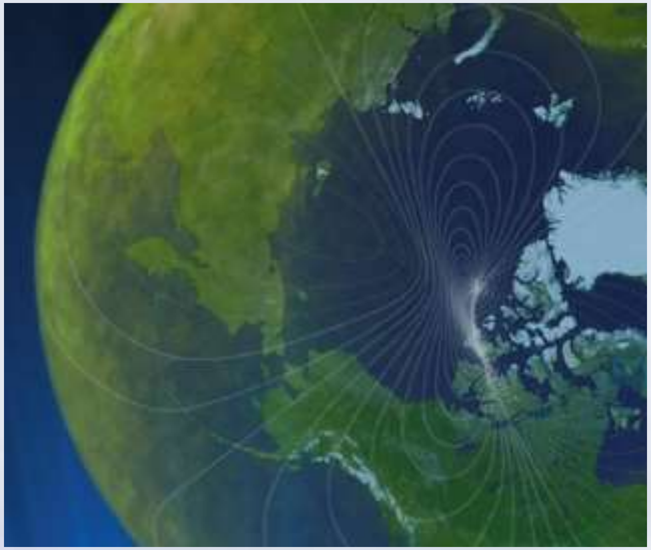
What is the Pedestrian Dead Reckoning Accuracy in Today's MEMS Sensors?

Becky Oh
President & CEO

POSITIONING
NAVIGATION
INTELLIGENCE

Who is PNI Sensor Corporation?

- PNI Sensor Corporation founded in 1987



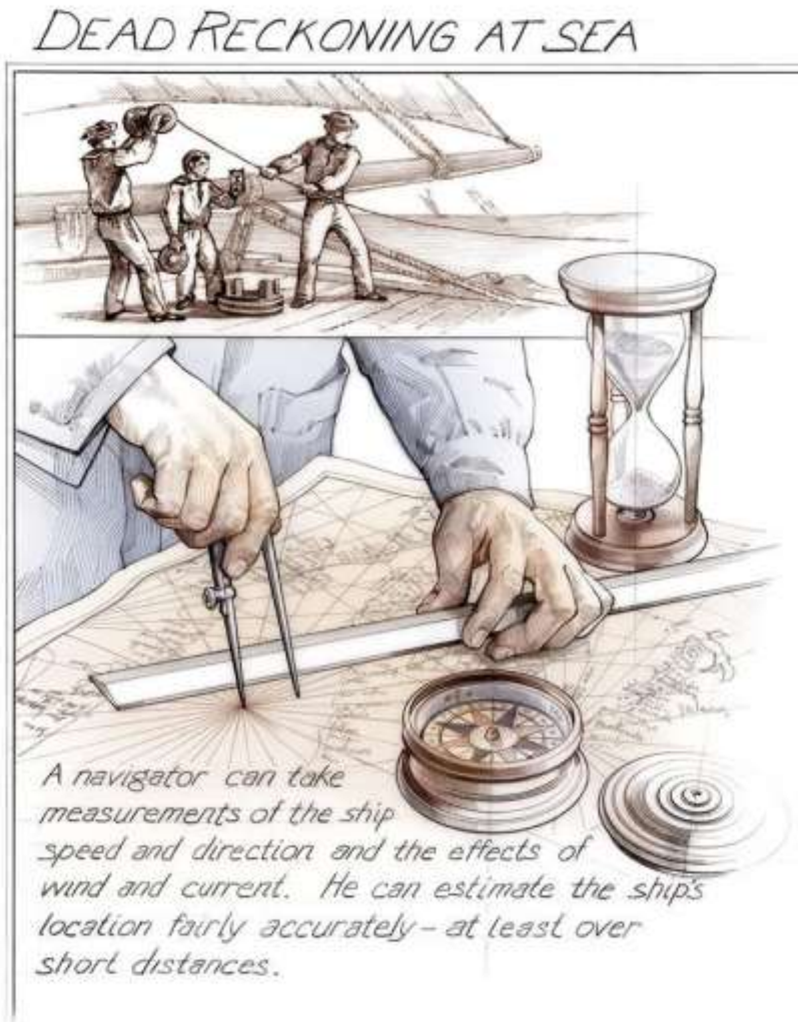
- HQ in Santa Rosa, CA with global distribution channels
- Patents and IP in magnetic sensor technology, sensor fusion and indoor positioning tracking algorithms
- Expertise in harnessing and fusing sensor data into useful military, scientific and consumer applications

PNI’s Sensor Fusion and Sensing Expertise

Agenda

- What is Pedestrian Dead Reckoning (PDR)?
- PDR error analysis:
  - Monte Carlo model
  - Sensitivity Analysis
  - Accuracy Prediction
- Hybrid PDR + RF:
  - Mapping
  - Localization
- Conclusions / Final Thoughts

What is Pedestrian Dead Reckoning (PDR)?



- PDR is a stand-alone inertial solution used to supplement other navigation systems with external reference points
  - Using inertial sensors in today's mobile devices
  - Key technology for Indoor navigation

http://timeandnavigation.si.edu/multimedia-asset/dead-reckoning-at-sea

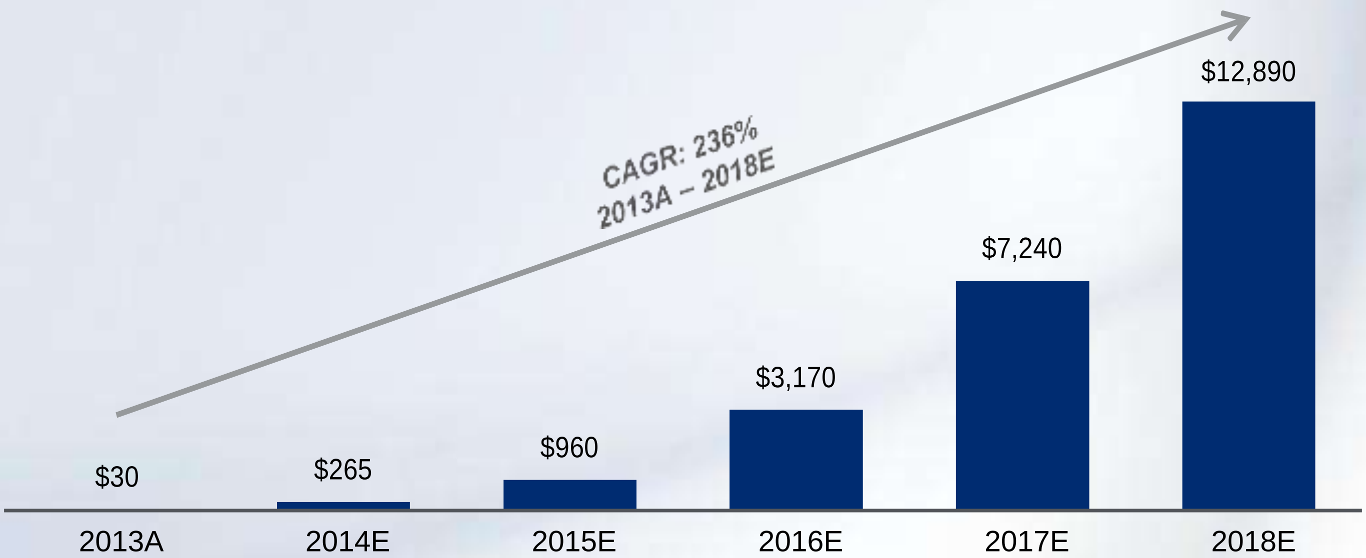
Why Pedestrian Dead Reckoning (PDR)?

- Motion sensing technologies have become ubiquitous
  - Building blocks for PDR
  - Requires no infrastructure

- ABI Research predicts that a hybrid of Wi-Fi / Bluetooth / RF based cellular technologies and sensor fusion solutions for indoor location will be available in over 900 million units in 2018

Why Pedestrian Dead Reckoning (PDR)?

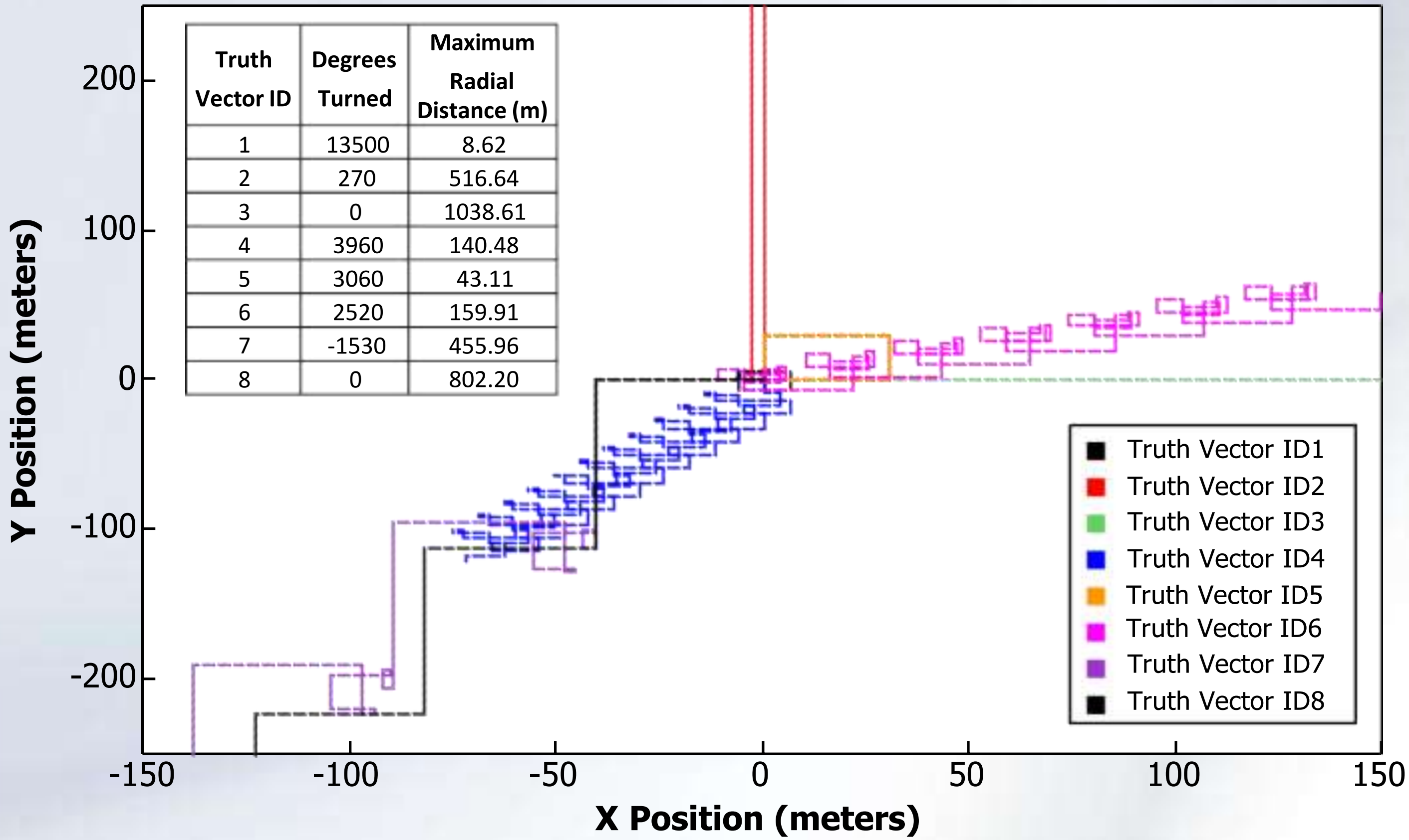
Massive Market Opportunity



Total Indoor Location Application Market

Combines Location-Based Services & Location-Enabled Services Application Markets
(Source: ABI Research, "Indoor Location Smartphone Applications", May 21, 2013)

Framing the Problem to Model PDR Accuracy



Truth Vector ID	Degrees Turned	Maximum Radial Distance (m)
1	13500	8.62
2	270	516.64
3	0	1038.61
4	3960	140.48
5	3060	43.11
6	2520	159.91
7	-1530	455.96
8	0	802.20

Note: Each Truth vector has 1363 steps (about 1 km)

Background On Our Monte Carlo Model

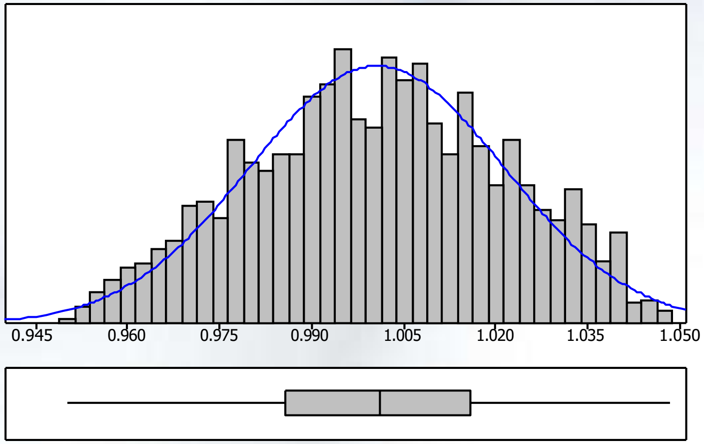
- PDR initialization errors
  - starting position & starting orientation offset errors
- Step identification errors
  - false positive & negative step probability per step
- Step length errors
  - zero mean step length errors
  - non-zero mean step length errors
- Gyroscope errors
  - DOT error from Gyro bias calibration offset (*i.e.*, residual bias)
  - DOT error from gyro scale factor errors
  - DOT error from gyro angular random walk (ARW)
  - DOT error from gyro rate random walk (RRW)
- Direction of Travel (DOT) errors
  - zero mean DOT errors
  - non zero mean DOT errors

PNI POSITIONING NAVIGATION INTELLIGENCE

Parameters for Monte Carlo Model

X Starting Position	0.0	m
Y Starting Position	0.0	m
Probability of False Step	0.00	%
Probability of Missed Step	0.00	%
Average Step Length	0.762	m
Step Length Variation (Zero mean)	7.50	% of step length
Step Length Offset	0.00	% of step length
Time between steps	0.60	seconds
DOT Uncertainty (Gyro Scale Factor Error)	0.200	%
DOT: Gyro Bias ARW	0.00100	deg/s
DOT: Gyro Bias Offset (Cal error)	-0.00100	deg/s
DOT: Gyro Bias RRW (offset error variation)	0.00010	deg/s
DOT Uncertainty (Other zero mean)	7.50	degrees
DOT Uncertainty (offset)	0.20	degrees/step
Initial X Position Offset Error	0.20	m
Initial Y Position Offset Error	0.20	m
DOT Initial Heading Offset Error	0.50	degrees
Truth Vector ID	2	ID

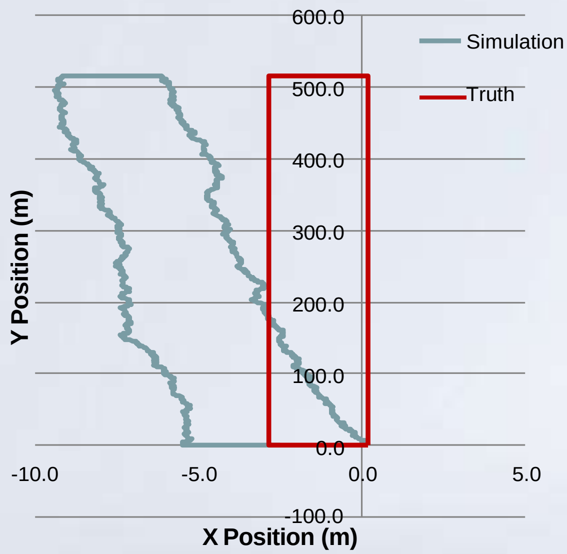
Randomization validation: step length @ 1 m and step length variation @ 5%

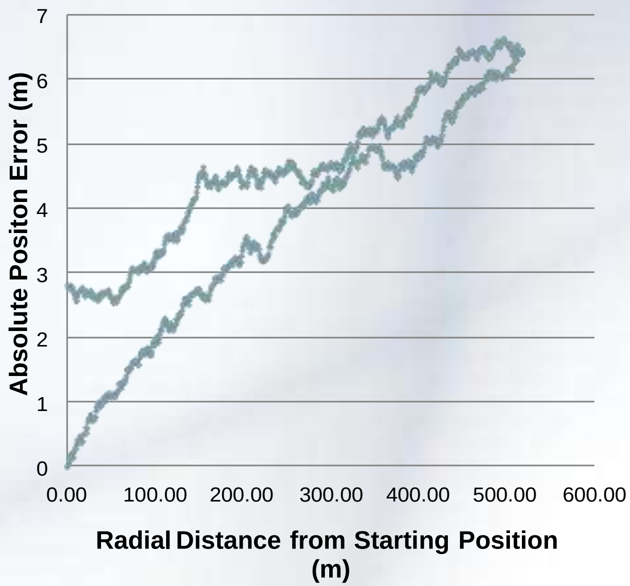


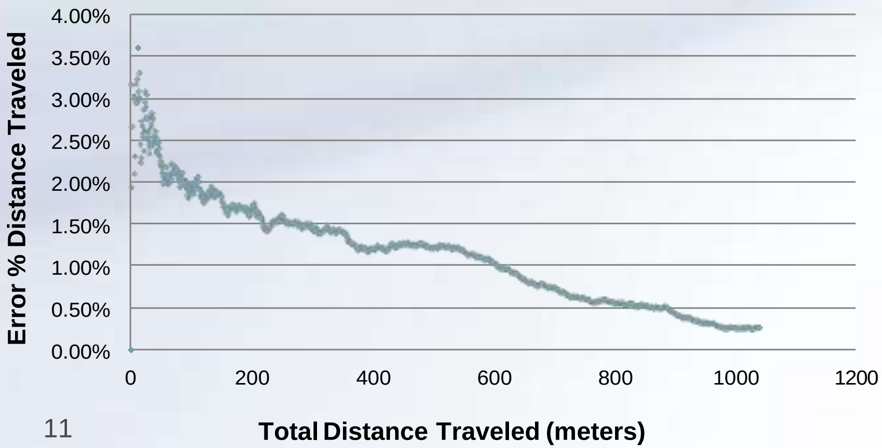
$\Rightarrow$ Randomization utilized is about +/- 3σ of limits

What accuracy is possible for Truth ID2?

Recall: starting offset is 0.2 m for X and 0.2 m for Y with 0.5 degrees DOT offset





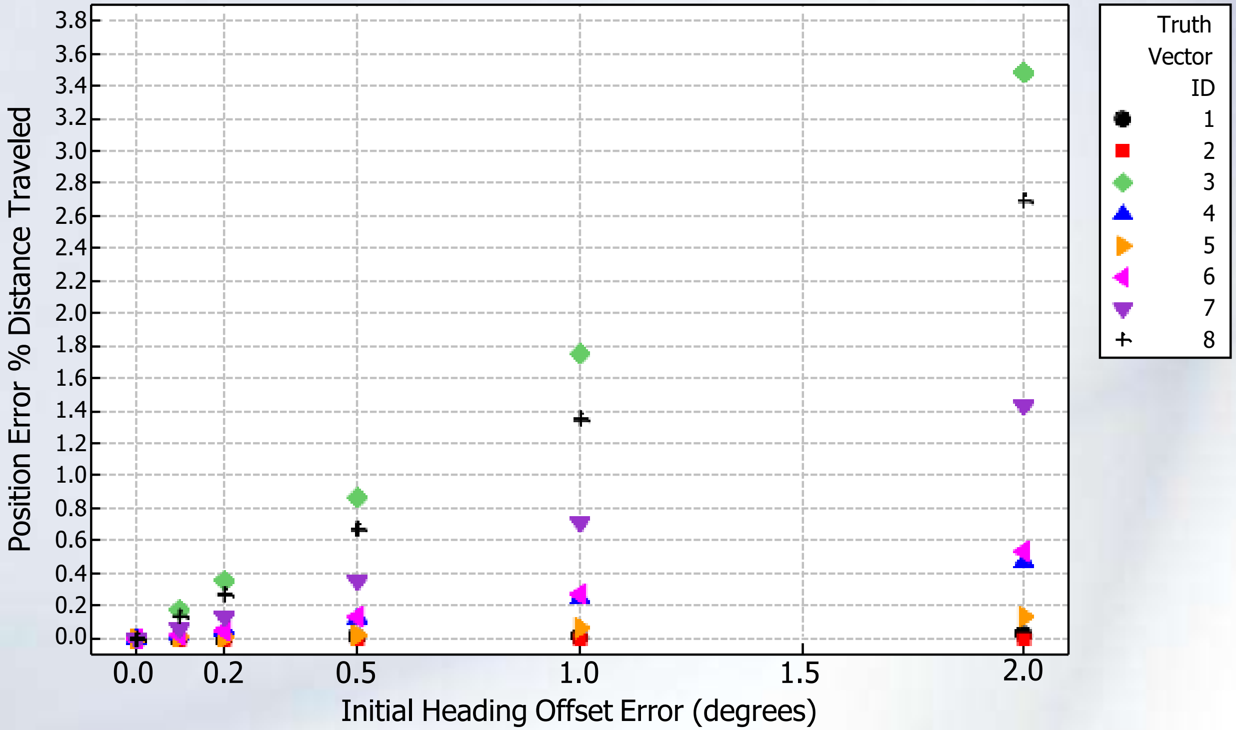


Ending error % was 0.27%
Maximum error % was 4.91% (⇒ start offset)
Average error % was 1.15%

Modeling: Sensitivity Analysis

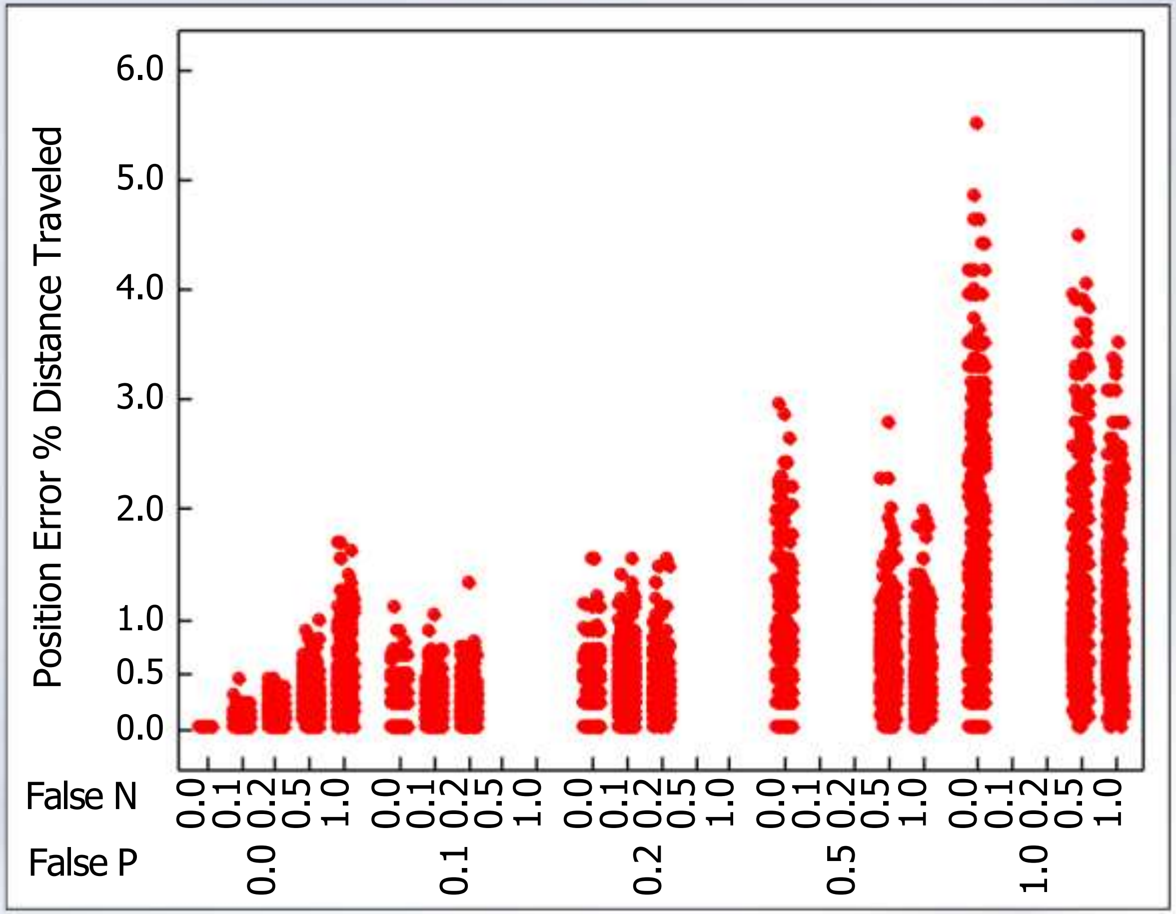
PDR initialization errors
Step identification errors
Step length errors
Gyro errors
DOT errors

Sensitivity Analysis: PDR Heading Initialization Error



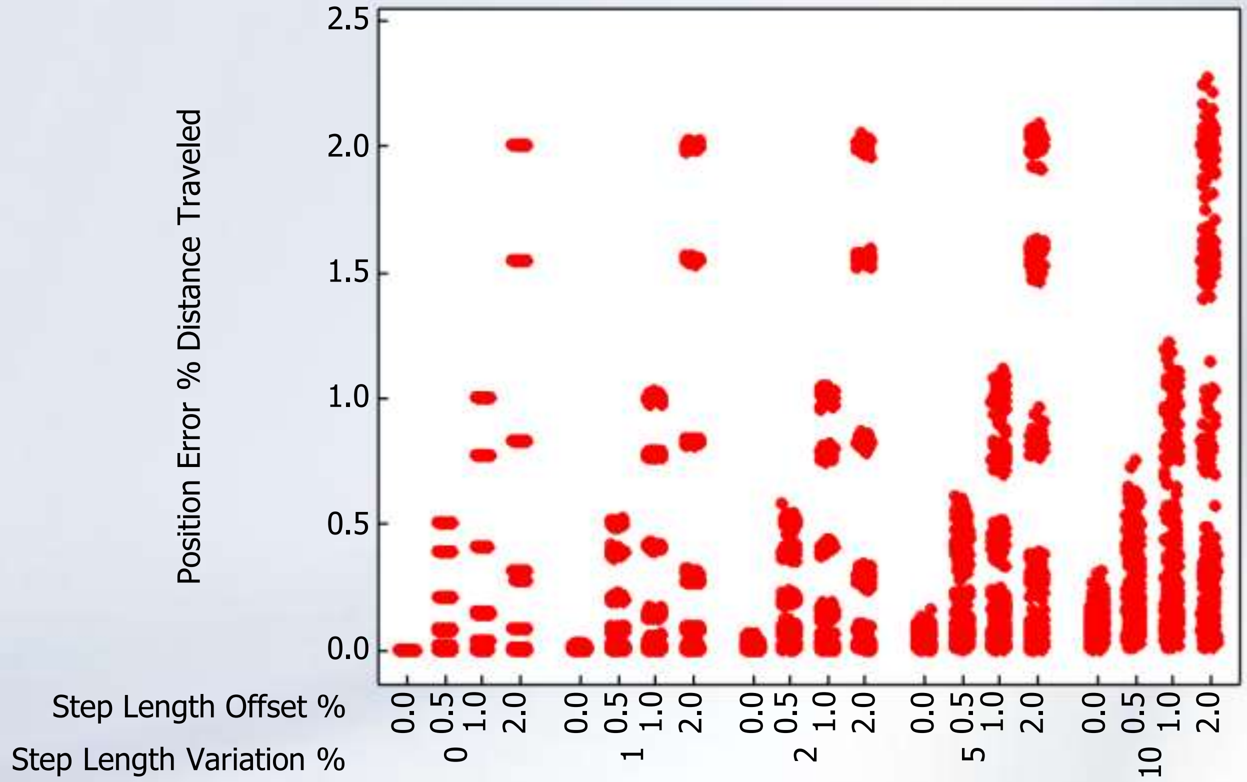
⇒ Must be about 0.50 degrees or less

Sensitivity Analysis: False Negative & Positive Step Probability



⇒ Need < 0.1% False Positive and Negative Step Probability

Sensitivity Analysis: Step Length Variation % and Offset %

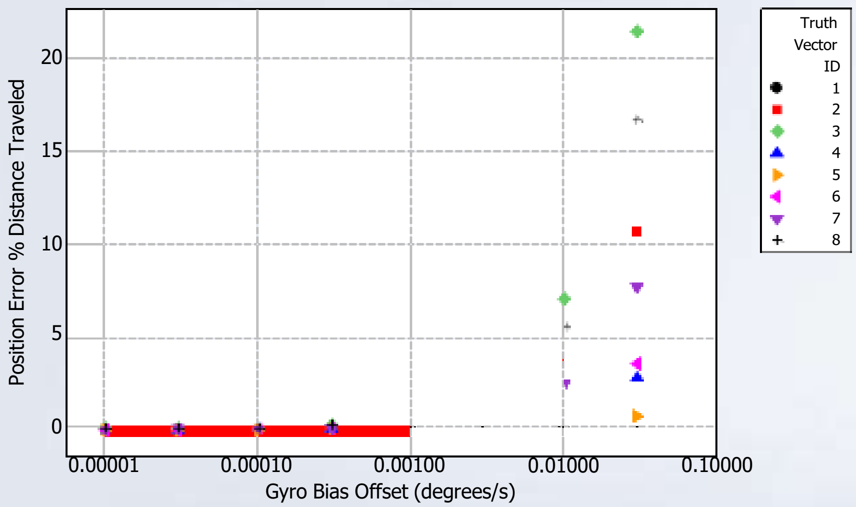


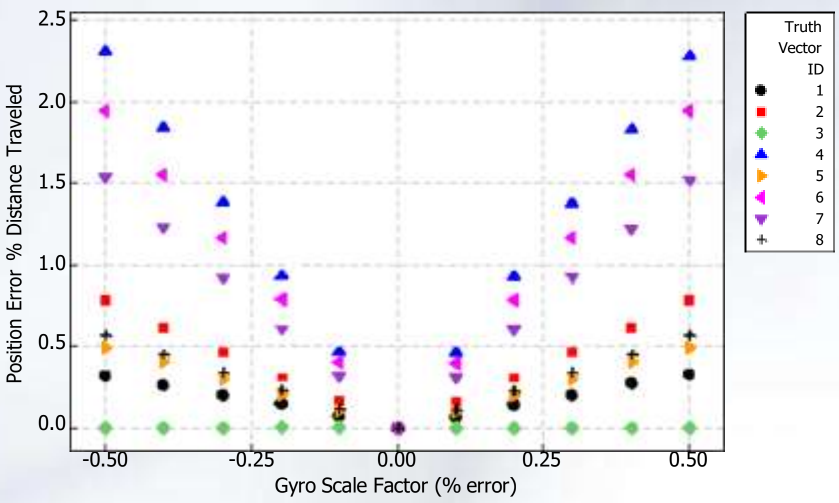
⇒ Step length variation can be 5%

⇒ Step length offset must be 0.5% or less

Cho, Dae-Ki, et al. "Autogait: A mobile platform that accurately estimates the distance walked,“ March 2010.

Sensitivity Analysis: Gyro Scale Factor and Gyro Bias Offset



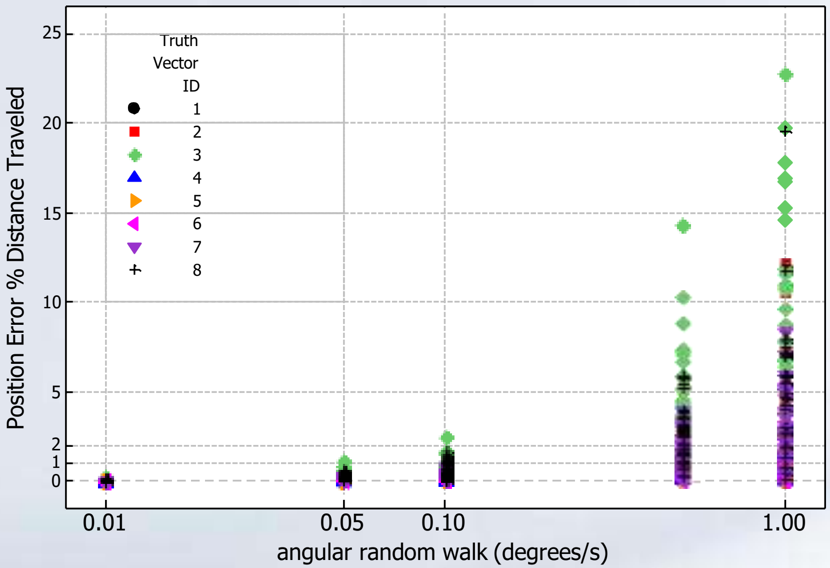


⇒ Static gyro bias must be resolved to within 0.001 degrees/s (3.6 degrees/hr)

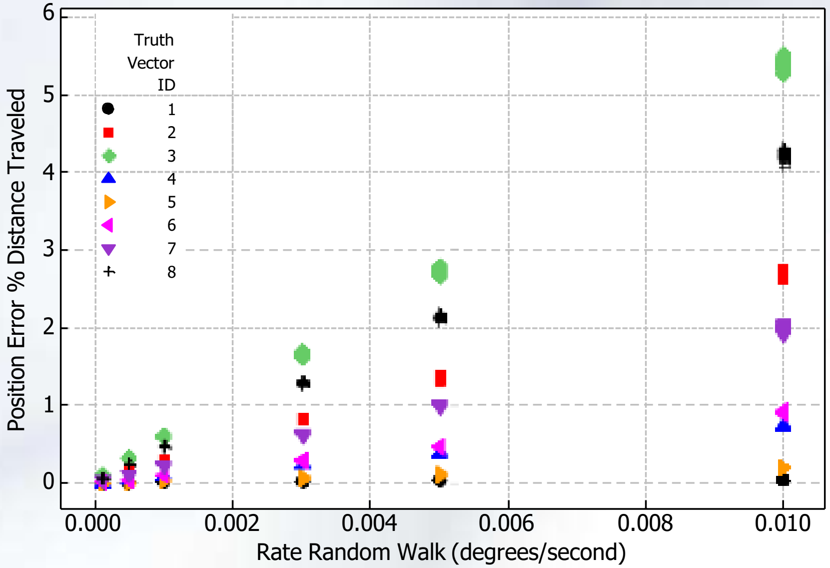
⇒ Must be below 0.1% error which is < 2 degrees after 5x 360 degree revolutions

Sensitivity Analysis: Gyro Angular Random Walk and Rate Random Walk

ARW



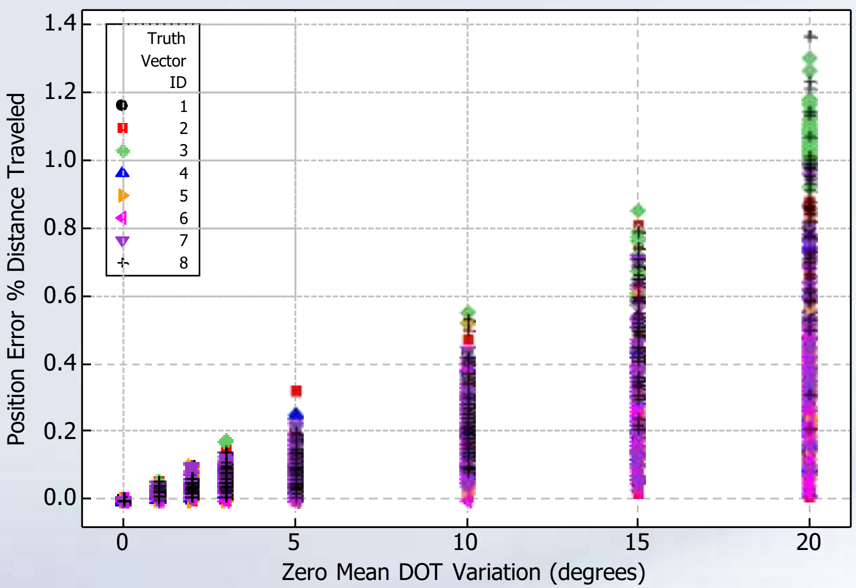
RRW

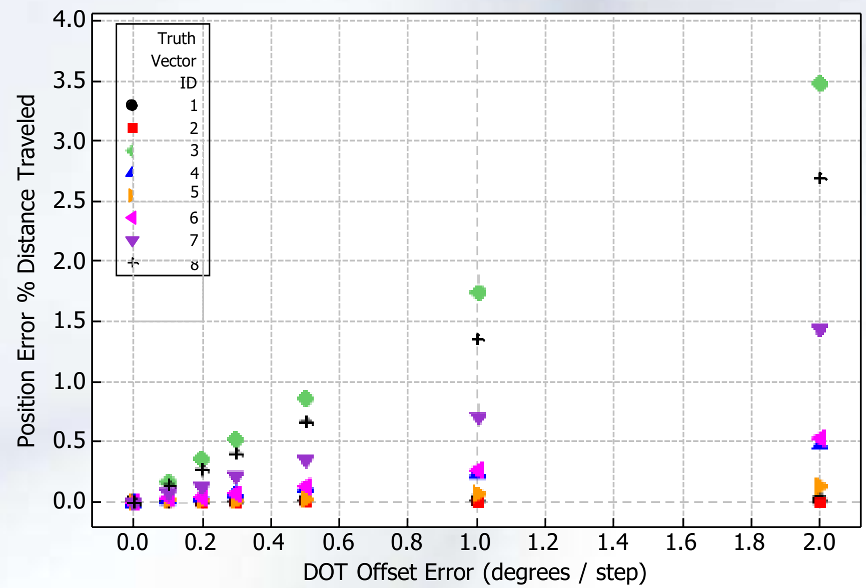


⇒ For 1 % position error % distance, must be below ~0.05 degrees / s (i.e., < 180 degrees/hr)

⇒ For 1% position error % distance, must be below ~ 0.001 degrees / s (i.e., < 3.6 degrees/hr)

Sensitivity Analysis: Zero Mean DOT Variation and DOT Degrees per step Offset Error





⇒ Can be as high as +/- 15 degrees

⇒ Must be below 0.5 degrees / step

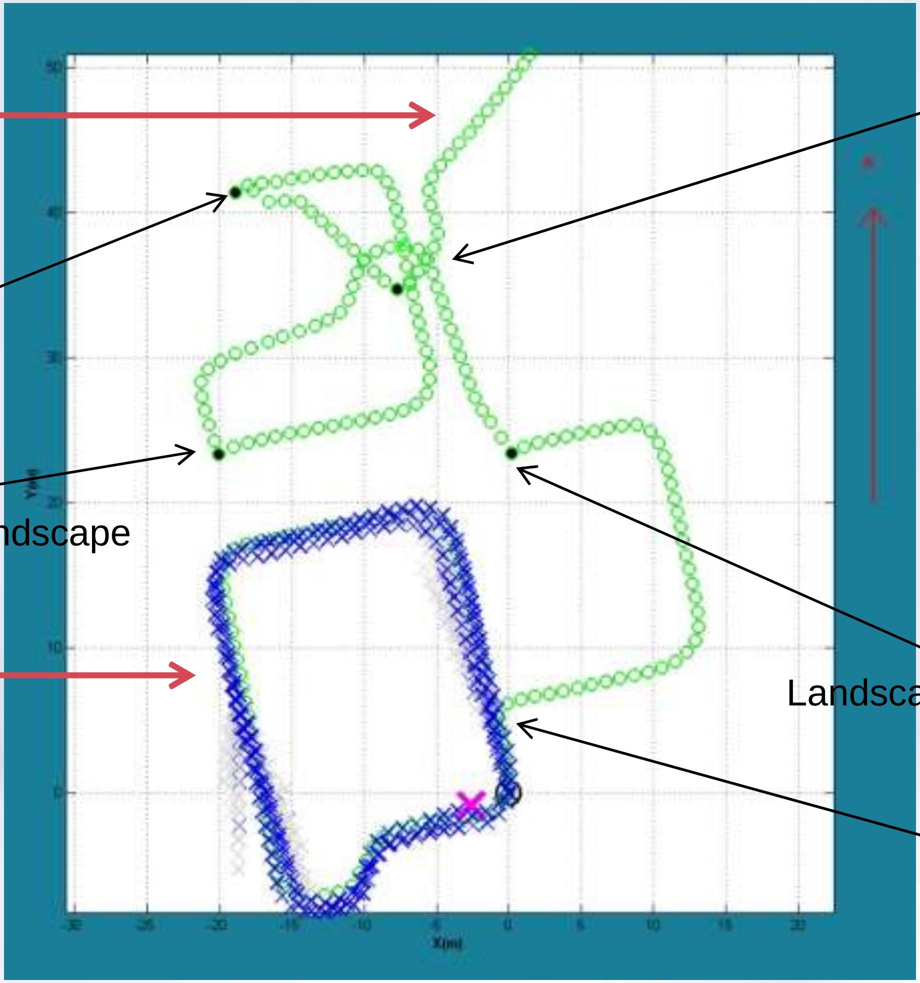
PDR with Device to Body Frame Transitions

NOT CORRECTED

Ear ->hand at side

Landscape -> ear

Upside down portrait ->landscape



CORRECTED

Landscape -> upside down portrait

Flat Portrait -> Landscape

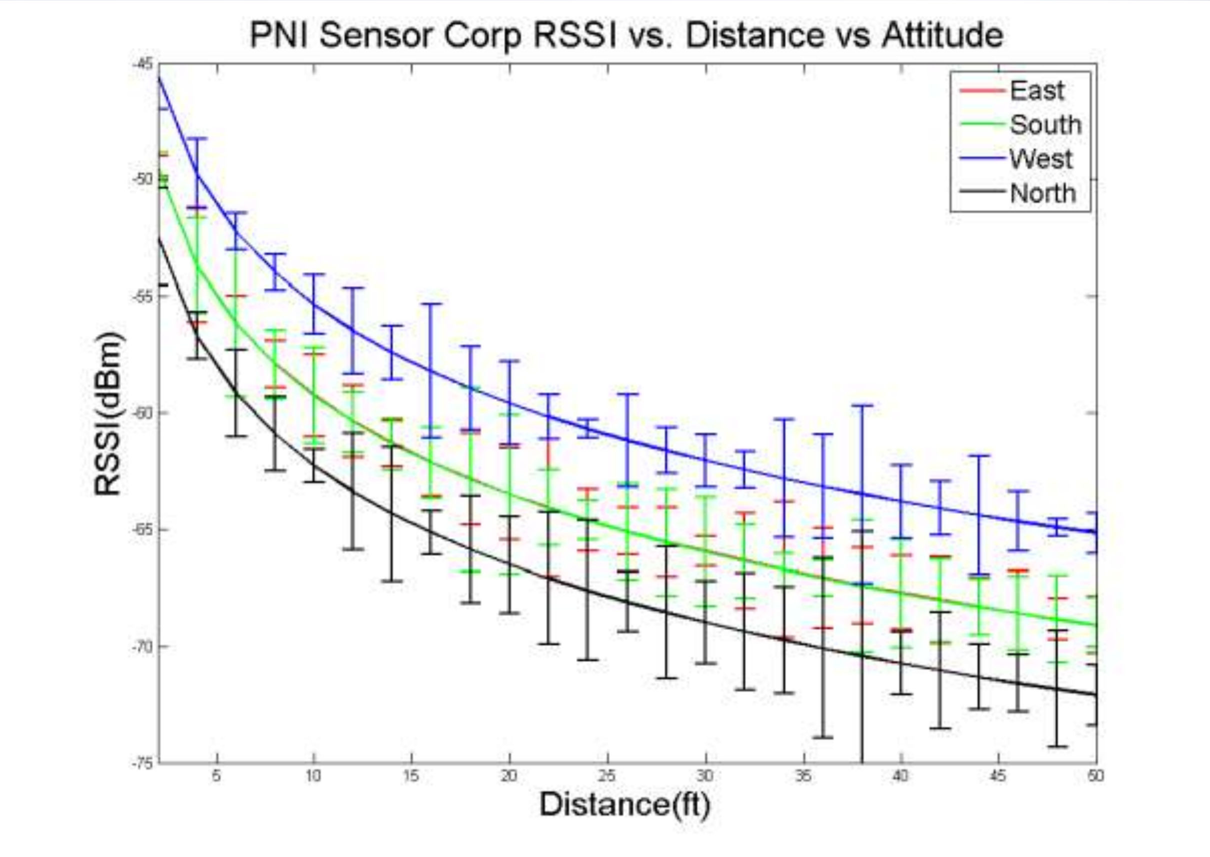
Modeling of Combined Errors for Three Scenarios

Model Parameters	**Units**	**Simulation Scenario 1**	**Simulation Scenario 2**	**Simulation Scenario 3**
Probability of False Step	%	0	0.1	0.2
Probability of Missed Step	%	0	0.1	0.2
Step Length: Variation	% of step length	5	7.5	10
Step Length: Offset	% of step length	0.2	0.4	0.5
Time between steps	seconds	0.6	0.6	0.6
DOT Uncertainty: Gyro Scale Factor	%	0.05	0.1	0.2
DOT Uncertainty: Gyro Bias ARW	deg/s	0.001	0.01	0.1
DOT Offset: Gyro Bias Offset	deg/s	0.0005	0.001	0.001
DOT Offset: Gyro Bias RRW	deg/s	0	0.0001	0.01
DOT Uncertainty: zero mean	degrees	5	7.5	10
DOT Offset: Step Direction	degrees/step	0.1	0.2	0.2
Initial X Position Offset Error	m	0.1	0.2	0.2
Initial Y Position Offset Error	m	0.1	0.2	0.2
DOT Offset: Initial Heading Offset Error	degrees	0.1	0.5	1
Simulations	count	3500	3500	3500
Median Position Error % Distance	**% Distance Traveled**	**0.28**	**0.69**	**2.39**
Median Heading Error	**degrees**	**1.29**	**2.75**	**10.7**

Known Challenges with BLE Ecosystem

- The user may not know the location of the beacons in advance
  - In iOS, the beacon UUID is not available unless you know the UUID *a priori*
  - For Gimbal Inc. beacons (spinoff from Qualcomm), they use a rolling UUID thereby forcing developers to use their SDK to get beacons to work properly
  - Both makes it challenging to map an unknown physical Beacon and its properties to a unique identifier (and store the data in the Cloud)

Explore: Is device and transmitter heterogeneity an opportunity?



⇒ 30 feet facing West looks like 10 feet facing North

$\vec{x}_0^i$

Particle Filter Description

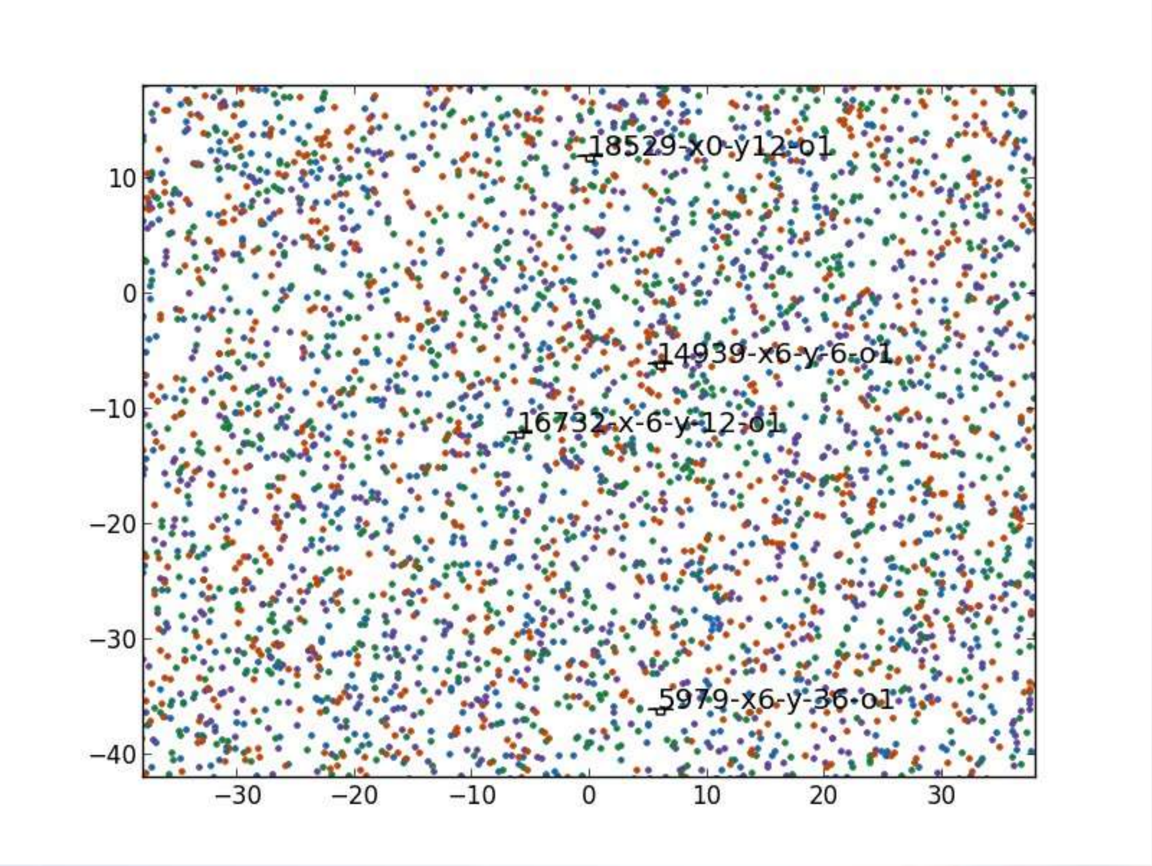
1. *Initialization:*
   Initialize particles, $\vec{x}_0^i$, $i = 1, ..., N$ to approximate the posterior distribution, where N is the number of particles.
   Our state vector, $\vec{x}_k$, is comprised of the position and orientation at step k: latitude, longitude, and heading

$$\vec{x} = \begin{pmatrix} lat. \\ long. \\ \theta \end{pmatrix}$$

2. *Motion update (prediction):*
   Update the particles with pdr step
3. *Measurement update*
   Update weights and normalize
4. *Resampling:*
   Randomly replace samples with a probability determined by weights
5. Return to motion update upon new step

Mapping: BLE Beacon Positions using PDR

– PDR output



Distances in feet

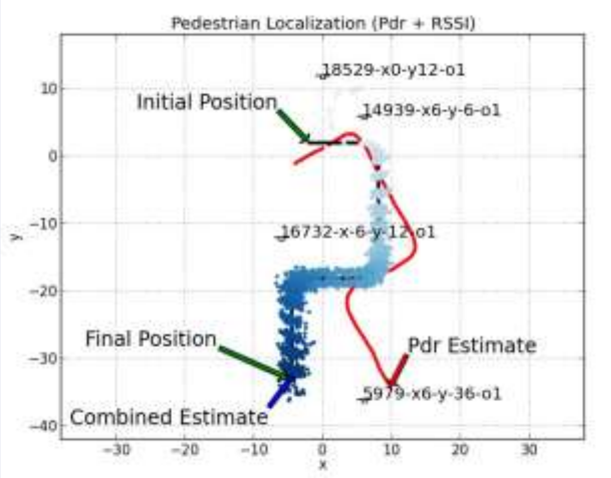
Beacon 5979:
truth: [6,-36]
estimate: [6.689, -34.063]
stddev: [0.528, 1.459]

Beacon 16732:
truth: [-6,-12]
estimate: [-6.274, -12.060]
stddev: [1.824, 0.341]

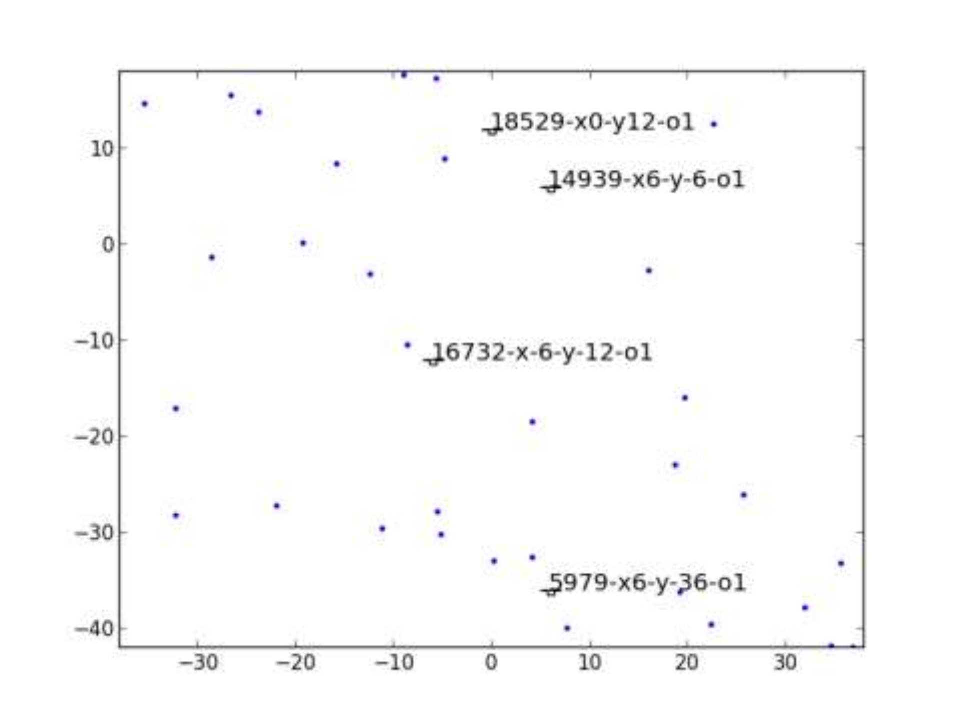
Beacon 18529:
truth: [0,12]
estimate: [2.226, 15.211]
stddev: [2.683, 1.144]

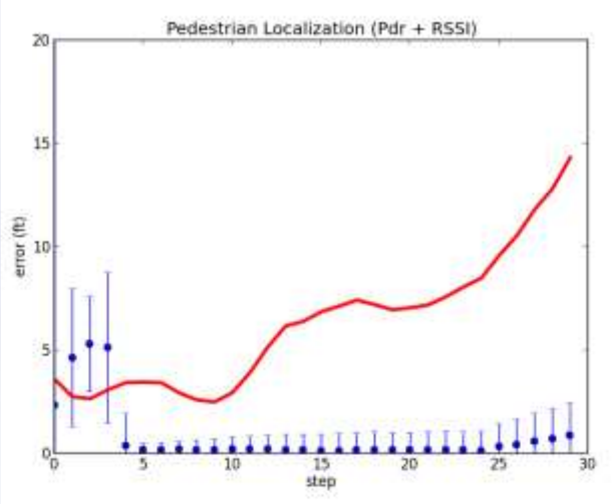
Beacon 14939:
truth: [6,-6]
estimate: [6.042, -6.115]
stddev: [1.68, 1.046]

Localization: Correcting PDR Initialization Errors using BLE RSSI



- – Truth Path
- – PDR only (w/ PDR initialization errors of -3.6 ft and 18 degrees error)
- · Particle Filter Output





Conclusions / Closing Thoughts

- Need device calibration for better than 1% position error.
- Error sources which result **in** offsets **are** most important
  - DOT offsets more important than step length offsets
- PDR heading initialization error needs to be low for indoor navigation in the earth coordinate frame
- Device to body frame transitions are key
- PDR accuracy scores must also reflect the PDR initialization errors

Conclusions / Closing Thoughts Con't

- BLE RSSI works OK inside 10 feet
- But need a local BLE properties cloud service
- A particle filter looks like a promising approach for Mapping and Hybrid Co-Localization
- PDR could be used to crowd source mapping BLE beacons
- PDR heading initialization offset error can be reduced with BLE beacons

PNI POSITIONING NAVIGATION INTELLIGENCE

PNI Sensor

2331 Circadian Way

Santa Rosa, CA 95407

www.pnicorp.com

(707) 566-2260

support@pnisensor.zendesk.com