Practical Position and Yaw Rate Estimation with GPS and Differential Wheelspeeds

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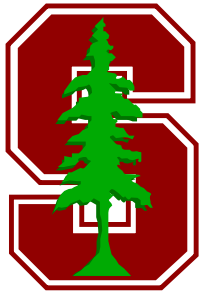
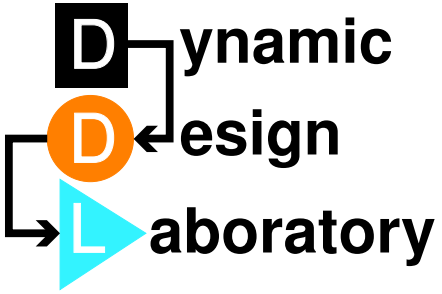
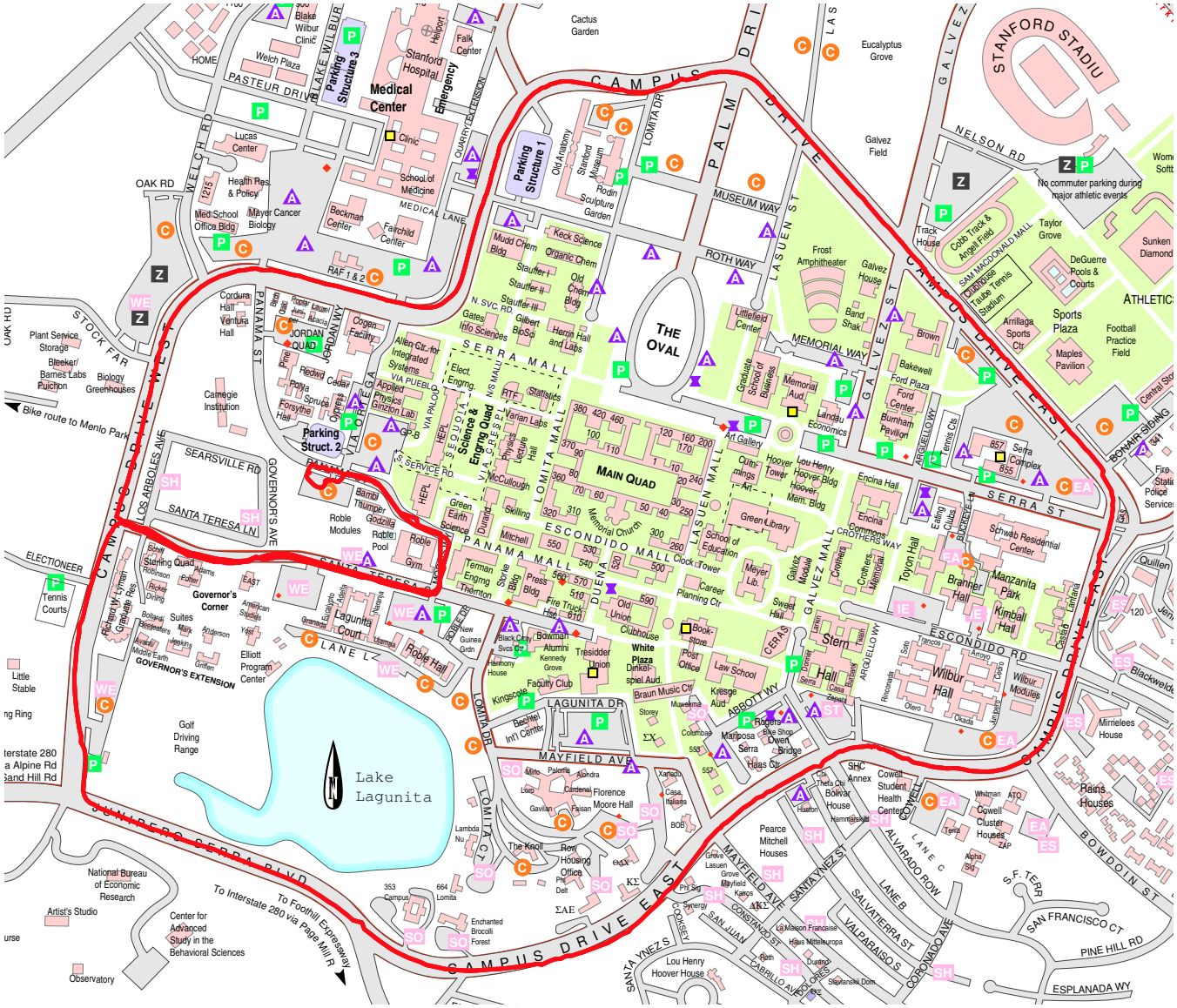
September 12, 2002





Goal: Robust Land Navigation



Motivation

- GPS signal frequently interrupted during urban driving
- Can not add an expensive INS system

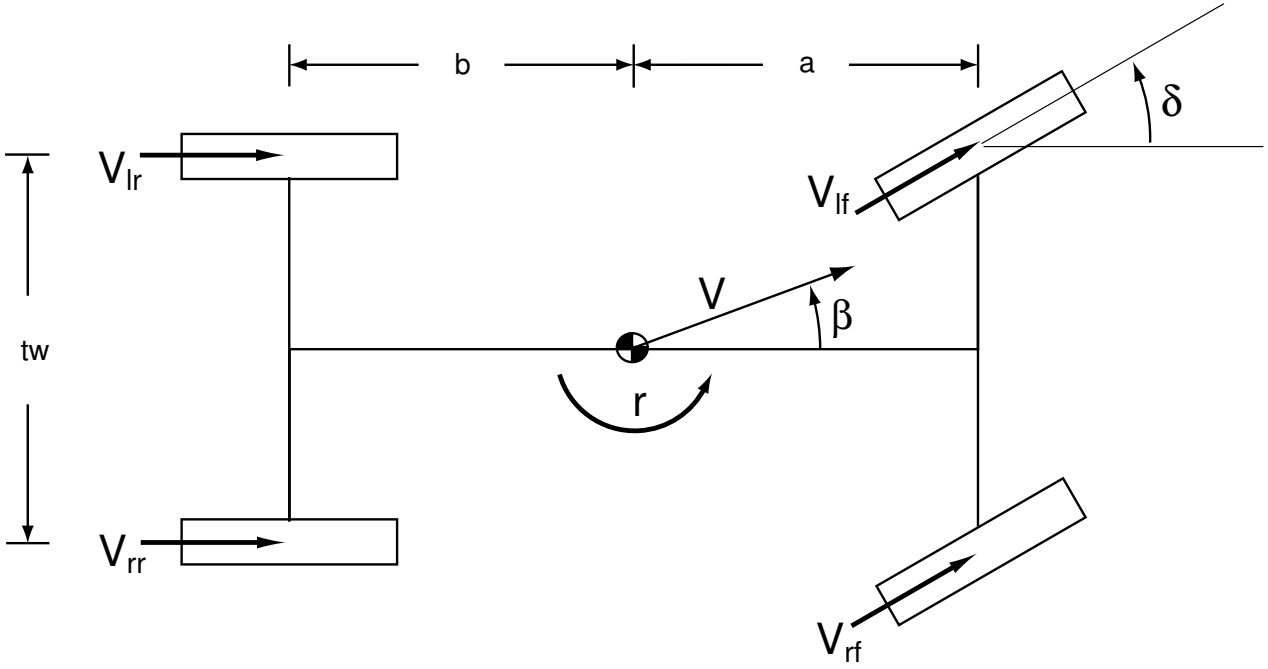
Detailed Questions

- It it possible to use ABS sensors to estimate vehicle heading?
- Does the (low?) ABS sensor resolution limit navigation accuracy?
- How sensitive is the position estimate to wheel radius?
- Will vehicle sideslip be an important factor?
- It it possible to use ABS sensors to eliminate the gyro?

Outline

- Vehicle Model
- Sensors
- Two Different Estimators
- Results
- Conclusions
- Future Work

Kinematic Vehicle Model



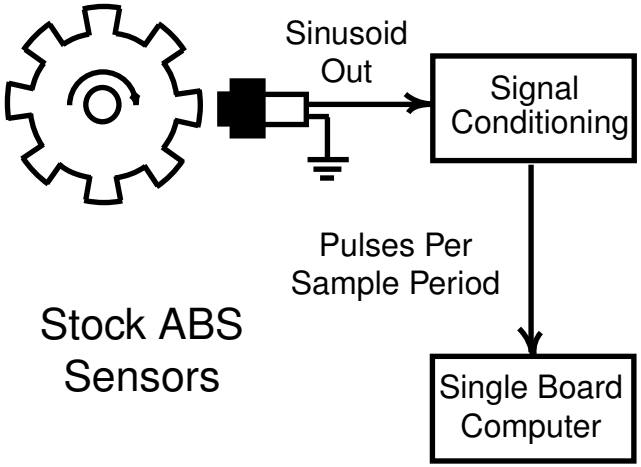
$$r = \frac{V_{rr} - V_{lr}}{tw_r} \qquad V = R\ \Omega$$

$$r = \frac{V_{rf} - V_{lf}}{tw_f \cos(\delta)}$$

Sensors

Bosch MEMS Gyroscope

Novatel GPS Receiver



Estimator Structure I, Gyroless

States

Measurements

$$\begin{bmatrix} \dot{E} \\ \dot{N} \\ \dot{\psi} \\ R^r \\ R^l \end{bmatrix} = \begin{bmatrix} -V\sin(\psi) \\ V\cos(\psi) \\ \hat{r} \\ 0 \\ 0 \end{bmatrix} \text{ and } \begin{bmatrix} GPS_E \\ GPS_N \\ GPS_\psi \\ GPS_V \end{bmatrix} = \begin{bmatrix} E \\ N \\ \psi \\ V^r/2 + V^l/2 \end{bmatrix}$$

$$\hat{r} = \frac{\hat{\Omega}^r R^r - \hat{\Omega}^l R^l}{tw_r}$$

GPS Velocity Unbiased

Wheel Radii

$$\text{Heading Error} \cong \int_0^t \frac{\Omega_{ws}(\delta R^r - \delta R^l)}{tw}\, d\tau$$

1 [mm] differential radius error $\Rightarrow$ 6[rad] error in 5 minutes travelling at 10[m/s]

Wheel radii estimates critical for accurate dead-reckoning

Estimator Structure II, With Gyro

States

$$\begin{bmatrix} \dot{E} \\ \dot{N} \\ \dot{\psi} \\ R^r \\ R^l \\ 1/a \\ b/a \end{bmatrix} = \begin{bmatrix} -V\sin(\psi) \\ V\cos(\psi) \\ \frac{1}{a}\hat{r} - \frac{b}{a} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Measurements

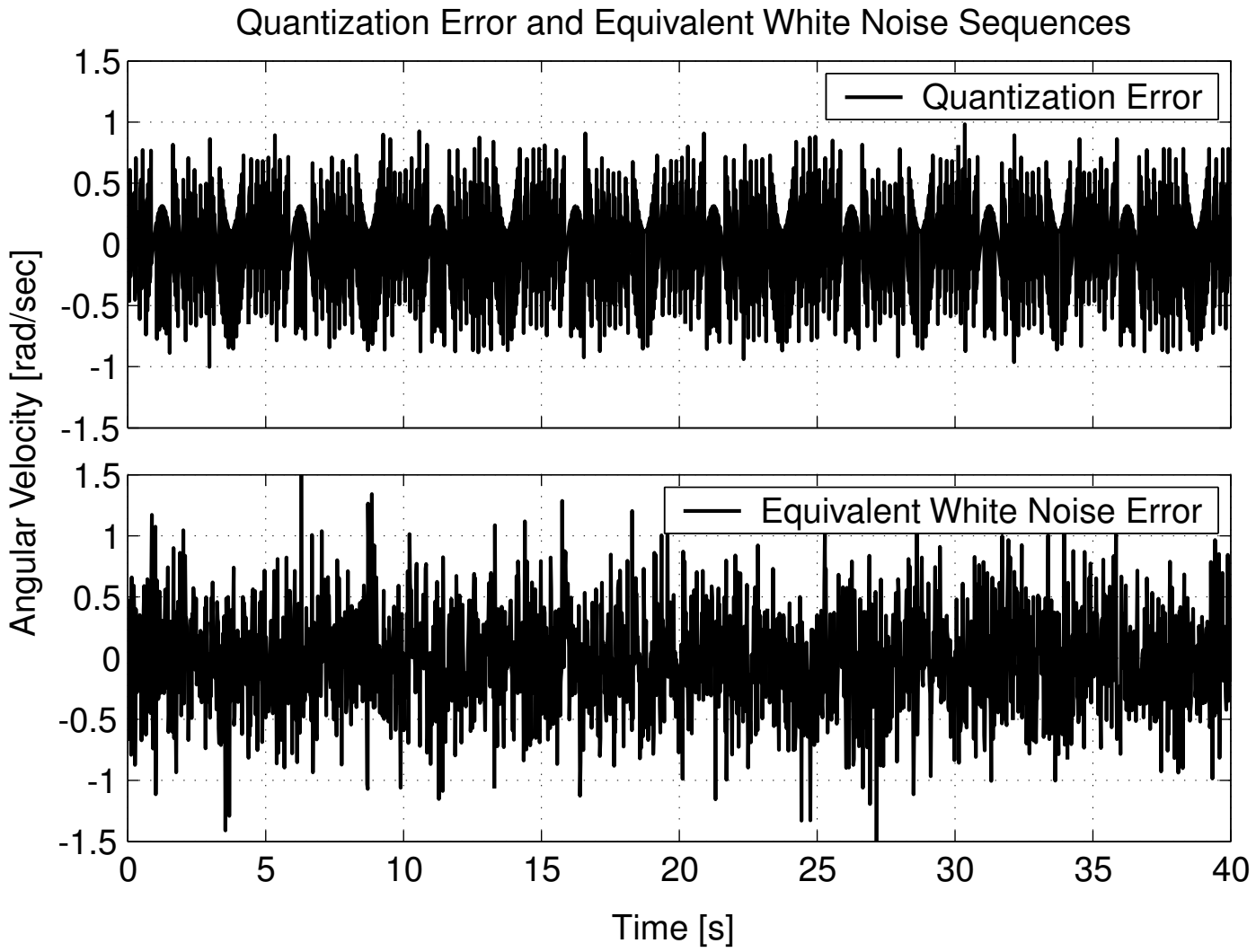
and

$$\begin{bmatrix} GPS_E \\ GPS_N \\ GPS_\psi \\ GPS_V \\ r \end{bmatrix} = \begin{bmatrix} E \\ N \\ \psi \\ V^r/2 + V^l/2 \\ V^r/tw_r - V^l/tw_r \end{bmatrix}$$

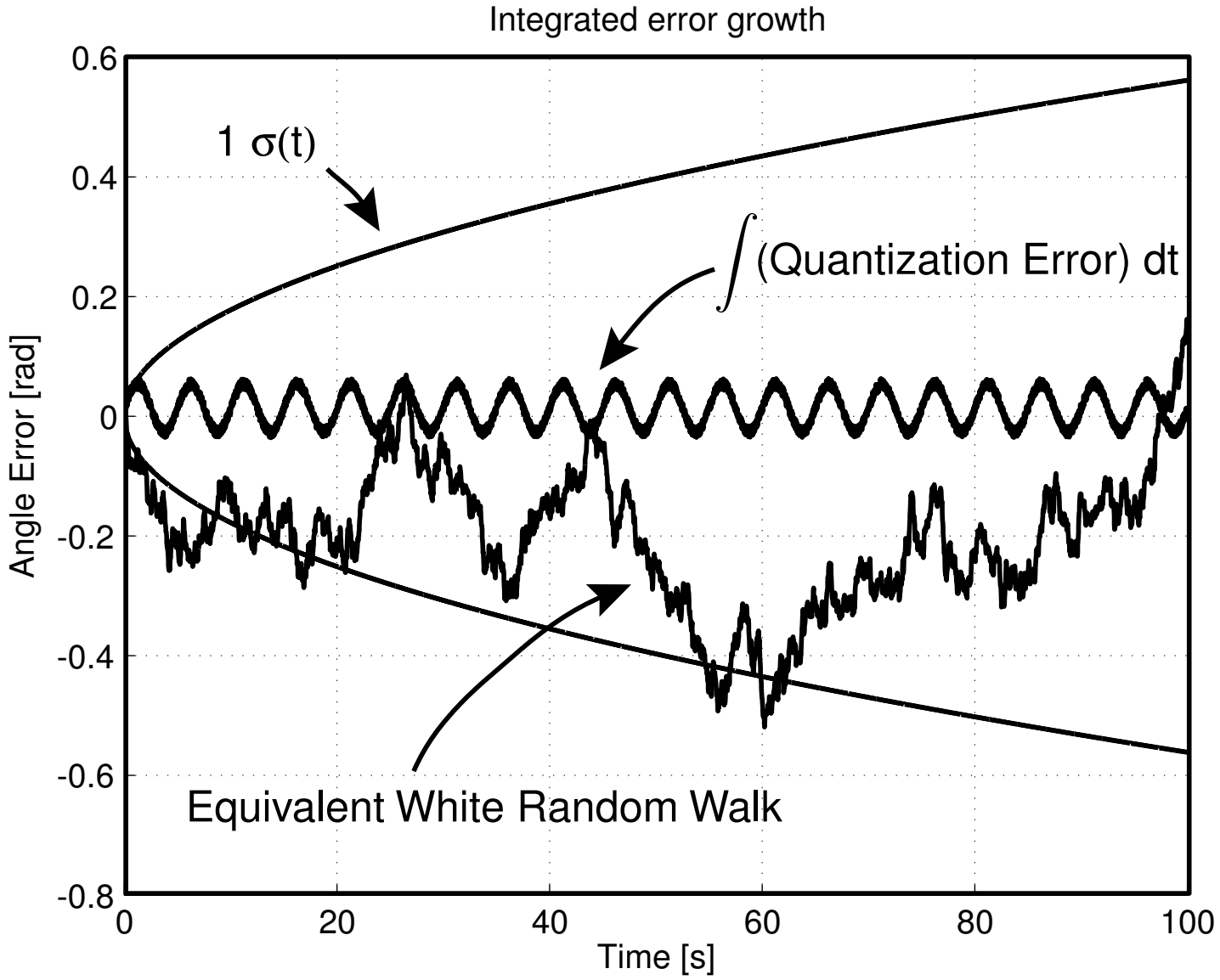
$$\hat{r} = ar + b$$

Quantization Noise Simulation

Encoder velocity errors look white

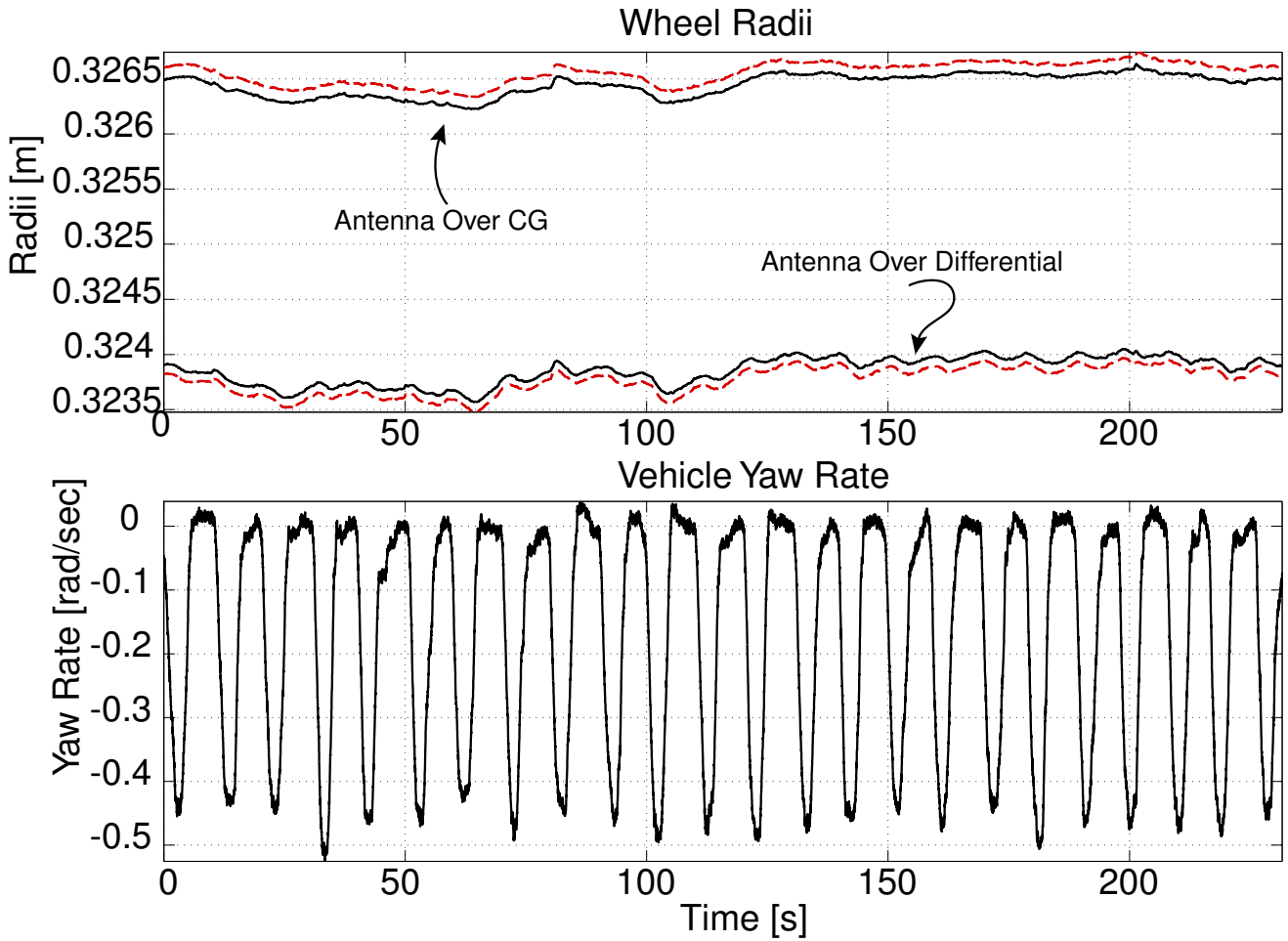


Estimator Structure: Integrate Noises

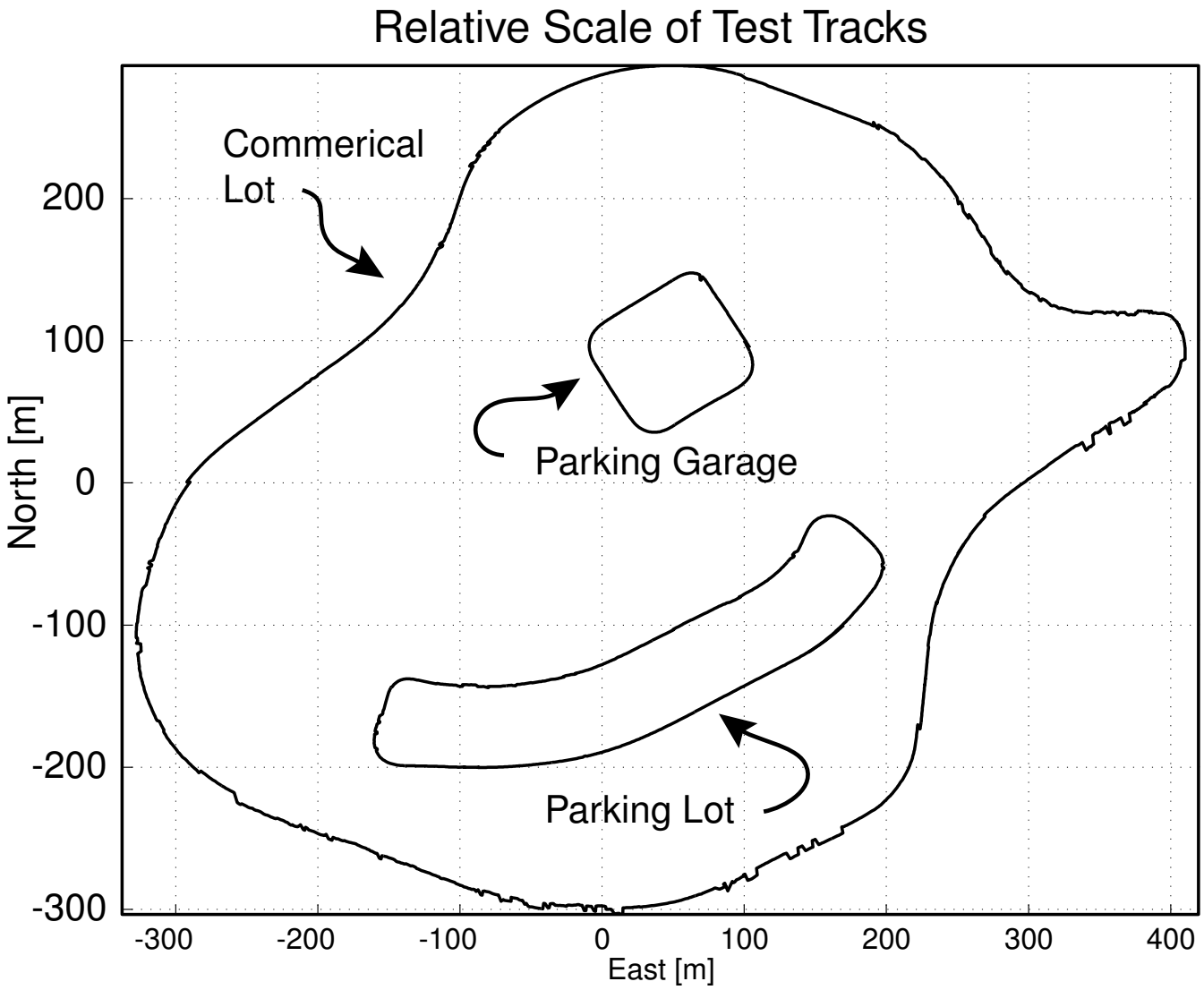


Antenna Placement

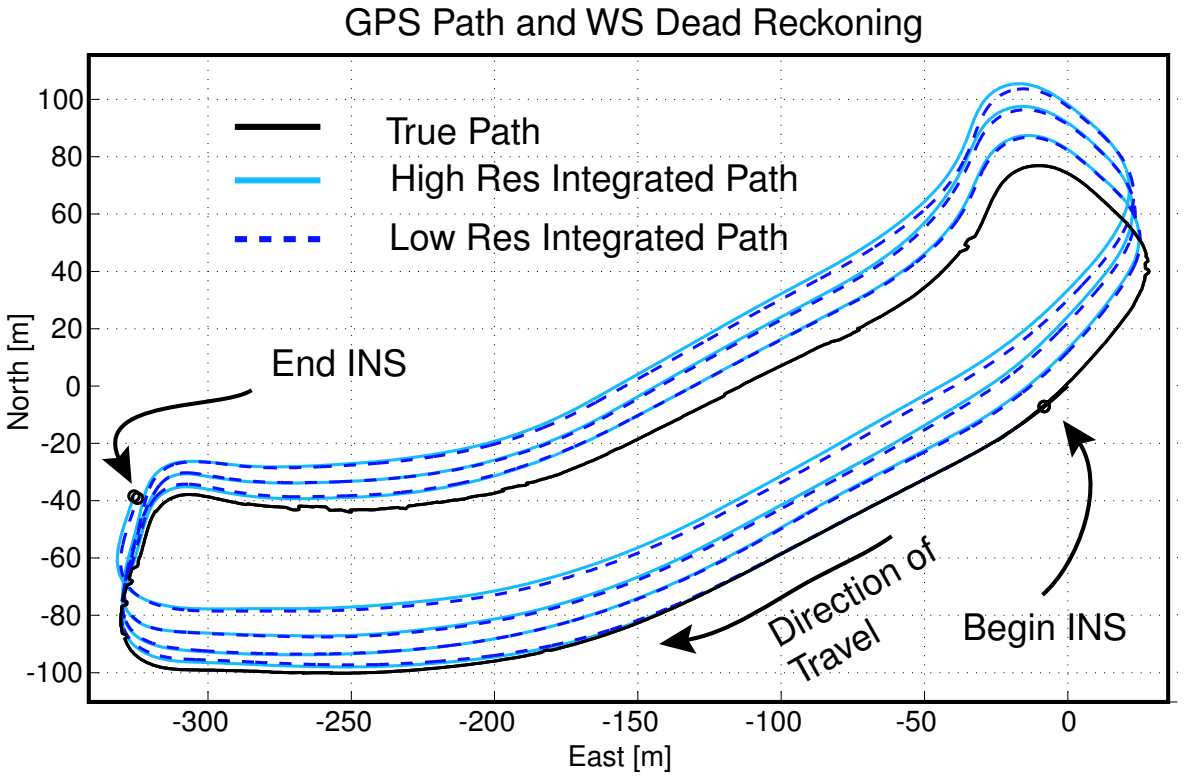
Cancel out yaw dependent velocity components by placing antenna over rear differential

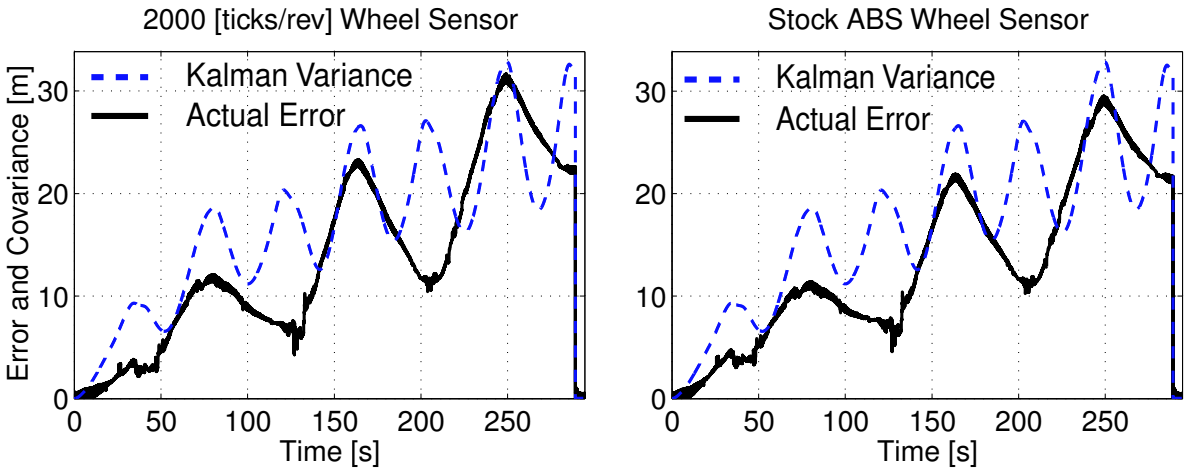


Results: Test Tracks



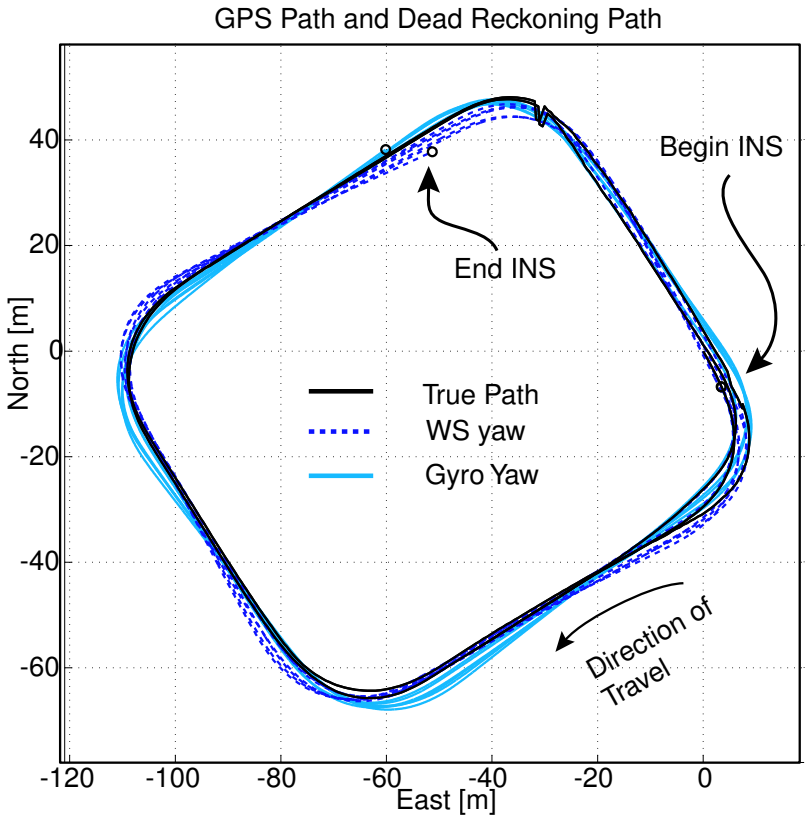
Results: Encoder Resolution

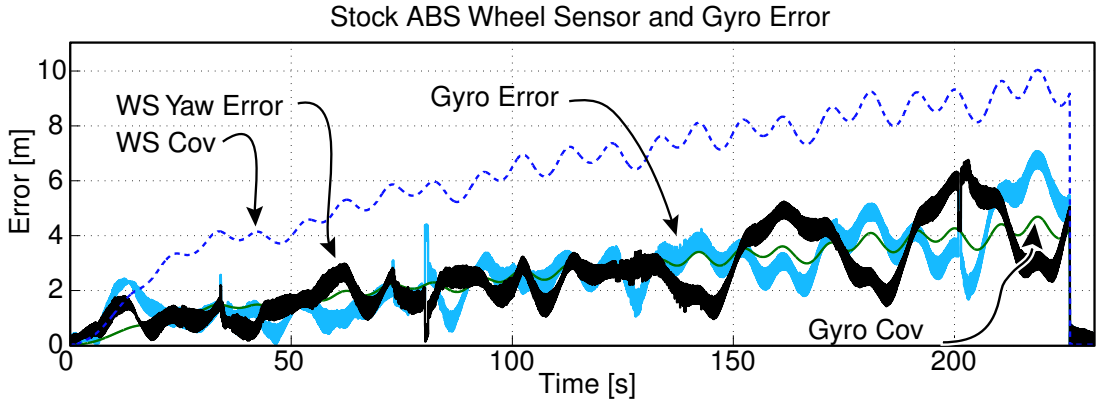




High resolution encoder and stock ABS sensors perform the same

Results: Small Scale



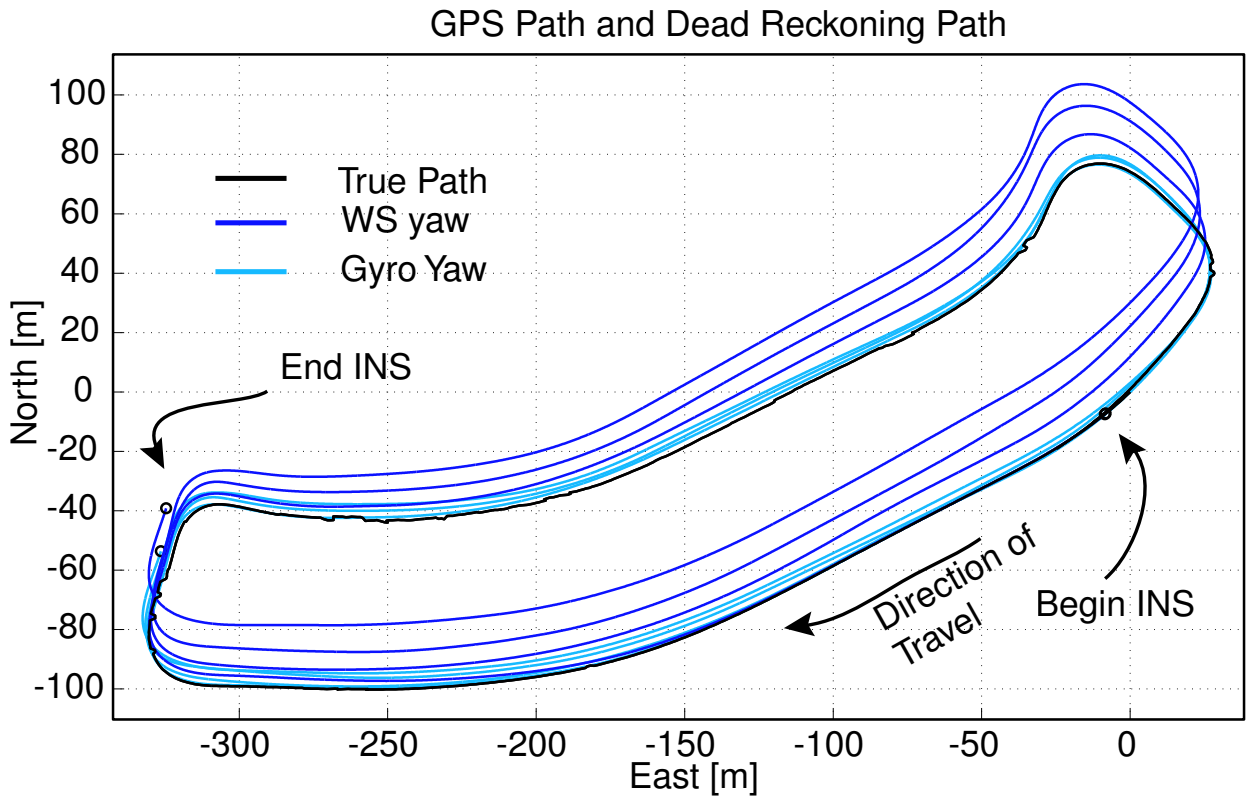


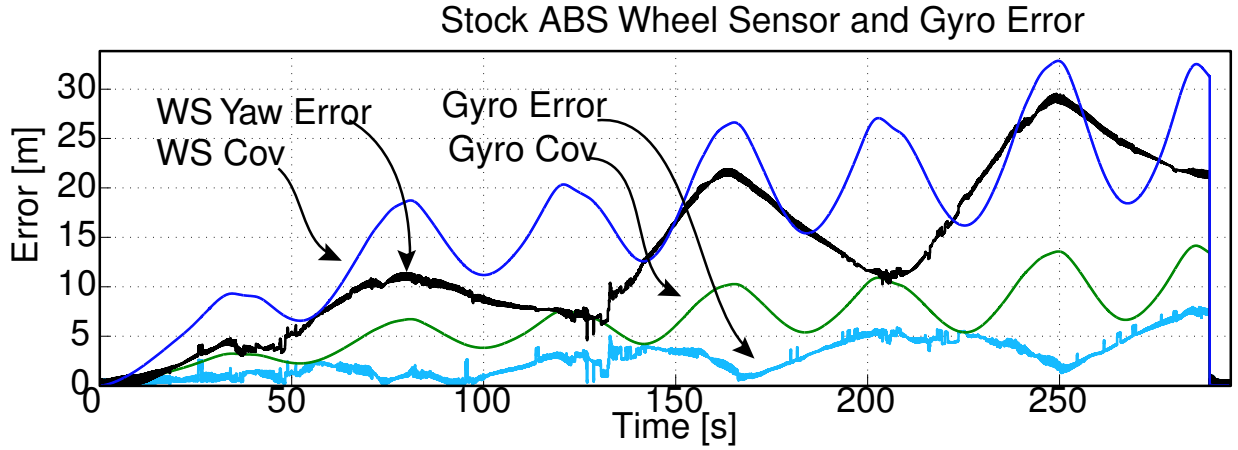
Test conditions are nearly ideal

- ☐ Flat
- ☐ Smooth
- ☐ No braking or acceleration

Gyro and differential wheelspeed systems perform equally well

Results: Medium Scale

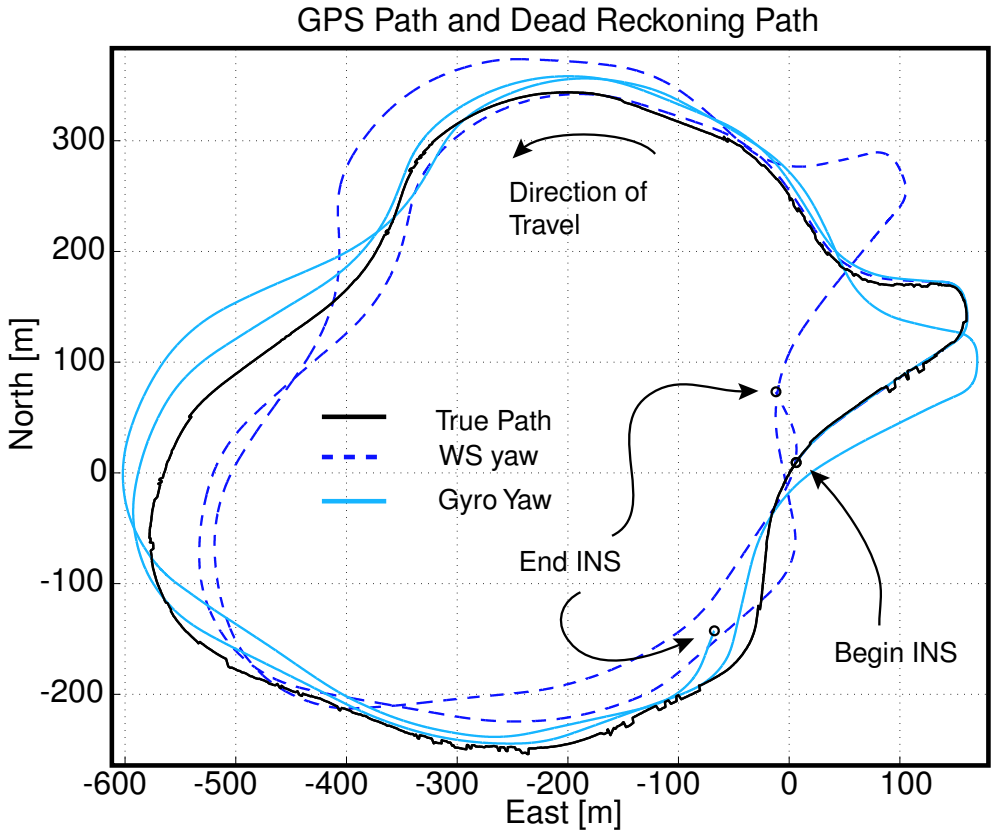


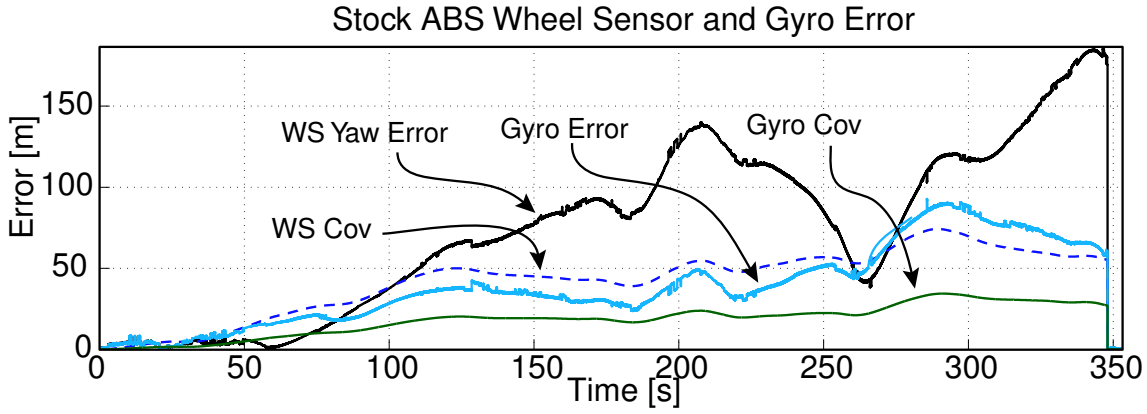


Medium Scale Test Results

- Test conditions are less ideal
  - Not quite flat
  - A little rougher road surface
  - Drain ditches etc. in road
- Still no hard acceleration or braking
- Gyro performs about twice as well as differential wheelspeed system

Results: Large Scale

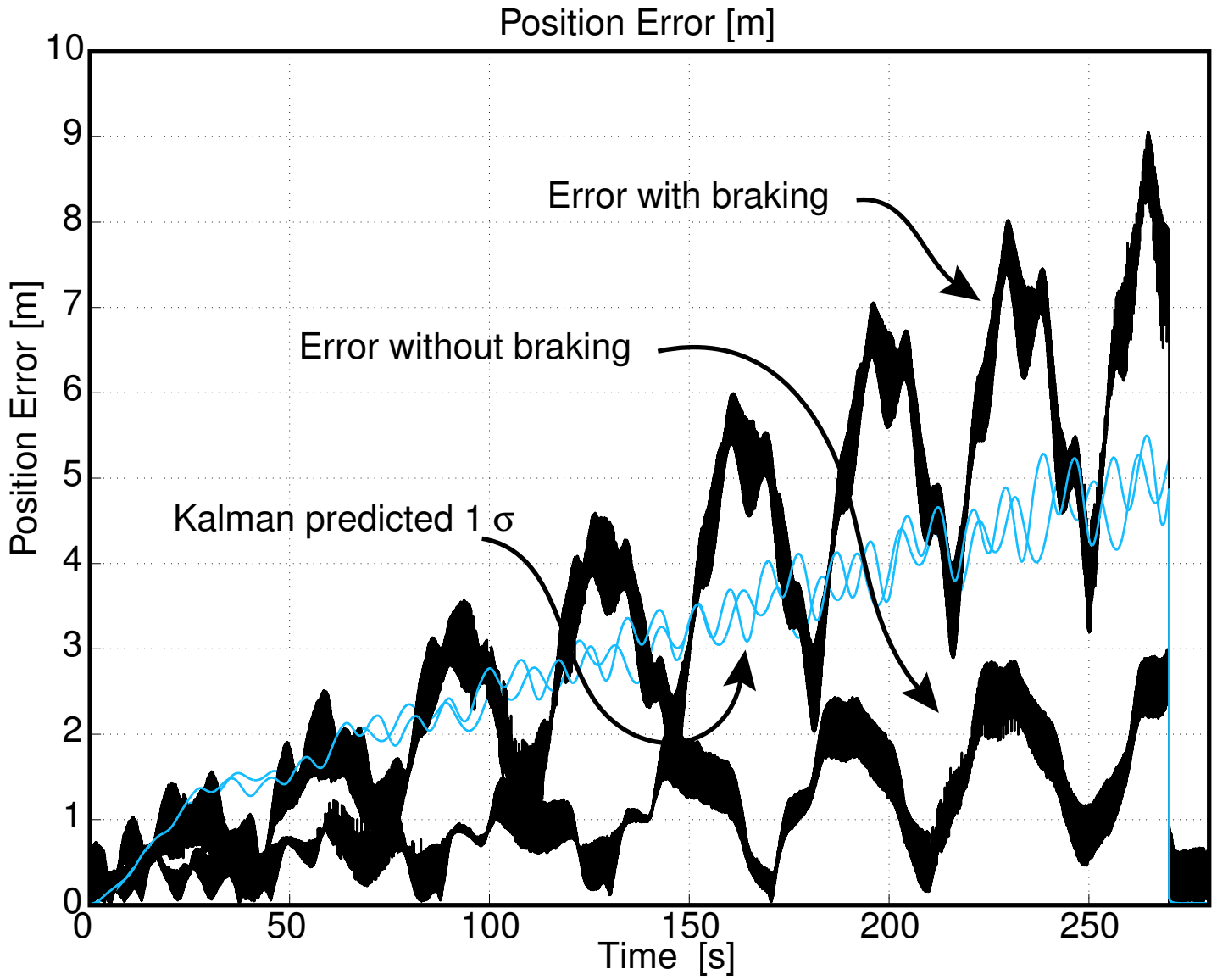




Large Scale Test Results

- Test conditions are even less ideal
  - Speed bumps with uneven height
  - Rougher road surface
  - Drain ditches etc. in road
- Still no hard acceleration or braking
- Gyro performs about twice as well as differential wheelspeed system

Results: Longitudinal Slip



Longitudinal Slip Test Results

- Gyro heading system
- Test conditions are nearly ideal
  - Flat
  - Smooth
- Except for hard braking and acceleration, $\sim$ 0.4 g
- System accumulates 3 times as much error during hard driving
- It may be possible to compensate this effect

Conclusions

- It is possible to estimate vehicle position using GPS and ABS sensors
- Wheel encoder resolution not the driving error factor
- Wheel radius estimation critical for filter performance
- Kinematic model suggest placing the antennae over the rear differential
- Gyro heading estimator more robust than wheelspeed based estimator
- Both estimators could benefit by modeling wheel slip

Future Work

- Experimentally determine the benefits of using WAAS corrected GPS
- Explicitly try to compensate for wheel slip in the linear region

Acknowledgements

- Mahesh Chowdhary
- Visteon Technologies

Questions ?