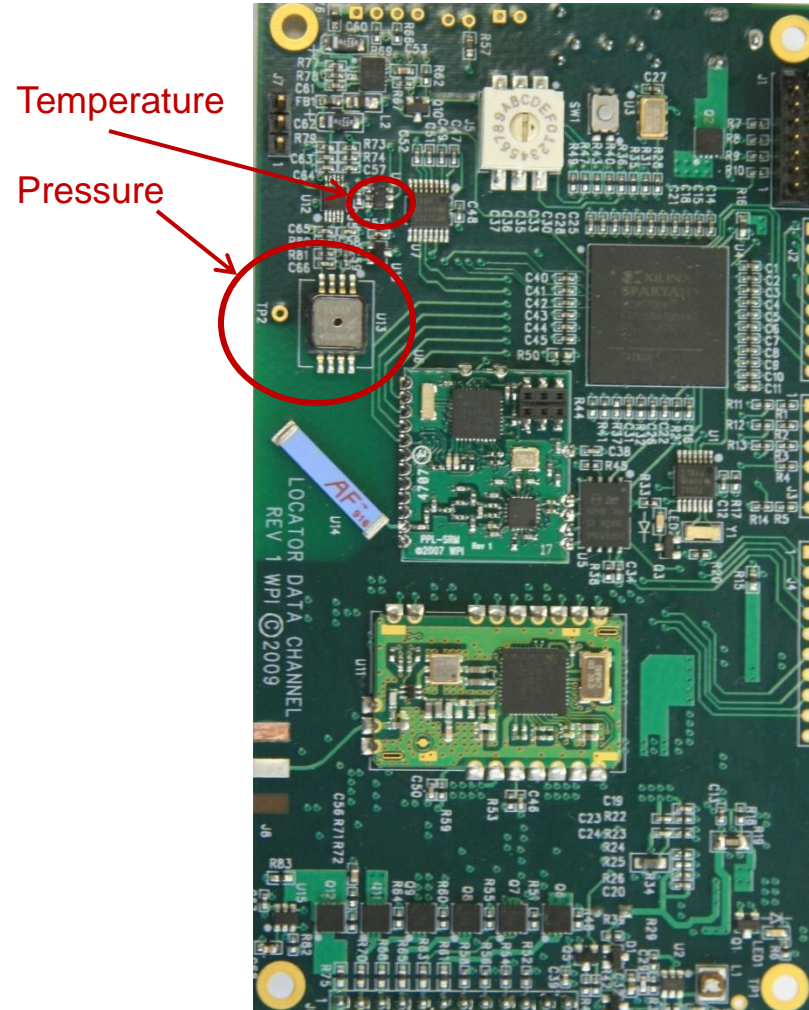
Barometric Data



- Fusion algorithm uses barometric data to help estimate the height, and ultimately the floor that the firefighter is on
- Reference unit on the ground used to cancel atmospheric effects
- Onboard temperature sensors remove thermal bias from sensor data

Barometric Measurement

- Temperature effects on the silicon barometric sensors can be compensated using the temperature sensor data



Bayesian Fusion Methods

- Bayesian estimators make use of a prior probability distribution
- Data is then fused to form a more precise distribution based on the prior
- The Bayesian metric is of the form:

$$L((x, y, z) | \{data\}, I)$$

- This is the likelihood that we are at point (x,y,z) given the data we are seeing, as well as all prior information about this point
- We exhaustively scan all possible values of (x,y,z) and select the value where this metric is maximum

Bayesian Fusion Data Sources

Information Source	X	Y	Z	Comments
Rapid Deployment/ σ ART	*	**	**	Dilution of precision in X
1D Ranging	*	*	*	Using additional RF signals to gather different information
Barometric			**	Independent of RF effects

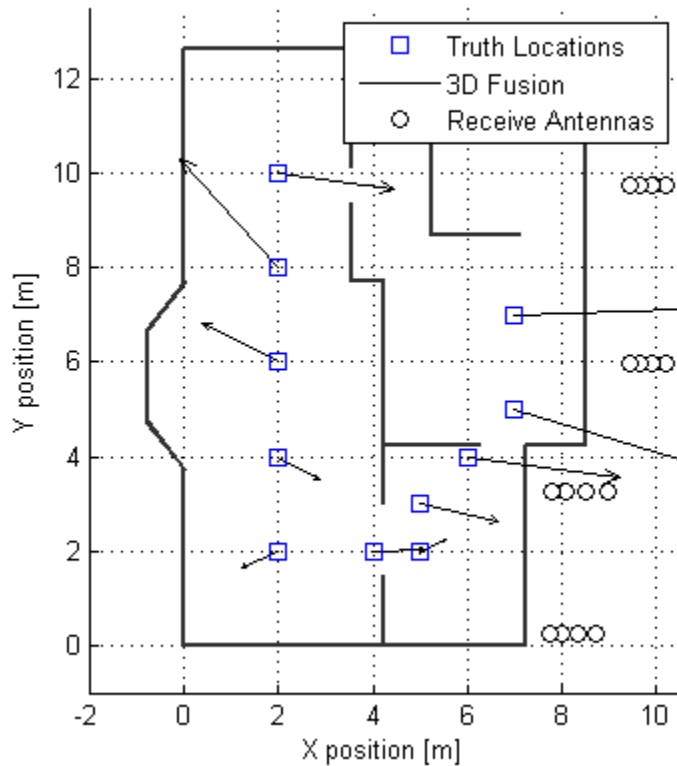
- Our fusion algorithm considers all available sources
- The metric is extremely tolerant of even large measurement errors
- Errors would only perturb the solution if they were to agree across three diverse measurement systems

Three Source Fusion Results– 4 Ladder

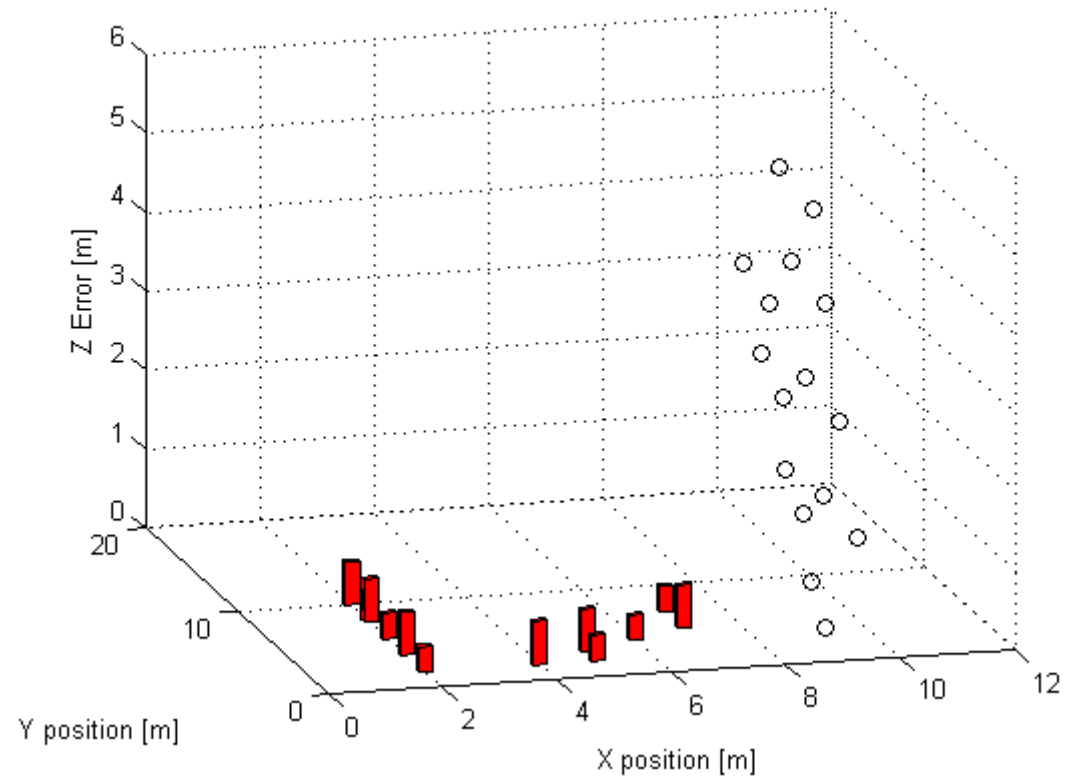
Rapid Deployment/Fusion

X,Y error: **2.49m** Z error: **0.45m**

Mean Absolute Error(2D):2.49



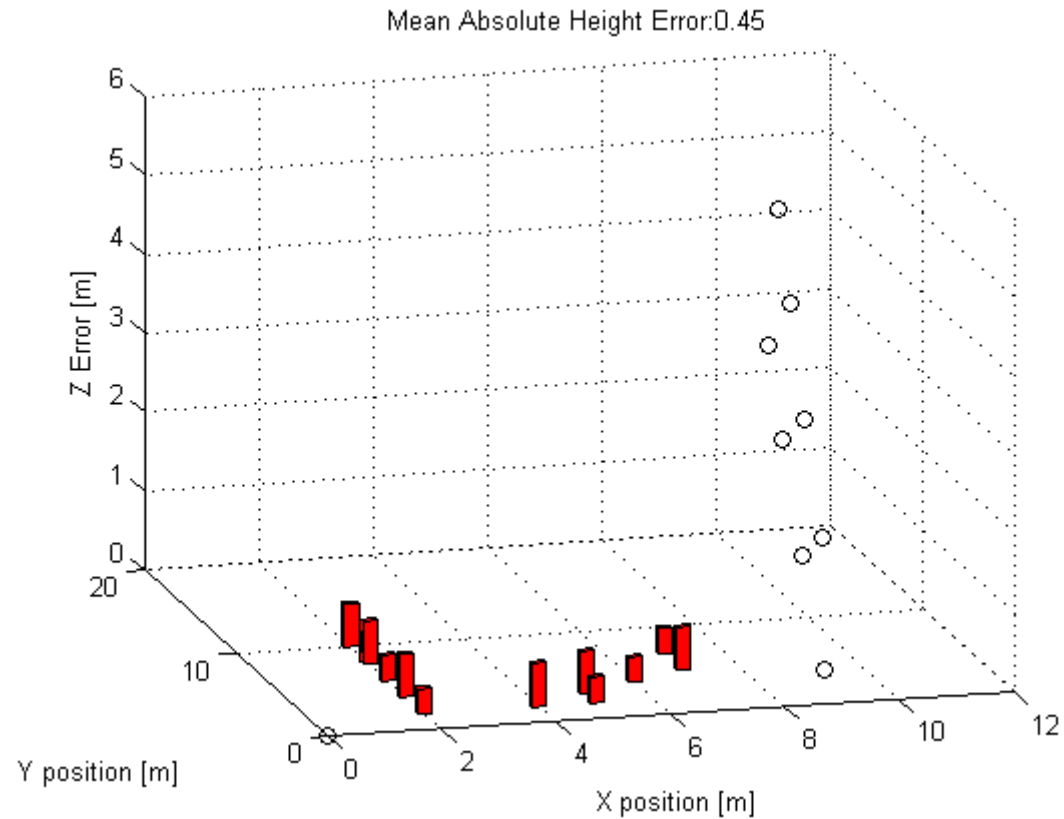
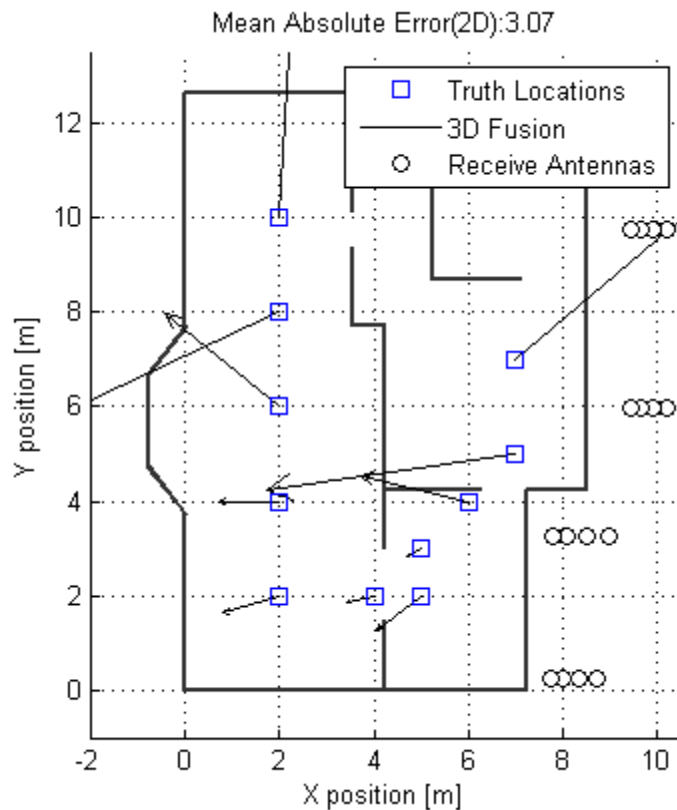
Mean Absolute Height Error:0.45



Three Source Fusion Results– 2 Ladder

Rapid Deployment/Fusion

X,Y error: **3.07m** Z error: **0.45m**



Summary of Results

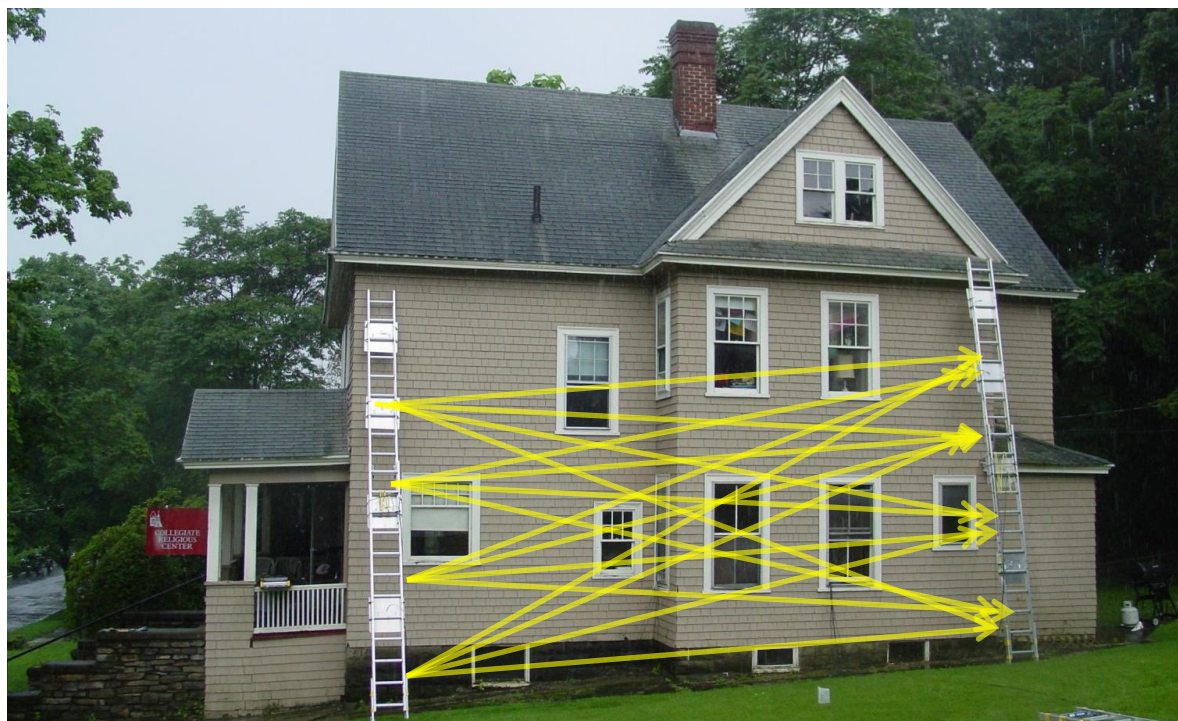
Method	3D Error	2D Error	Z Error
Original Deployment	1.32 m	0.93 m	0.95 m
Rapid Deployment (2 ladder)	6.60 m	6.43 m	1.51 m
Rapid Deployment (4 ladder)	4.03 m	3.95 m	0.82 m
Fused Deployment (2 ladder)	3.10 m	3.07 m	0.45 m
Fused Deployment (4 ladder)	2.53 m	2.49 m	0.45 m

Evaluation of Results

- While the Rapid Deployment/Fusion outcomes are less precise than the original deployment approach:
 - The floor is always correctly identified
 - Considered single most valuable piece of information by firefighters for timely rescues
 - The Y direction information has approximately 2 meter maximum error (4 ladder case)
- This fusion only considered Barometric and RF data
- Independent inertial / σ ART fusion tests have been shown to reduce x,y errors

Additional Rapid Deployment Aspects

- These “arrays” ideal for geometric auto-configuration
 - Signals exchanged between arrays to determine relative positions without manual measurements
 - Algorithms and hardware have been developed

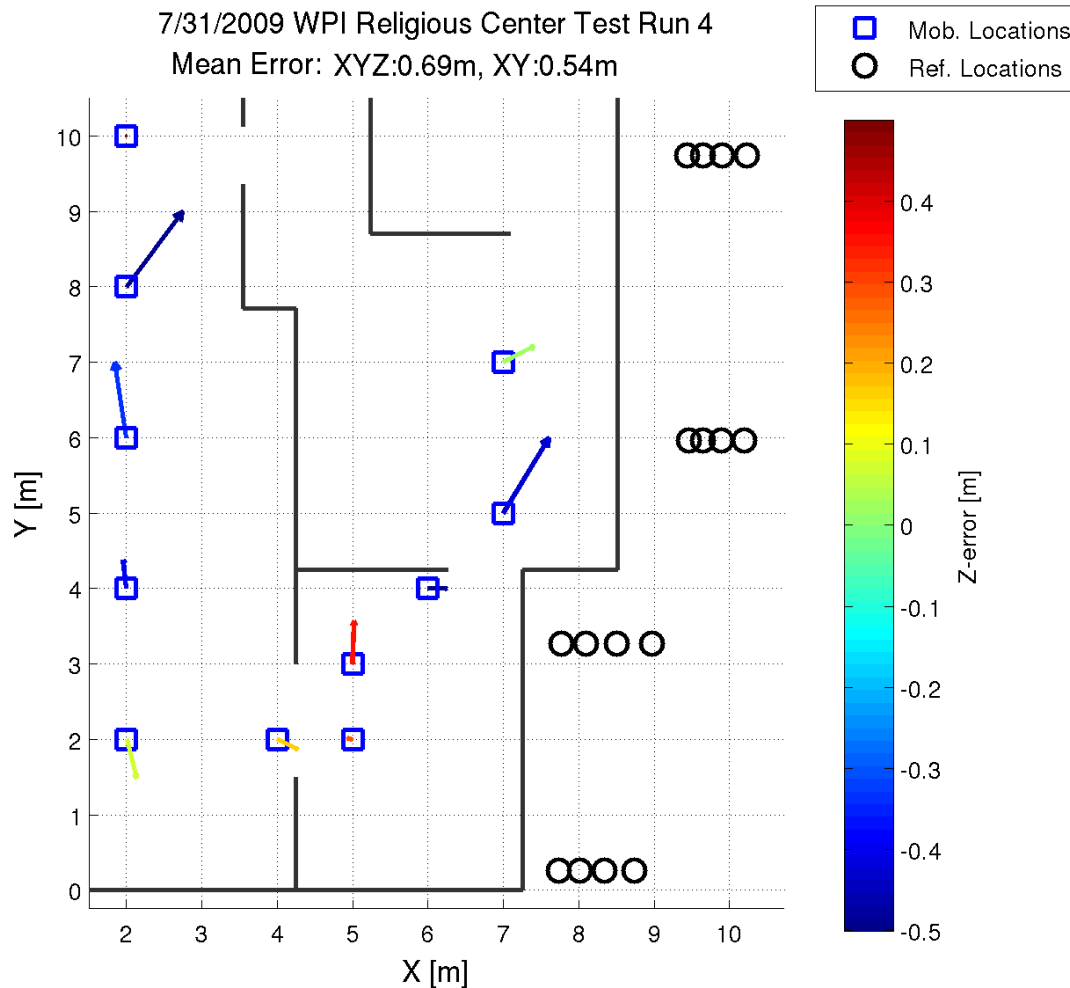


Conclusions

- This work investigated the impact of minimizing our setup complexity on our location accuracy
- The Rapid Deployment setup causes a significant geometric dilution of precision in the X direction compared to the original WPI PPL system's σ ART algorithm
- Fusion of data from other sources boosts the accuracy of the system to useful levels
- With only two “ladder antennas”, the fused system correctly identified the floor and floor sector every time
- Viability of a rapid deployment, single-building-side system has been successfully demonstrated.

Performance – Rapid 4 Ladder

Rapid Deployment/New Fusion X,Y error: 0.54m Z error: 43.m



Indoor Location Workshop

- WPI hosting 5th Annual International Workshop on *Precision Indoor Personnel Location and Tracking for Emergency Responders* in August 2-3, 2010 in Worcester, Mass.
- www.ece.wpi.edu/Research/PPL

WPI Precision Personnel Locator

- Acknowledgements
 - The rest of the WPI team
 - Worcester Fire Department
 - The support of
 - NSRDEC
 - Honeywell

- Thank you!

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