Performance Evaluation of the NavShoe Personal Dead-Reckoning System

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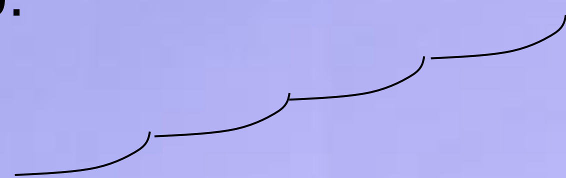
Outline

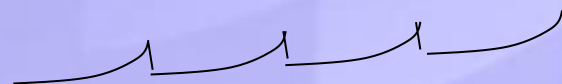
- Introduction and old results with COTS MEMS inertial sensors and magnetometers
- NavChip™ IMU performance improvements
- Improved NavShoe experimental evaluation
- Error accumulation model for unaided NavShoe
- Conclusions
- Future roadmap

NavShoe™ Concept

- Foot-mounted inertial measurement unit (IMU)
- Short-term inertial navigation measures the 6-DOF trajectory of each step – works with any kind of motion
- Break cubic error growth by resetting velocity to zero after each step:



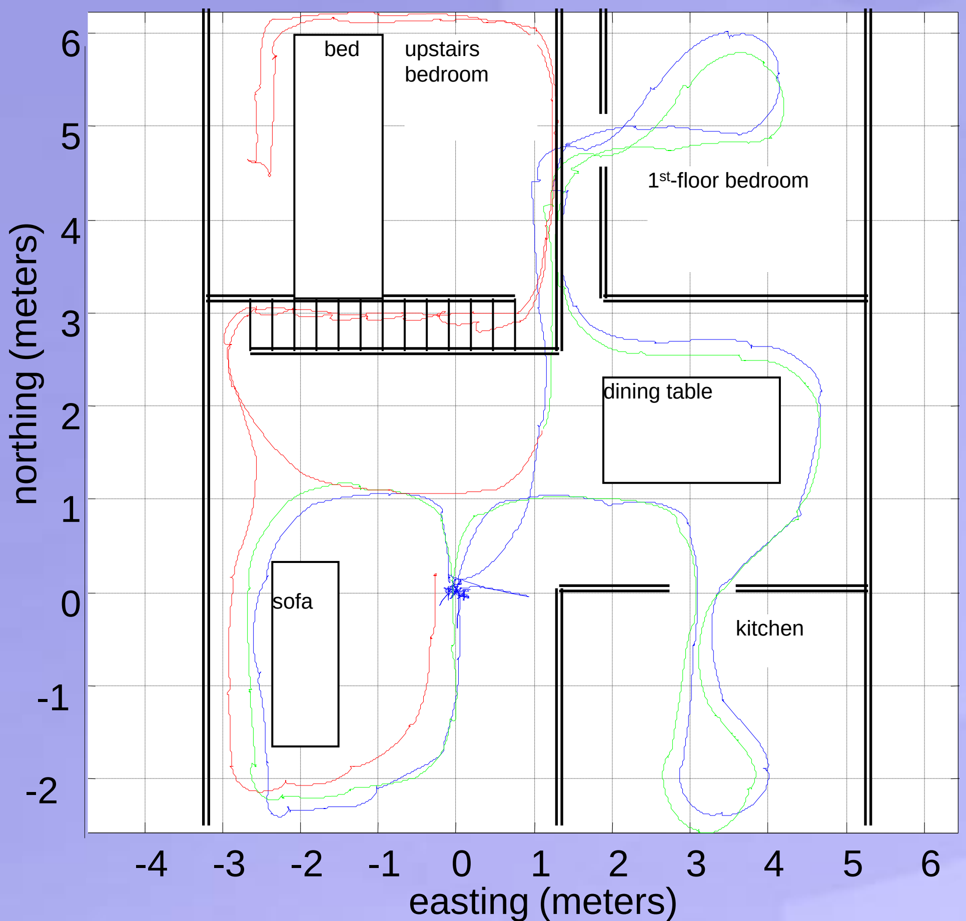
- Take advantage of correlated position/velocity errors in Kalman filter to also remove most position error with each ZVU:



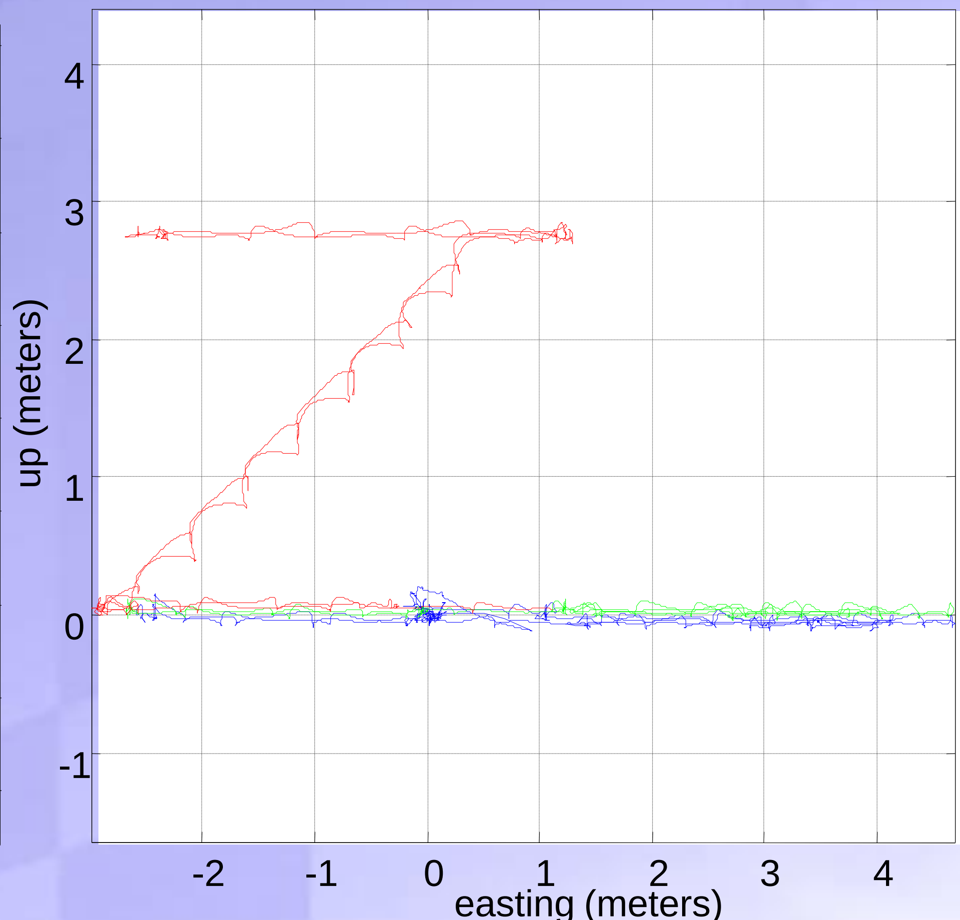
- Correct heading drift of small MEMS gyros, based on compass measurements averaged over a long distance

2005 Results

Trajectory of NavShoe during 118.5 m (322 s) exploratory path through house. Final position error was (-0.32 0.10 -0.06), about 0.3%



Plan view

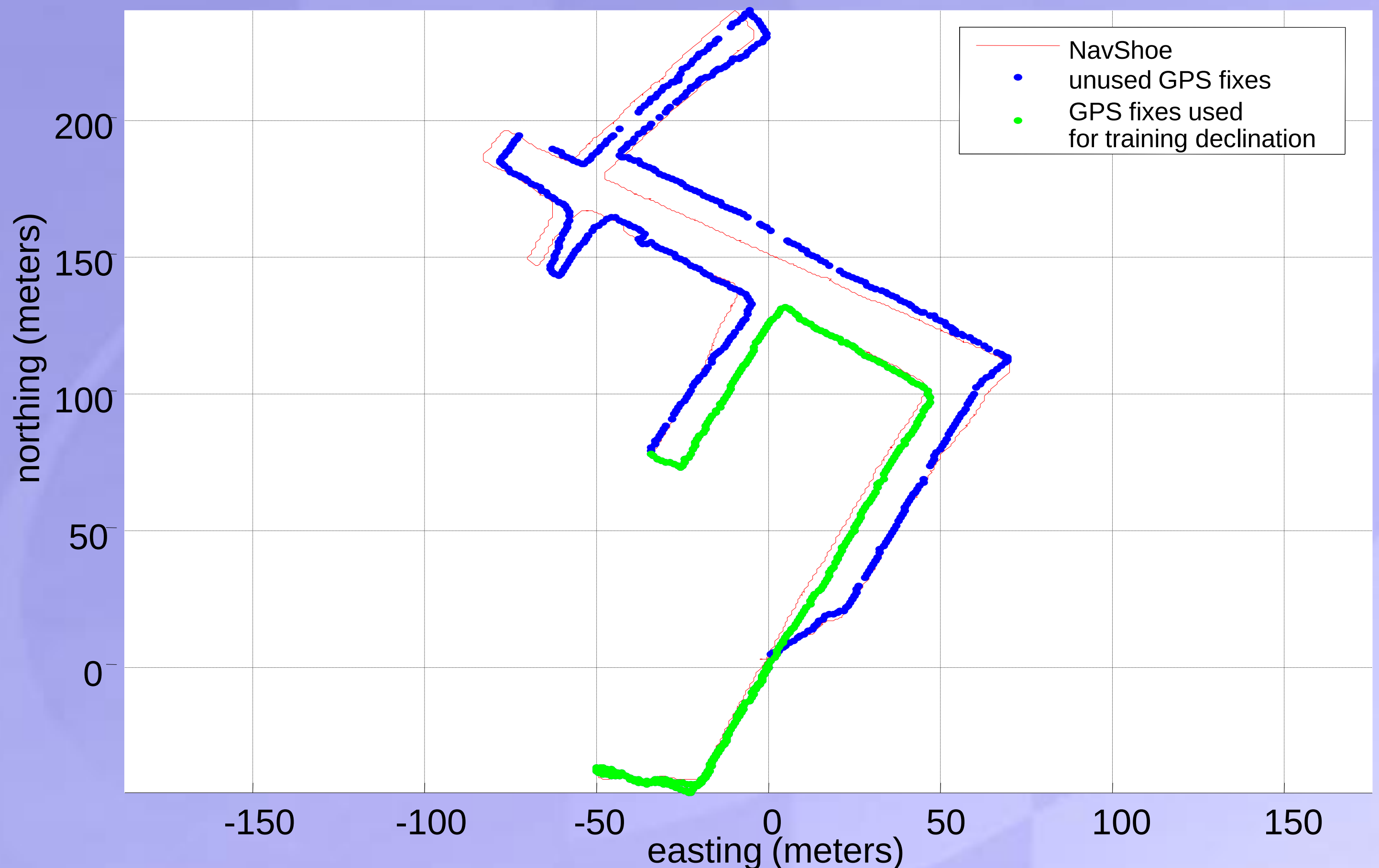


Elevation

GPS & Magnetometer Integration Algorithm

- Initial heading and declination high covariances which become highly correlated
- When GPS becomes available, we used Transfer Alignment measurements after each step to align inertial heading very precisely to true geodetic North.
- Because of the high correlation, this allows the filter to make a precise estimate of magnetic declination.
- During GPS outages, the compass is compensated with declination, and used to keep the inertial heading aligned to geodetic North.

GPS & Mag Integration (2005)



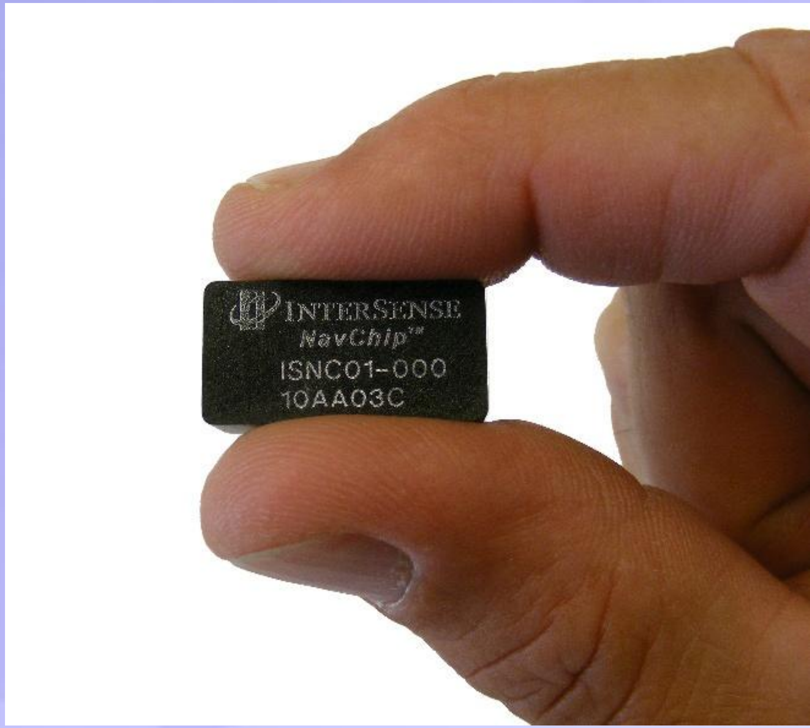
- This is the solution to initial alignment and calibration of boot IMU, automatically on the fire truck or between the truck and the building

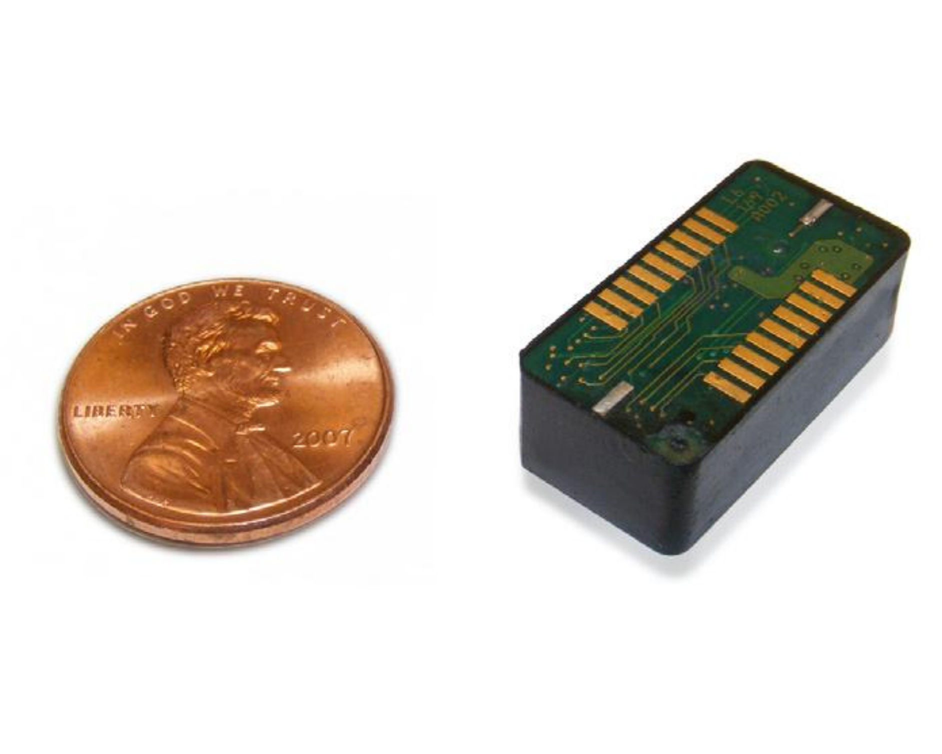
Fast Forward to 2010

- Outdoor and wood-frame house results were excellent, but heading errors were noticeable in office buildings containing lots of steel.
- Ability to reject magnetic disturbances is proportional to quality of gyros, so InterSense embarked on development of next generation MEMS IMU, “NavChip™”
- Now shipping Engineering Samples and Developer Kits

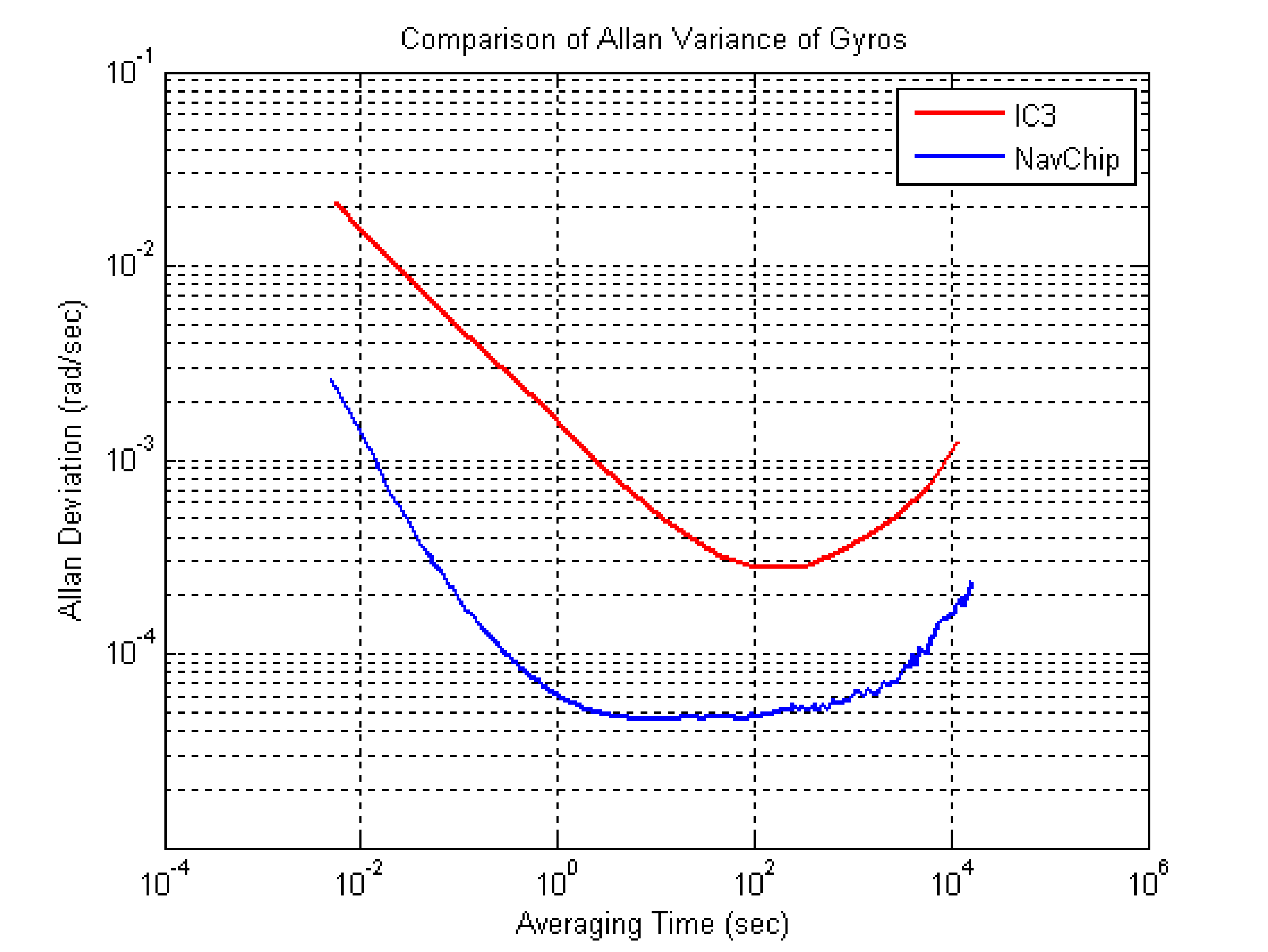
NavChip SWaP

- 12 x 24 x 8 mm
- 7 g
- 240 mW

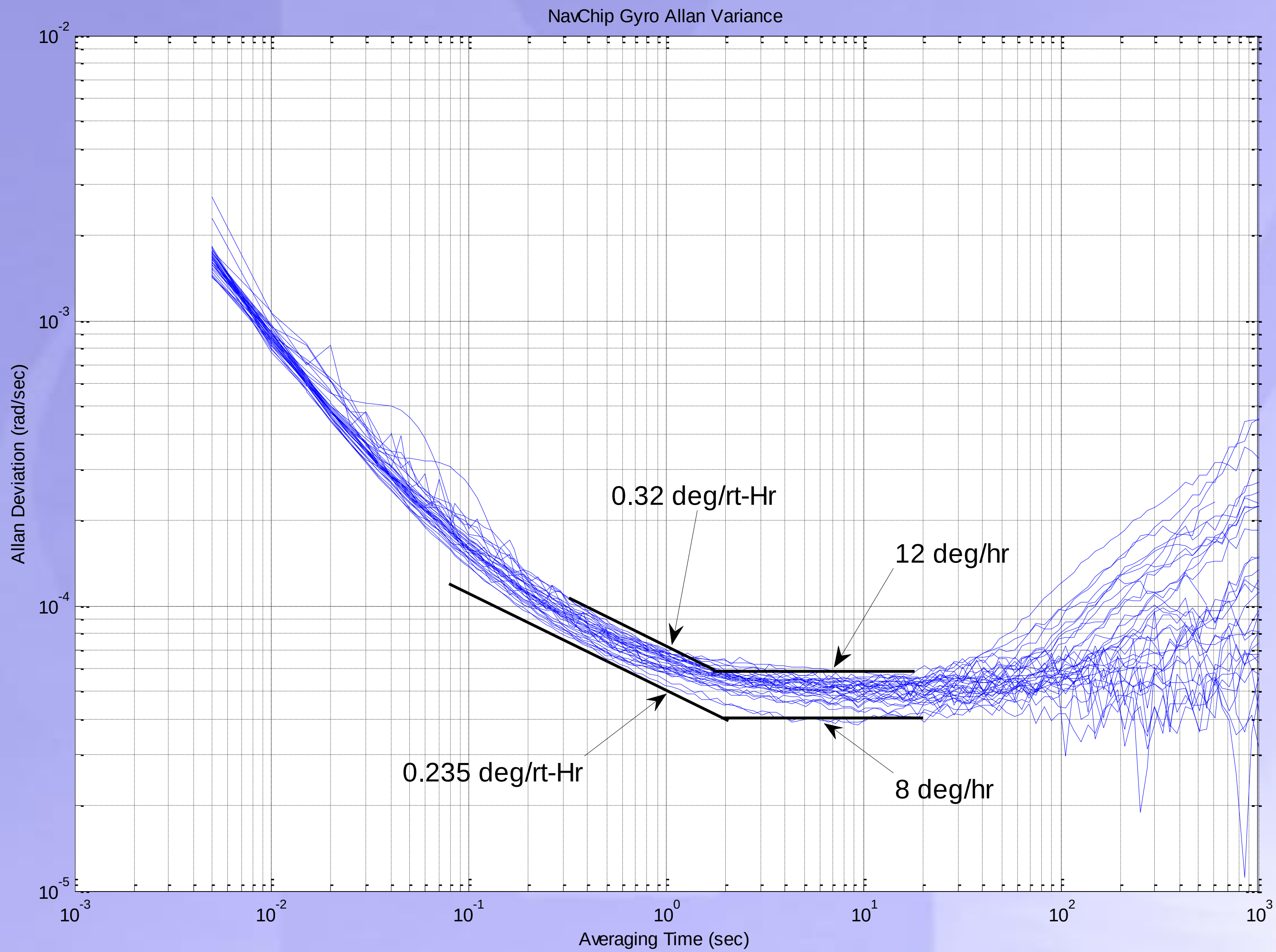




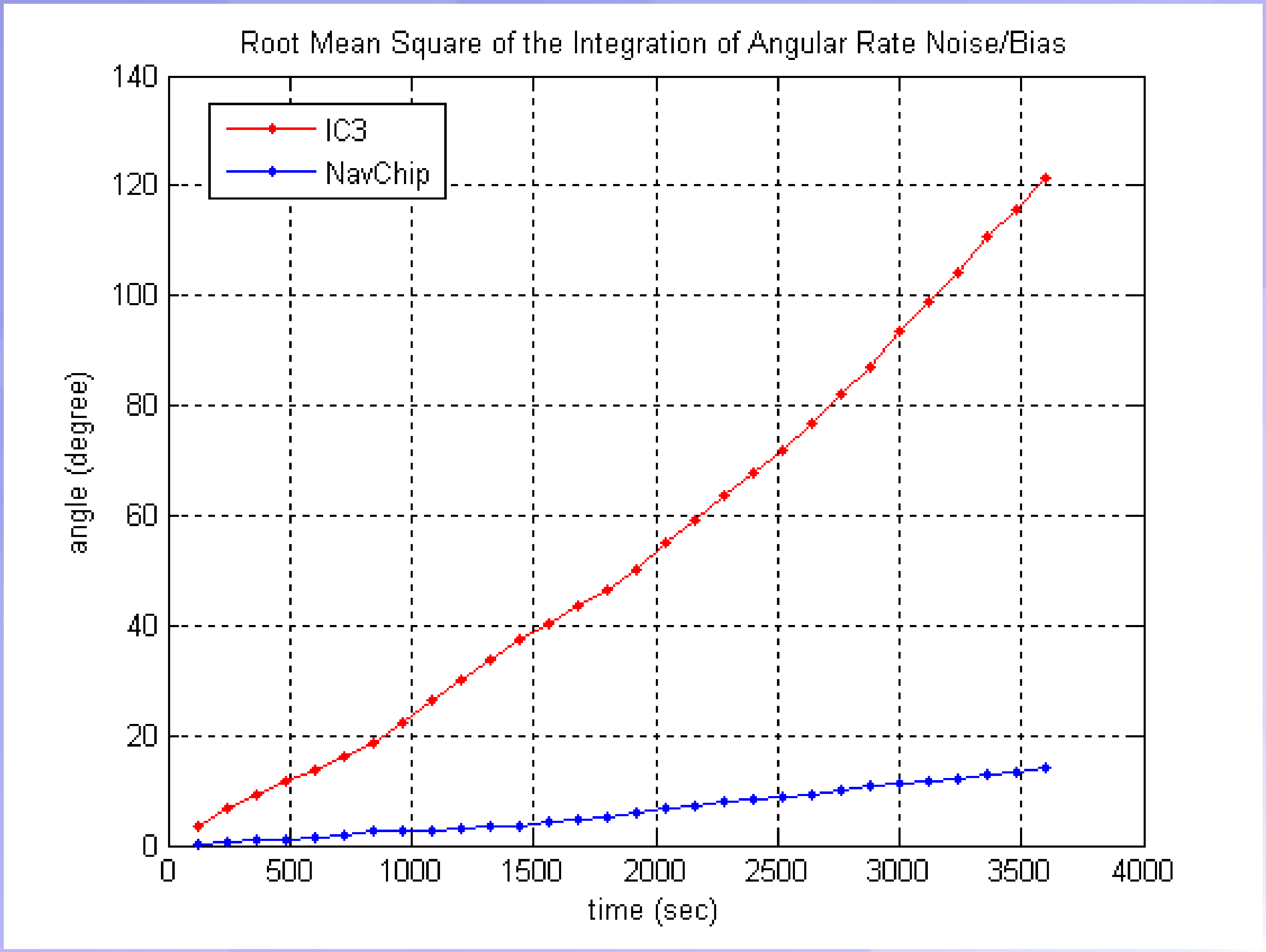
Gyro Allan Variance



Allan Variance of 33 gyros



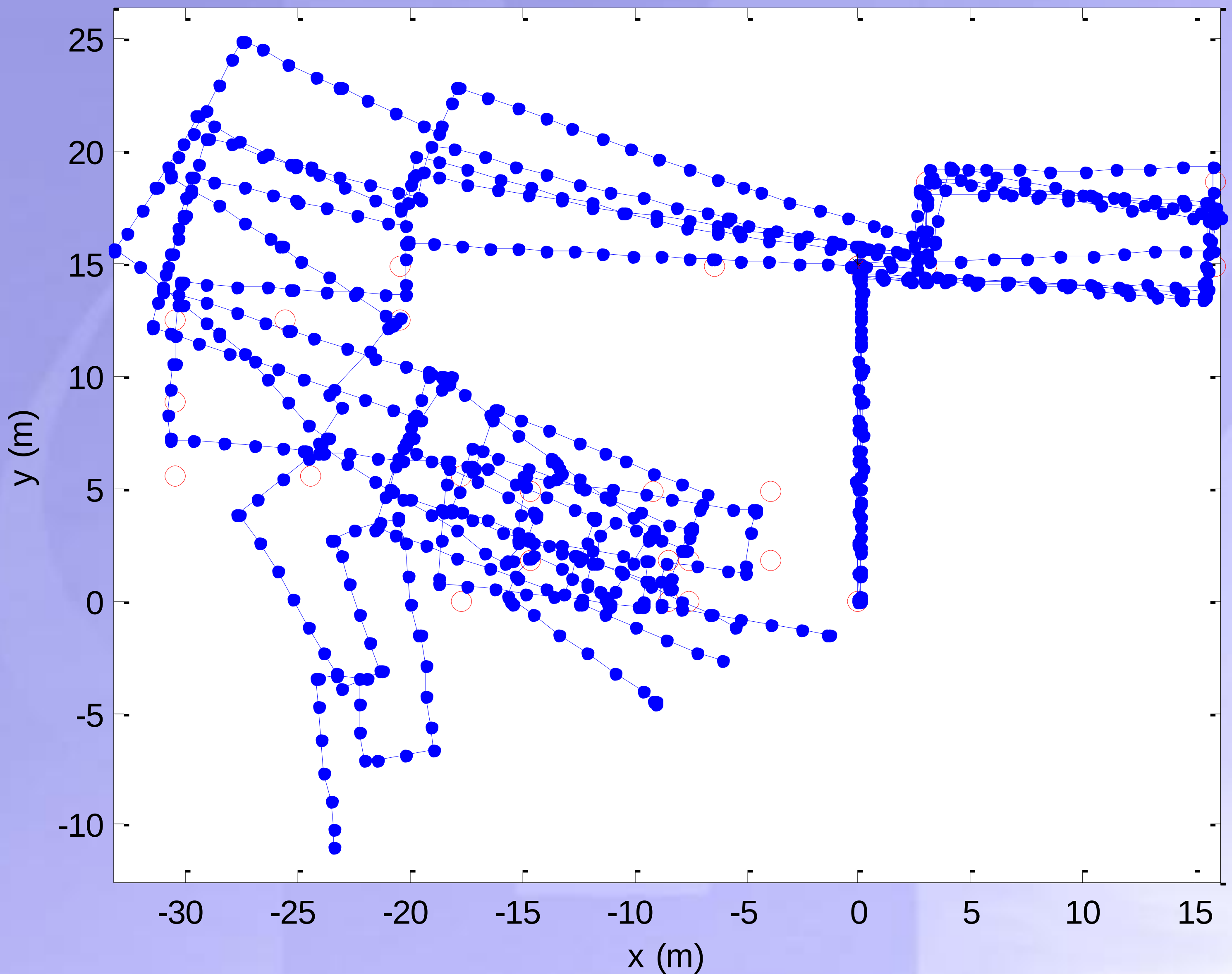
Gyro Integration Drift Comparison



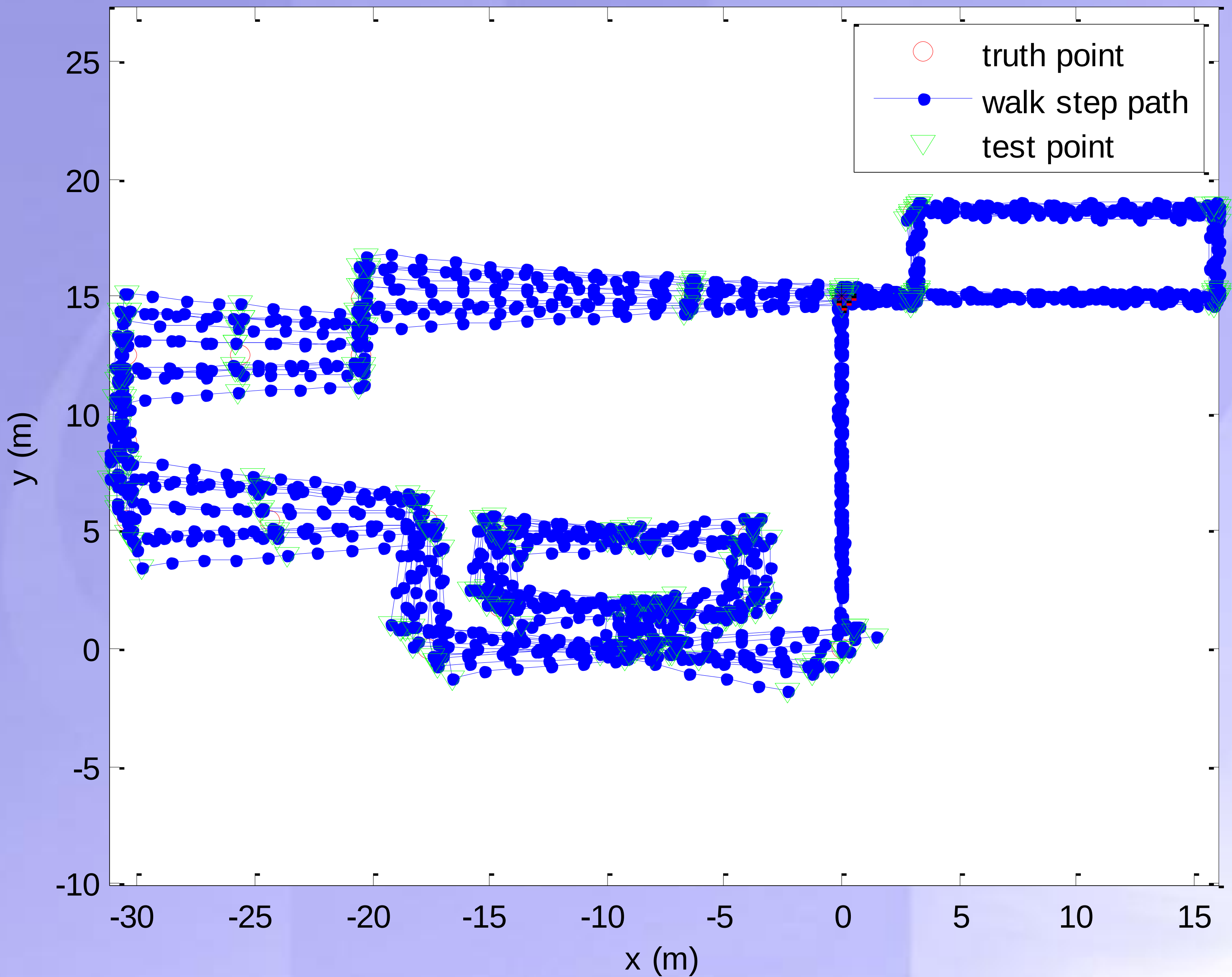
Test Procedure

- Surveyed 160m path through office with 27 measured test points along the way.
- 3 subjects, 13 trials total
- Tested two NavChip samples and two IC3 samples
- Subjects marked each test point with double heel lift
- First two test points establish initial heading

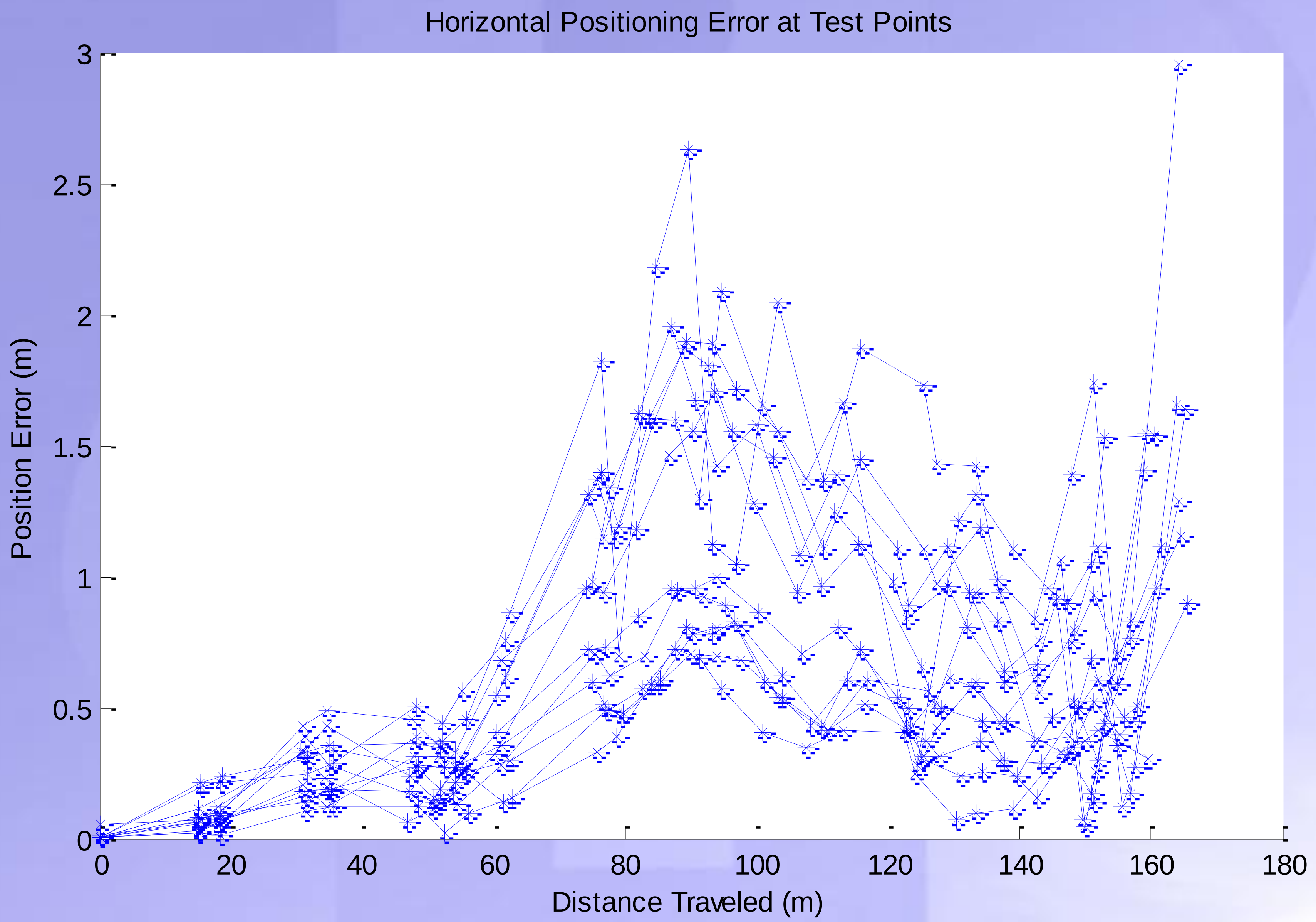
Results with InertiaCube3



Results with NavChips



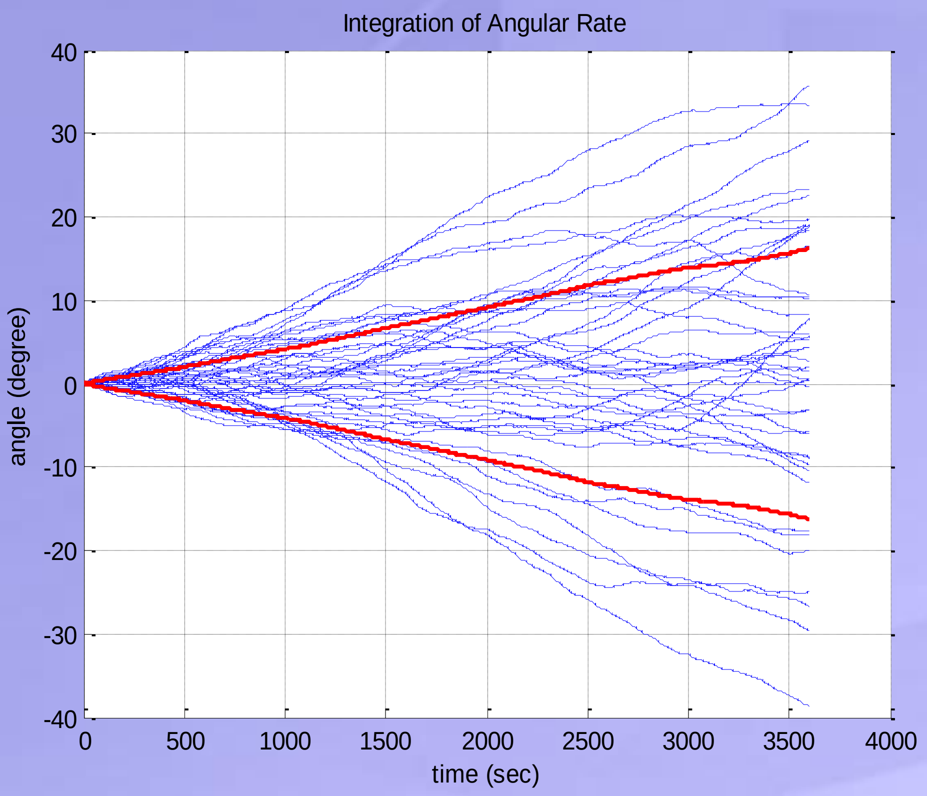
Error Distribution



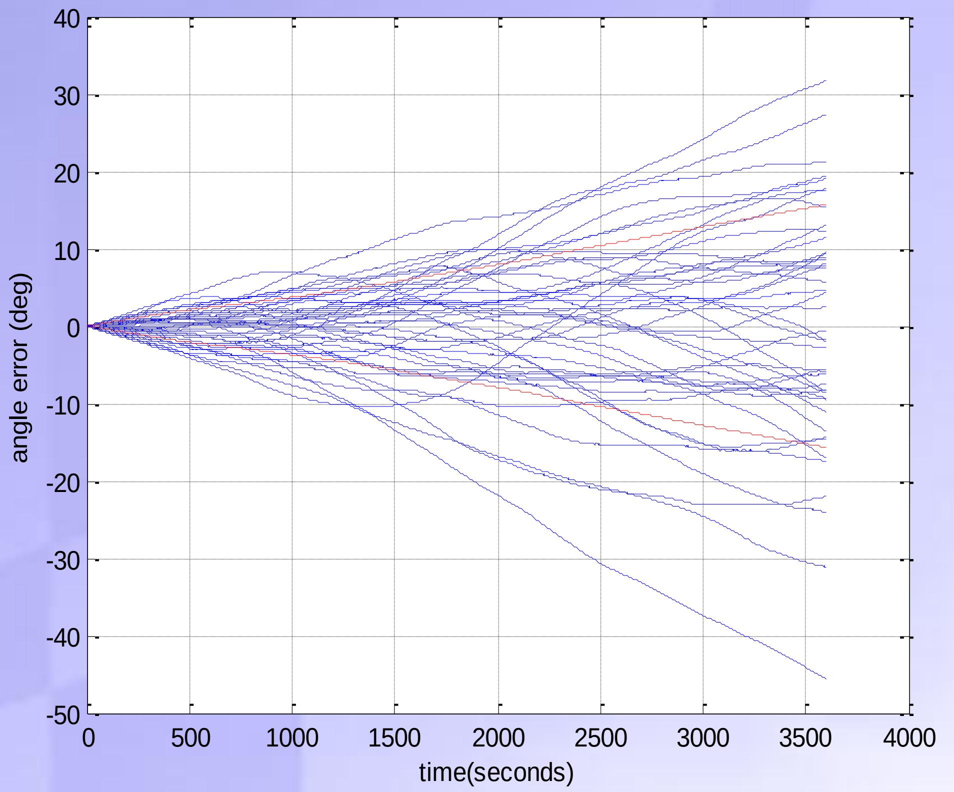
PDR Simplistic Error Model

- Assume all the position error is due to heading drift
- Assume gyro bias random walk and angle random walk a function of time (not distance)
- At each step, accumulate small additional cross-track error proportional to length of the step and current heading error.

Tune Simulation Parameters for Similar 1-hr Gyro Integrals

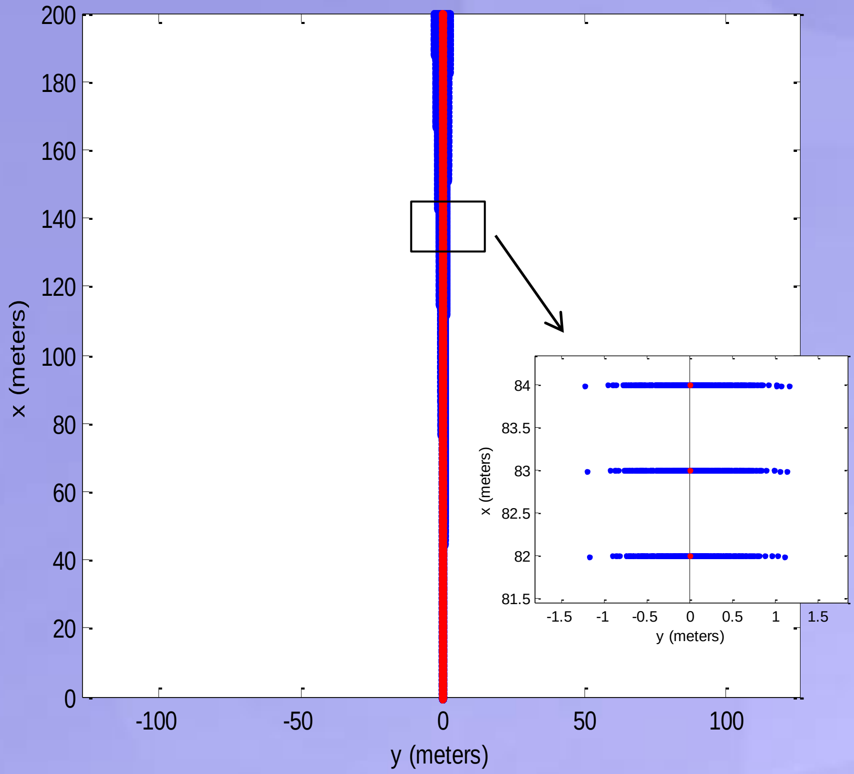


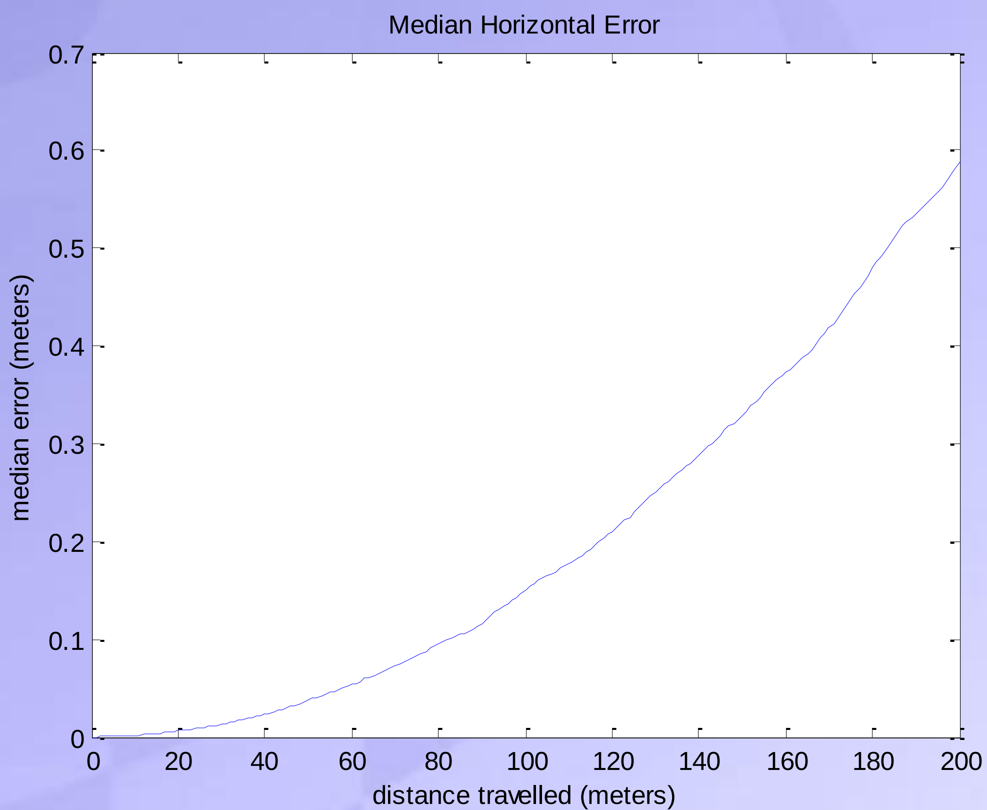
Real NavChip Data



Simulated NavChip Data

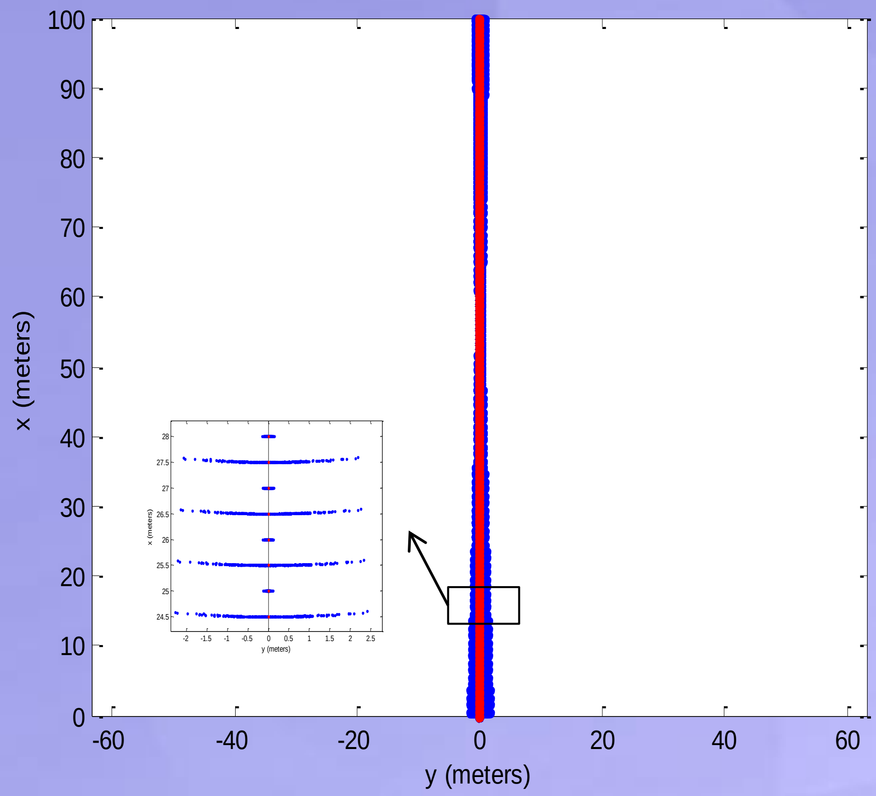
Simulated Straight Walk

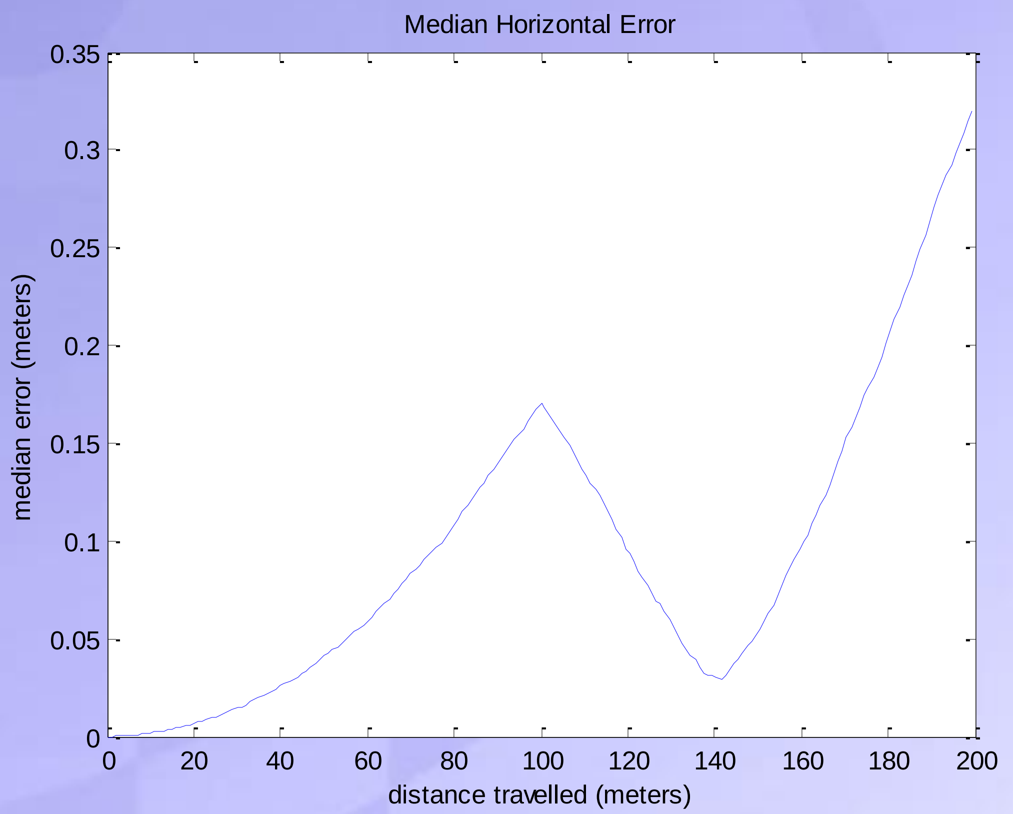




- Error proportional to distance AND time (dt^x, where in this case x=1)

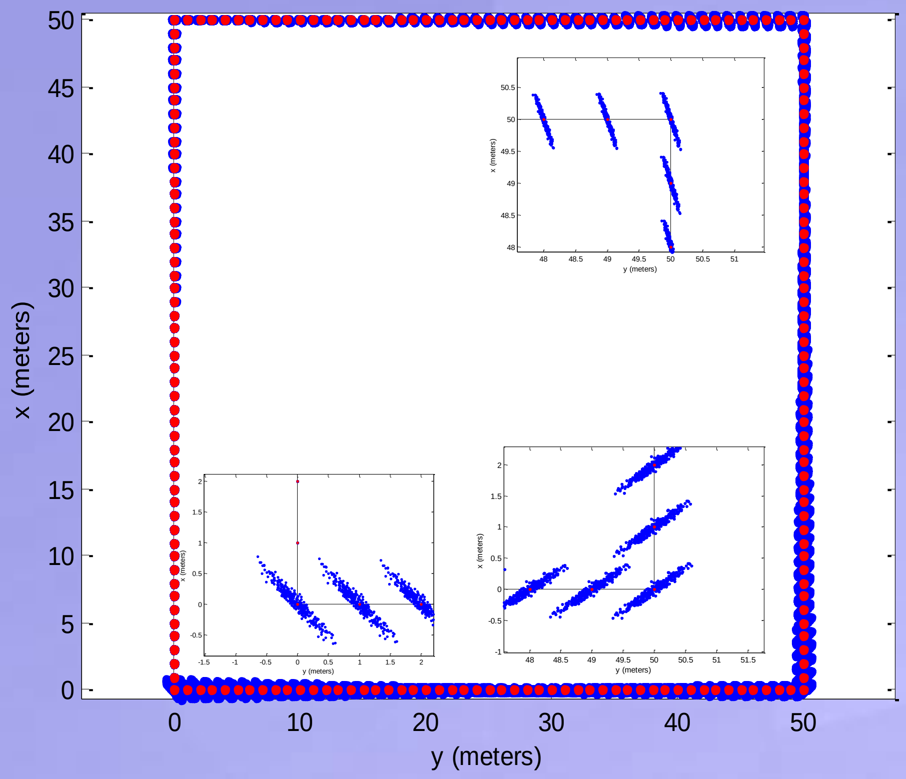
Forward and Back

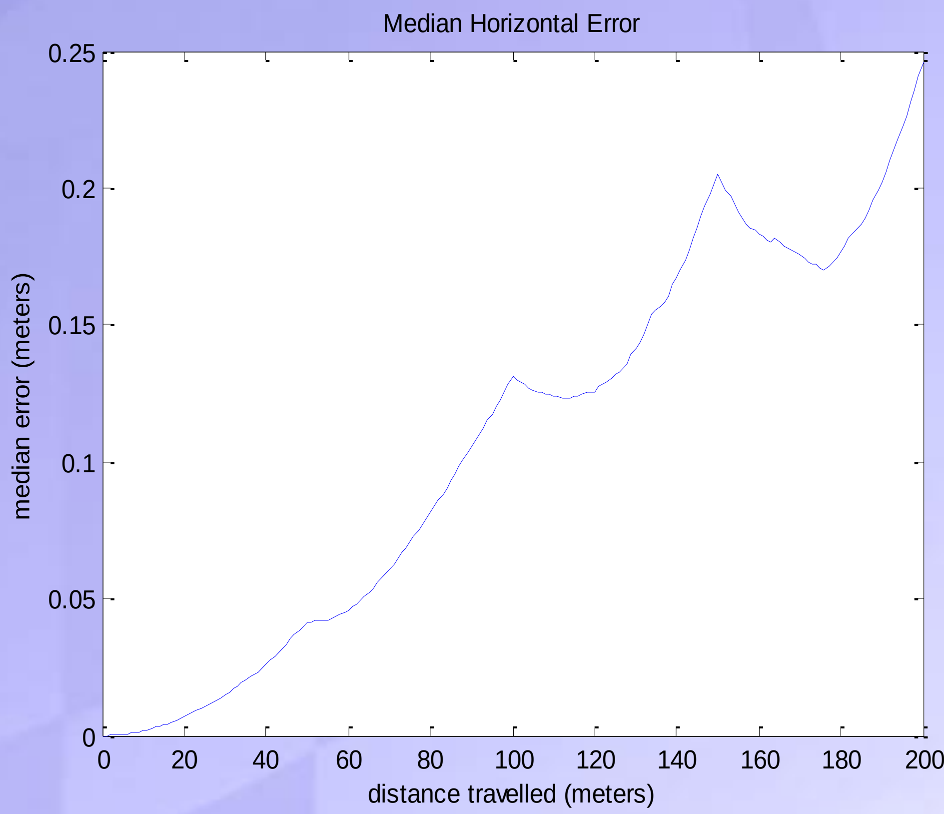




- Same total distance, half the error
- Error distribution still basically 1-D

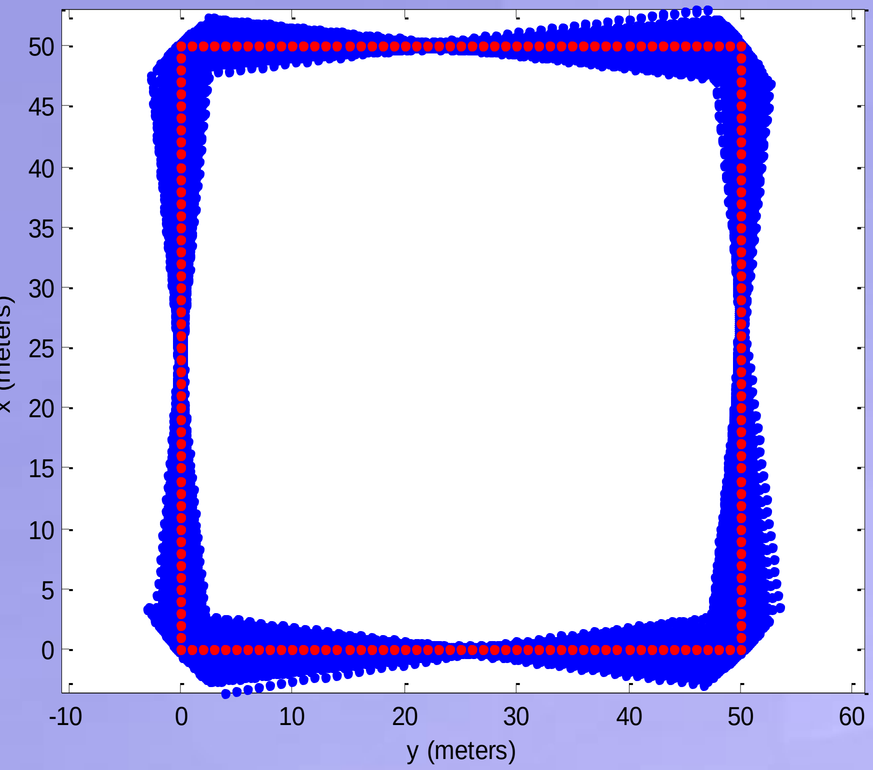
Square

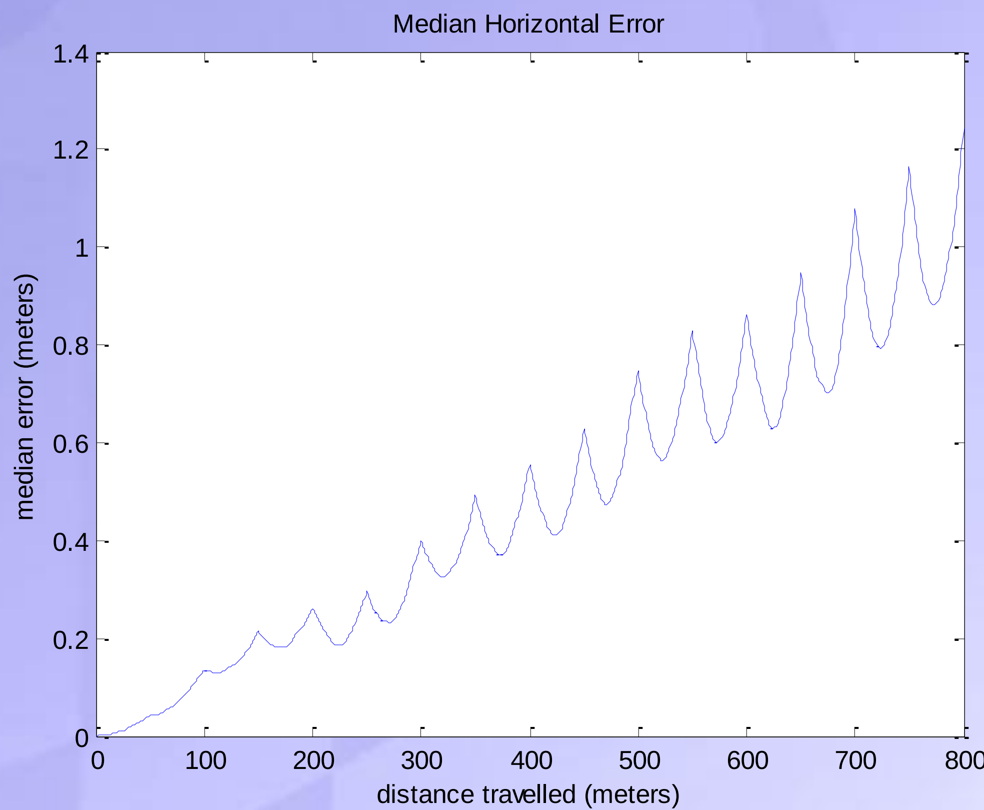




- Same distance, even less error

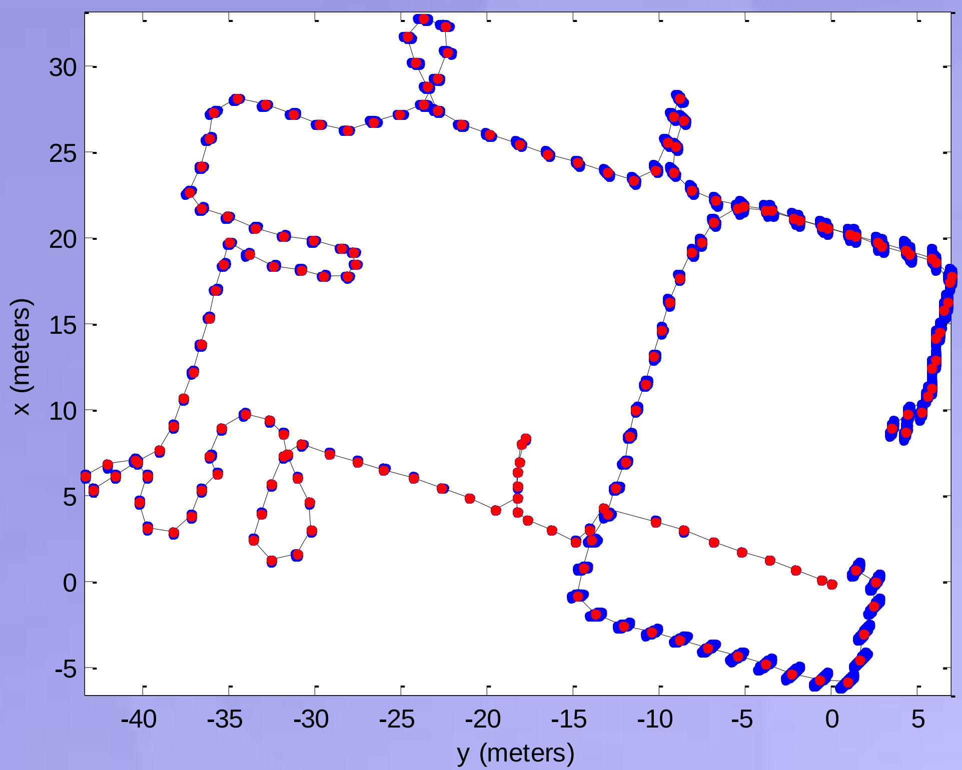
4 Repeated Laps

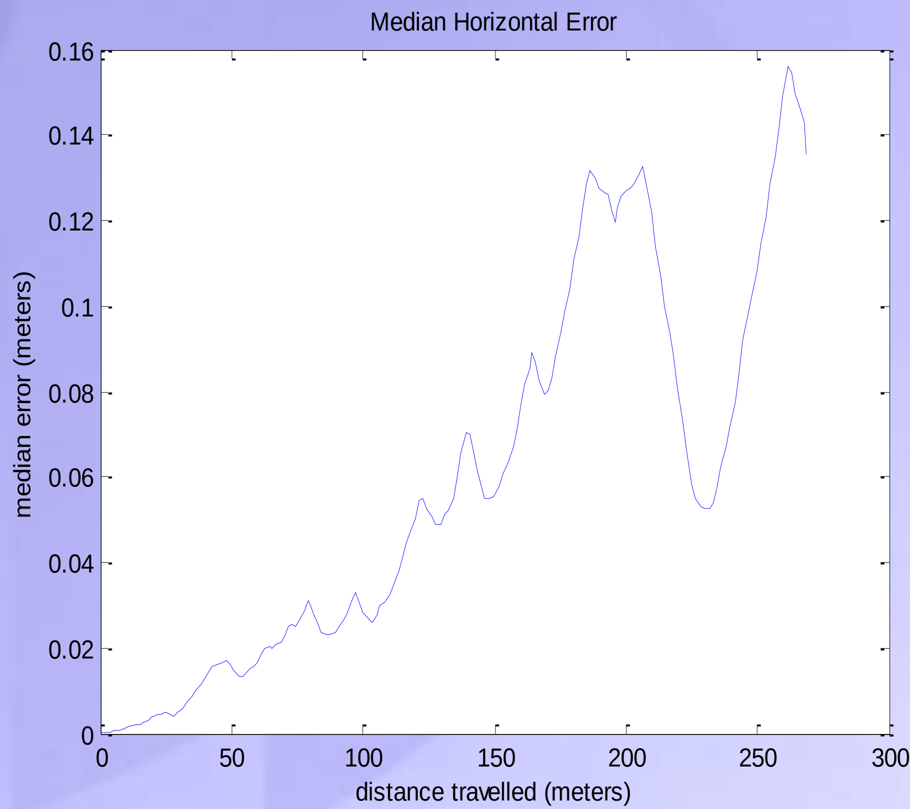




- Error growth linear instead of quadratic

“Realistic” search path



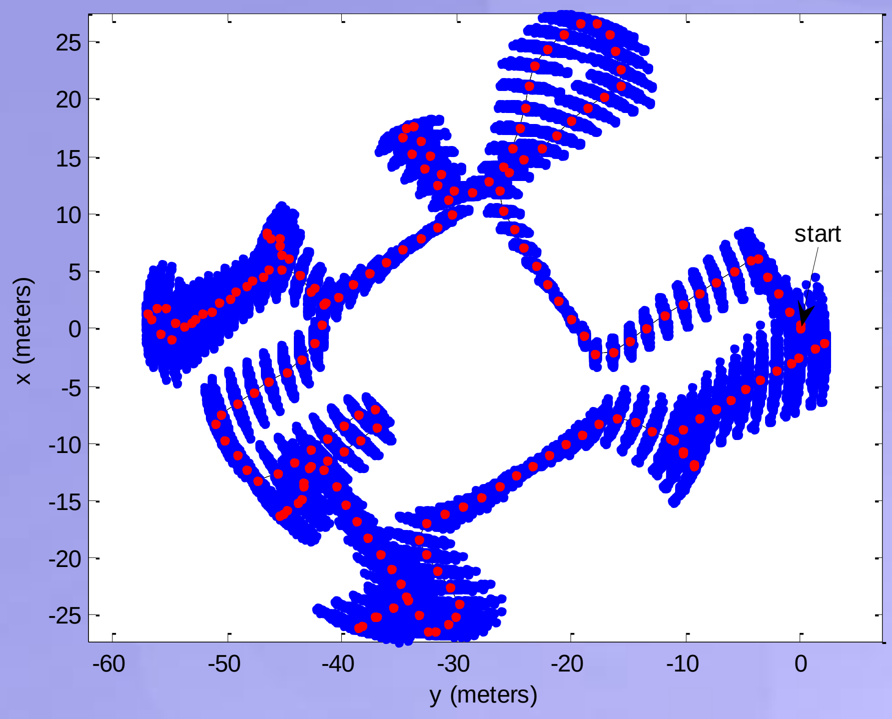


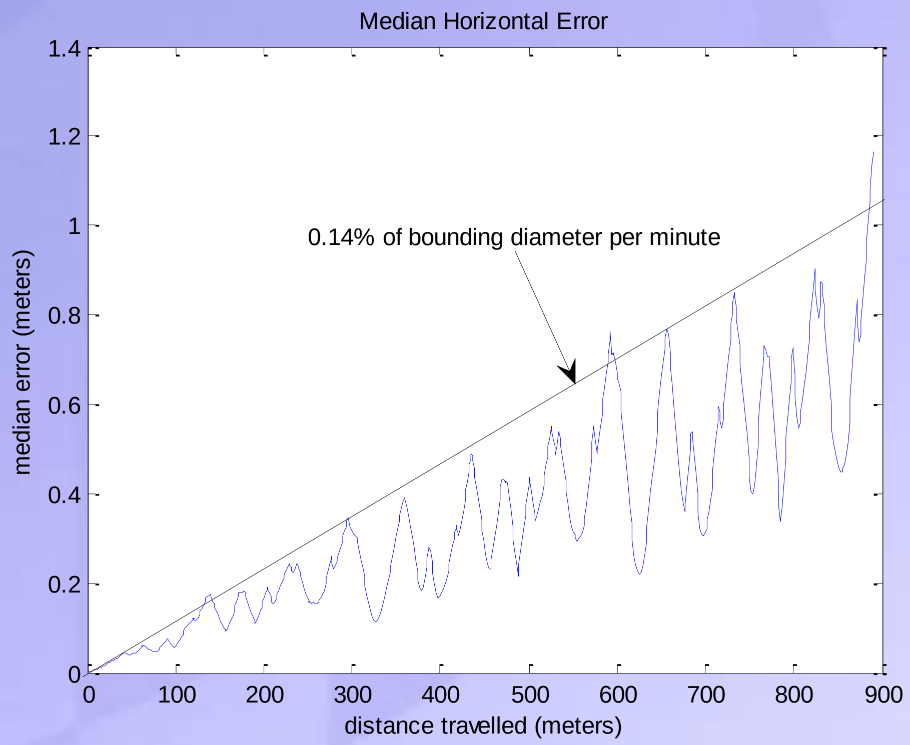
- Much lower error! Apparently circuitous path improves performance.
- Actual errors much bigger than simulation predicts. Need to find causes.

Error model rules-of-thumb

- For rectangles (including lines & squares), error is quadratic in distance
- However, 272 m complex path has less error than 200 m square.
- Trend of peak errors (which occur at outer corners of path) is proportional to time and diameter of bounding circle
- **NavChip: "0.14% of bounding diameter per minute"**

Longer example





- 300 m loop X 3 laps over 12.5 minutes, compared to rule-of-thumb prediction

Generalized rule for gyro dead-reckoning systems

- Error ~ Dt^x
- D is diameter, not distance
- x=1 for gyros dominated by flicker noise (like NavChip)
- X = 1/2 for gyros with only white noise (non-existant)
- X = 3/2 for gyros with bias random walk (most gyros exhibit this after a few minutes)

Conclusions (1)

- Error not percentage of distance travelled
- Depends also on time (if using open-loop heading gyro), and strongly on path shape
- Specifying positioning accuracy of PDR products is going to be nearly impossible!
- Fortunately, the only component significantly effecting accuracy is gyro, for which there are well-developed characterization methods

Conclusions (2)

- NavChip brings a significant (~6X) improvement in accuracy, while simultaneously lowering SWaP and cost.
- It will still need occasional aiding for most applications, but integration of aiding sensors gets a lot easier and more robust with a fairly reliable dead-reckoning sensor.

1.7 km Indoor/Outdoor/Indoor Walk With Gentle Mag Aiding

Future Roadmap

- NavShoe Developer Kit (for evaluation and system integration) – late 2010
- NavChip ISNC02 with built-in mags and built-in navigation algorithms, including NavShoe ZUPTing Kalman filter
- Continue to develop multi-sensor fusion platform (inertial, sparse ranging, GPS, heuristic algorithms, etc)
- Partner with integrators to bring personnel navigation solutions to various markets