Twin IMU-HSGPS Integration for Pedestrian Navigation

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Pedestrian Navigation Applications

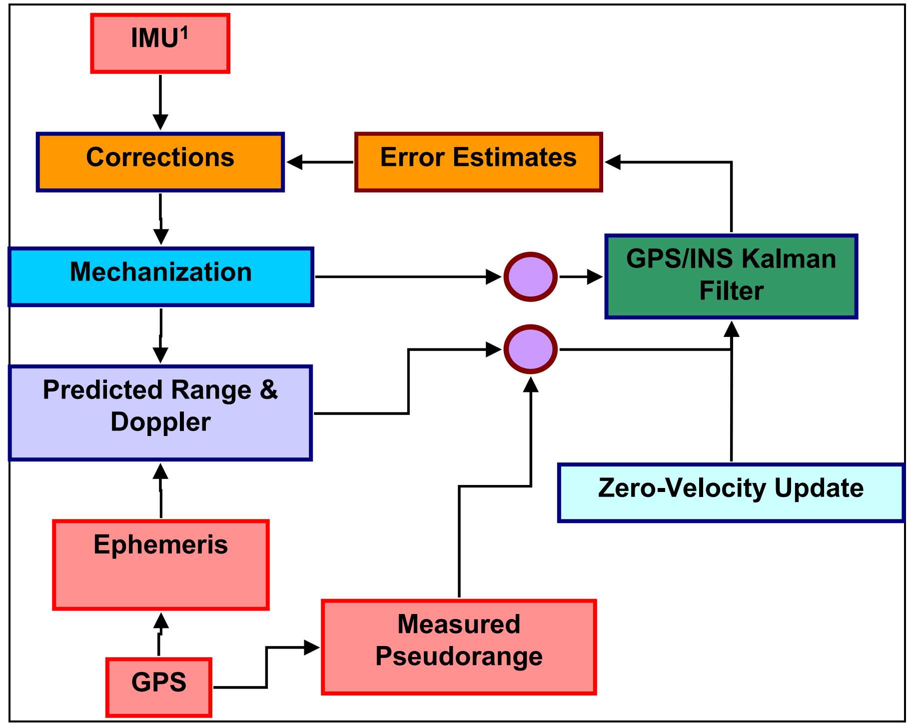
- Locate personnel in any conditions
  - Military applications
  - Fire fighting, police force and emergency services
  - Navigation in urban areas
  - Location Based Services (LBS)
- Typical Environments
  - Forest canopy
  - Urban canyons
  - Indoors
  - Underground parkades

Why Use 2 IMUs?

- Because 2 is better than 1!
- Better accuracy in GPS limited areas
- Improving availability for users
- Improving reliability for users
- In the event of an IMU failing or temporary data outages, the system can operate in a single IMU configuration

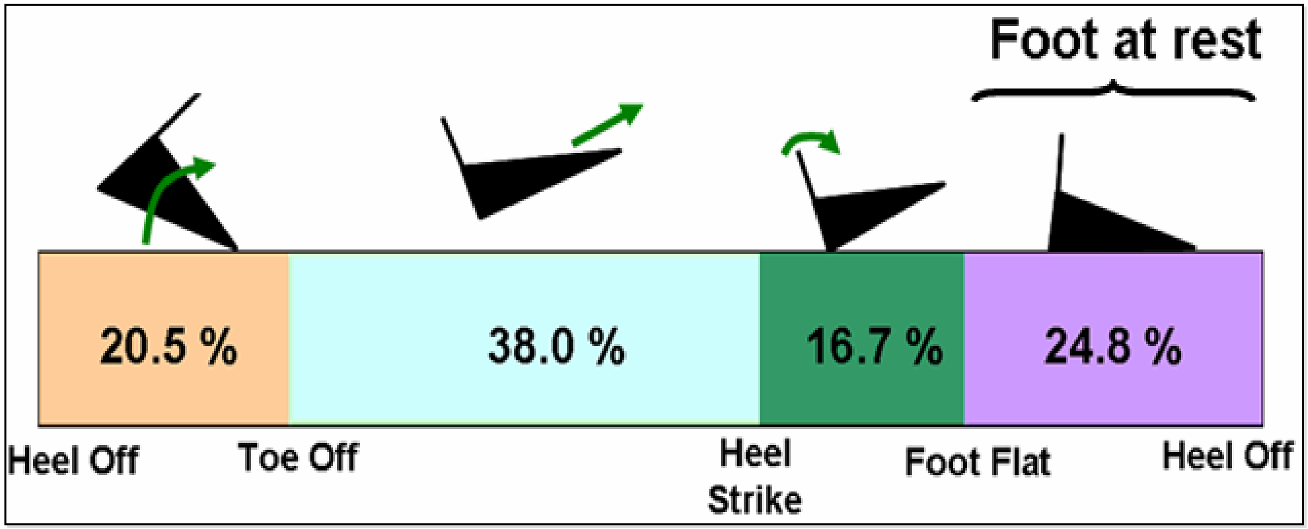
Review of Single IMU Integration

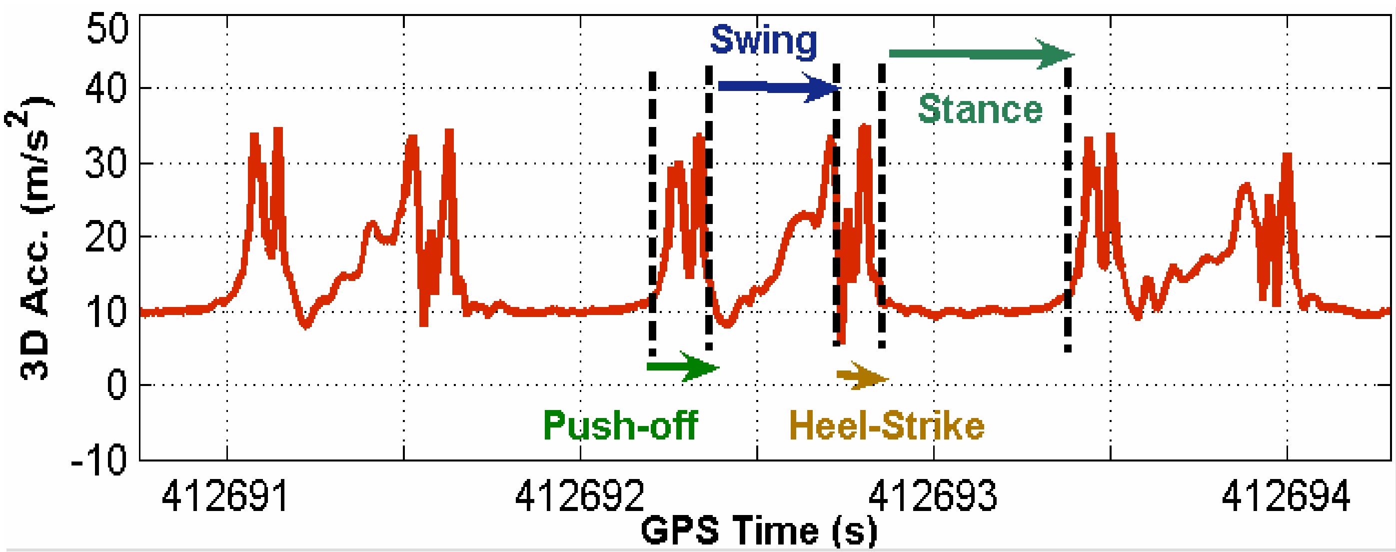
- 29-state filter
  - Position, Velocity, Attitude (9)
  - Accelerometer and Gyro
    - Biases (Gauss Markov) (6)
    - Scale Factor (Gauss Markov) (6)
    - Turn on Biases (Random Constant) (6)
  - GPS Clock Errors (2)
- Tight integration approach
- Zero Velocity Updates (ZUPT) performed when foot is at rest during gait cycle
- GPS observations weighted using C/N_0 ratio



MEMS Accelerometer and Gyro

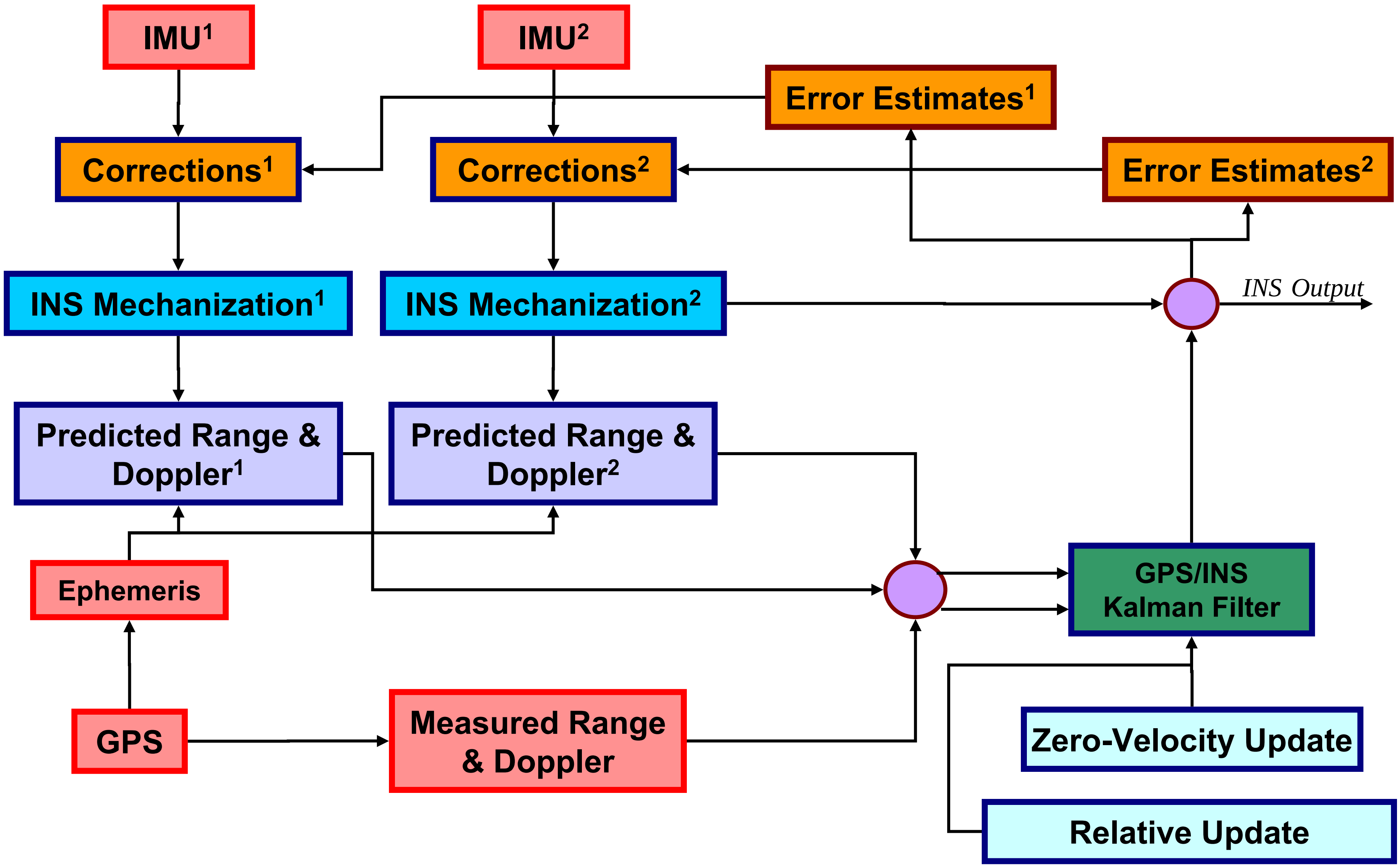
Stance Phase Detection





From: Godha, S., G. Lachapelle and M.E. Cannon (2006) Integrated GPS/INS System for Pedestrian Navigation in a Signal Degraded Environment. Proceedings of GNSS06 (Forth Worth, 26-29 Sep, Session A5), The Institute of Navigation, 14 pages.

Twin IMU Integration Scheme



Twin IMU Integration

- **Two single IMU filters are stacked to form a larger twin IMU filter – a 56-state model**
  - **Each block within the filter (for each IMU) contains its own set of states, transition matrix, design matrix, covariance matrices, etc.**
  - **The twin filter can be accessed as a unit, or individually, as necessary**

Prediction Cycle

$$\begin{bmatrix} \partial x_{k+1}^{1} \\ \partial x_{k+1}^{2} \end{bmatrix} = \begin{bmatrix} \Phi_{k,k+1}^{1} & 0 \\ 0 & \Phi_{k,k+1}^{2} \end{bmatrix} \begin{bmatrix} \partial x_{k}^{1} \\ \partial x_{k}^{2} \end{bmatrix} + \begin{bmatrix} w_{k}^{1} \\ w_{k}^{2} \end{bmatrix}$$

System Dynamic Model

$$\dot{x}(t) = F(t)x(t) + G(t)w(t)$$

Discrete Time Transformation

Update Cycle

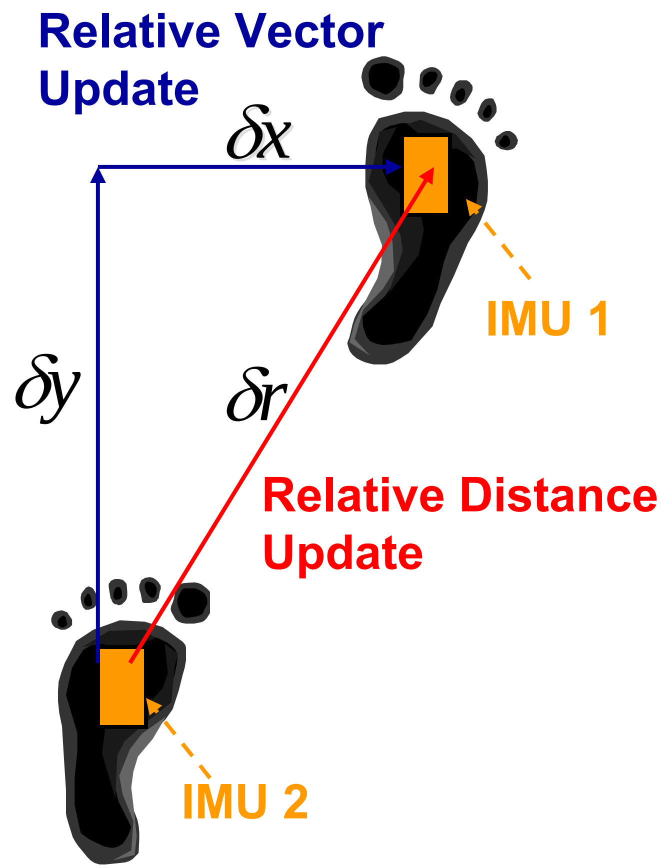
$$\begin{bmatrix} \partial z_{k+1}^{1} \\ \partial z_{k+1}^{2} \end{bmatrix} = \begin{bmatrix} H_{k+1}^{1} & 0 \\ 0 & H_{k+1}^{2} \end{bmatrix} \begin{bmatrix} \partial x_{k+1}^{1} \\ \partial x_{k+1}^{2} \end{bmatrix} + \begin{bmatrix} \eta_{k+1}^{1} \\ \eta_{k+1}^{2} \end{bmatrix}$$

System Observation Model

$$z(t) = H(t)x(t) + \eta(t)$$

Twin IMU Relative Position Updates

- **Relative Vector Update (RVUPT)**
  - Uses the vector between the feet
  - Observations derived from integrated step length (*y*), approximate width between feet (*x*), and assumed zero elevation difference between feet (*z*)
- **Relative Distance Update (RDUPT)**
  - Uses the magnitude of the relative vector (*r*)



Relative Vector Updates (RVUPT)

- The observations are the vector between the feet derived from the step length
- The rear foot, which is just about to enter the heel off stage forms the local frame
- The relative vector is rotated into the ECEF frame via a rotation matrix
  - The weakness of this update lies in the error of the rotation matrix, in particularly the heading error

$$\left(\hat{\bar{r}}_{IMU_1} - \hat{\bar{r}}_{IMU_2}\right)_{3x1} - \delta\widehat{\bar{r}}_{3x1} = \begin{bmatrix} I_{3x3} & 0_{3x24} & -I_{3x3} & 0_{3x24} & 0_{3x2} \end{bmatrix} \delta\bar{x} + \bar{\eta}_{\delta r}$$

$$= H\delta\bar{x} + \bar{\eta}_{\delta x}$$

Test Data Collected

- A tactical grade IMU was used to provide a reference solution (NovAtel OEM4 + HG1700 1 deg/hr IMU)
  - Processed with RTS Smoothing to provide < 6 m 3D (1σ) accuracy indoors
- HSGPS (SirfStarIII Receiver) @ 1 Hz
- MEMS IMU (x2) (Cloud Cap Technology's Crista) @ 100 Hz

IMU Specifications

•2 deg/s Gyro bias

•0.2 m/s^2 Accelerometer bias

MEMS Accelerometer and Gyro

Trajectory of Data Collection

High multipath from building

Added noise from green leaved trees

Green leaved trees reducing observability

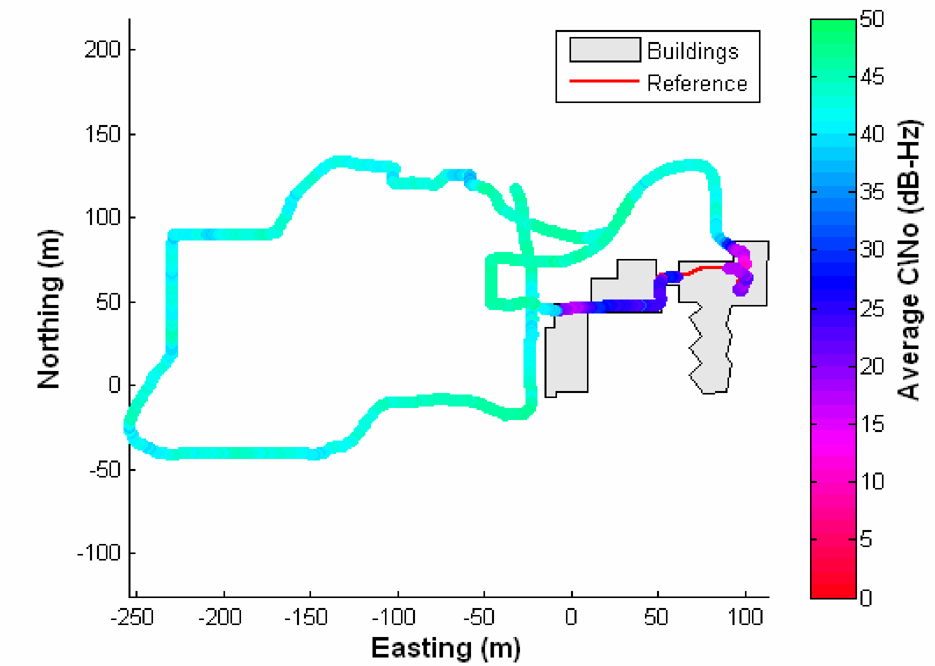
Walking in bushes

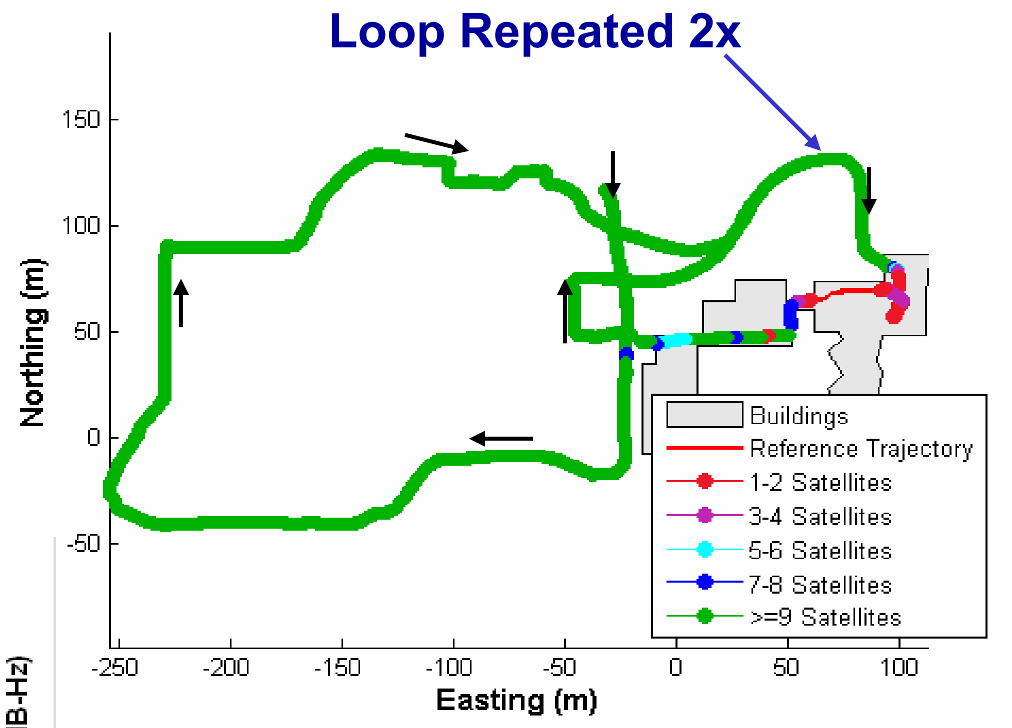
Extreme multipath in building with low C/N_0

Satellite Observability and Signal Strength

Outside Data

- Outside under leaved trees, receiver continuously tracked more than 9 satellites
- Average C/N_0 outside is 41 dB-Hz, with occasional intervals ranging 35 - 39





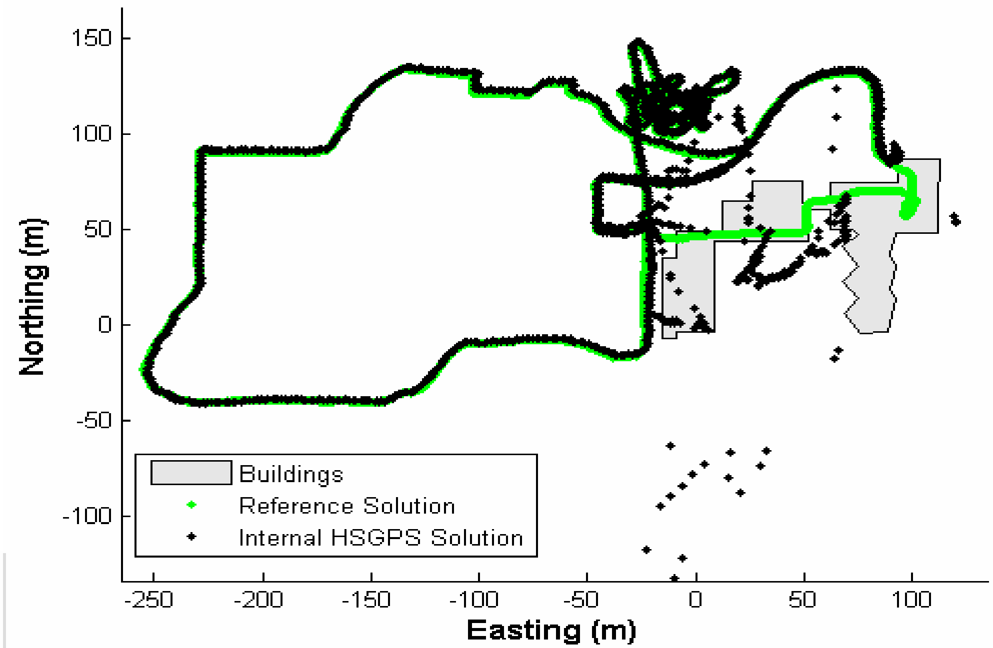
Indoor Data – 2 Loops

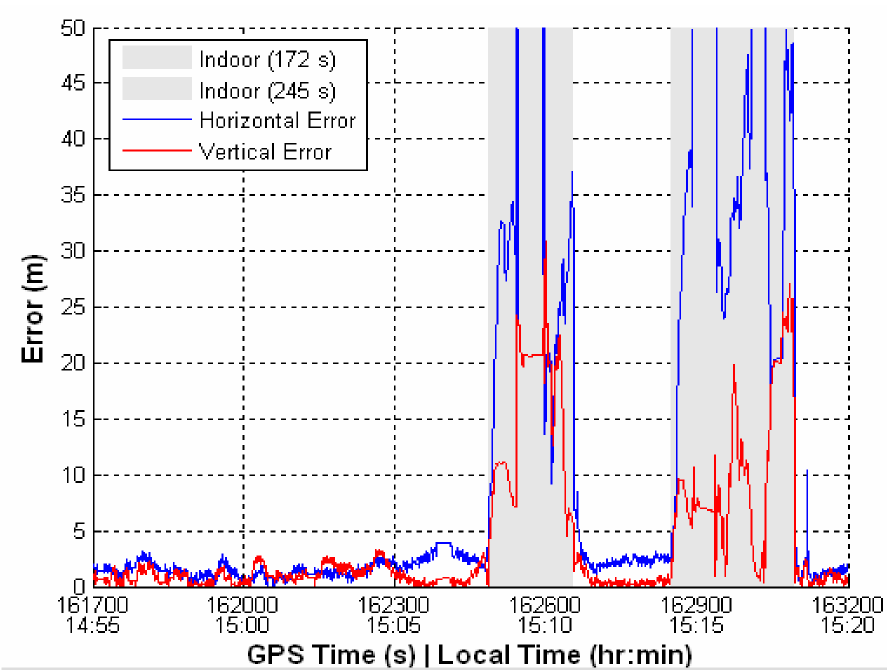
Indoors	172 s	245 s
Satellites Tracked	0 - 8	0 - 8
Complete Outages	53 s	62 s
C/No (dB-Hz)	10 - 27	10 - 29

GPS Only Navigation Solution

Outside Data

- **HSGPS compares very closely with reference trajectory**
- **1.6 m mean horizontal error**
  - **1.7 m RMS**
- **1.0 m mean vertical error**
  - **1.2 m RMS**





Indoor Data

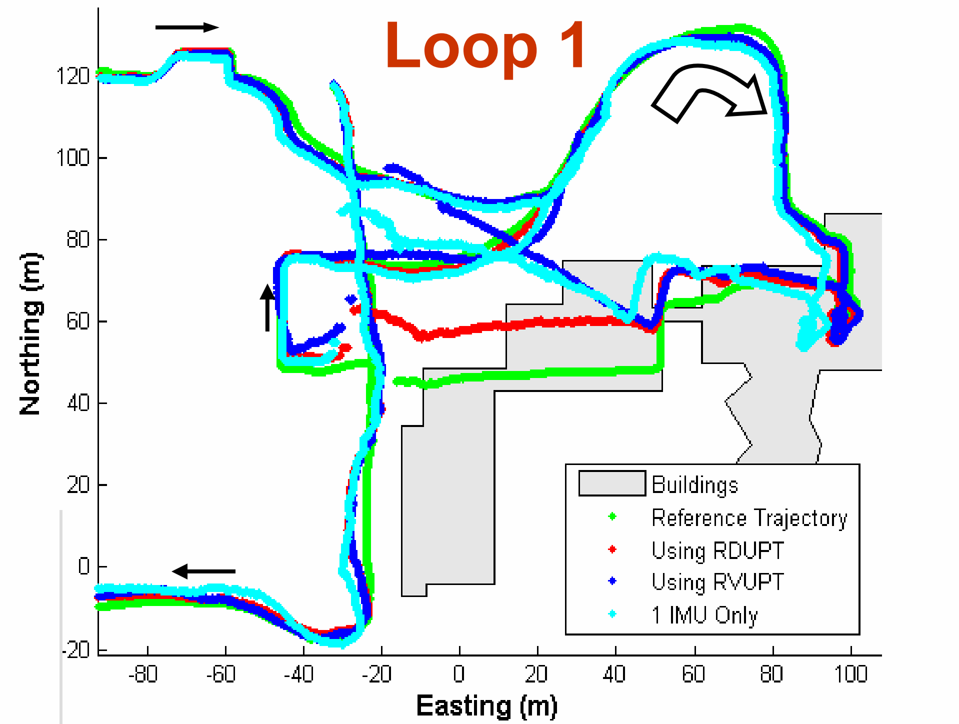
- An erroneous solution

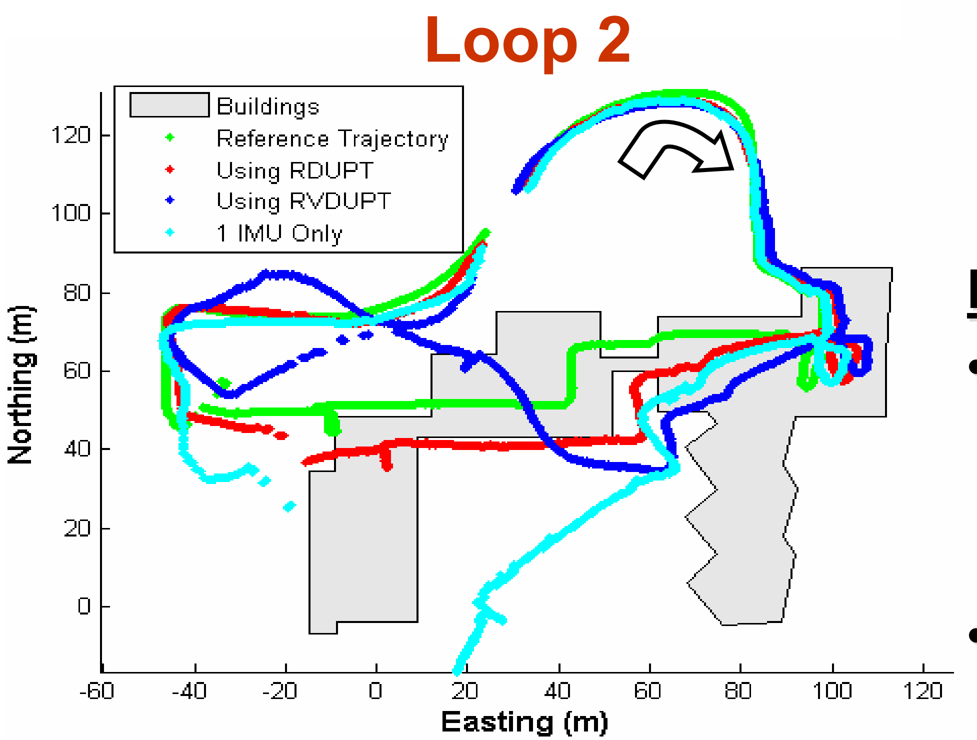
Indoors	172 s	245 s
Mean Hz Error (m)	68.3	65.5
RMS Hz Error (m)	98.3	93.9
Mean Vt Error (m)	15.1	8.2
RMS Vert Error (m)	16.5	13.8

Twin IMU Navigation Solution

Outside Data

- Twin IMU follows the GPS solution and provides similar results to that of a GPS only filtered solution

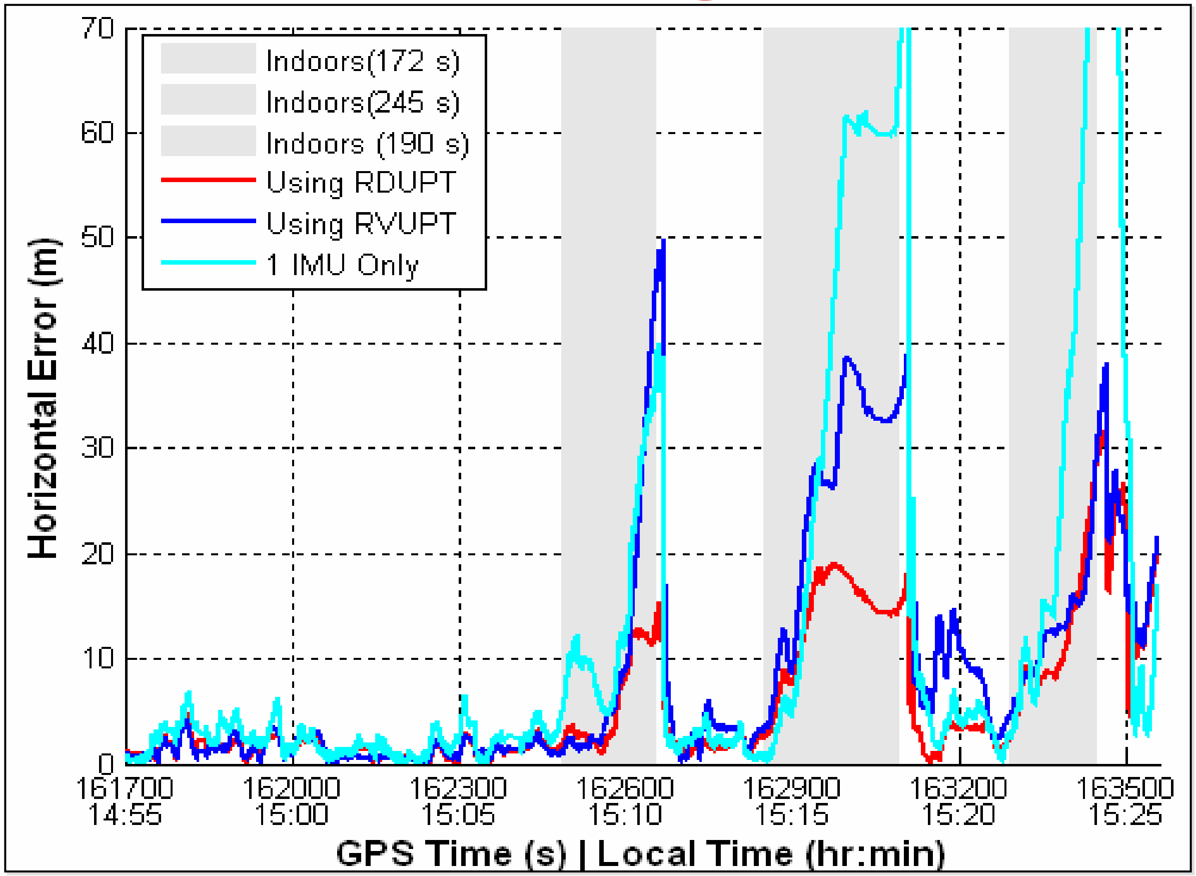




Inside Data

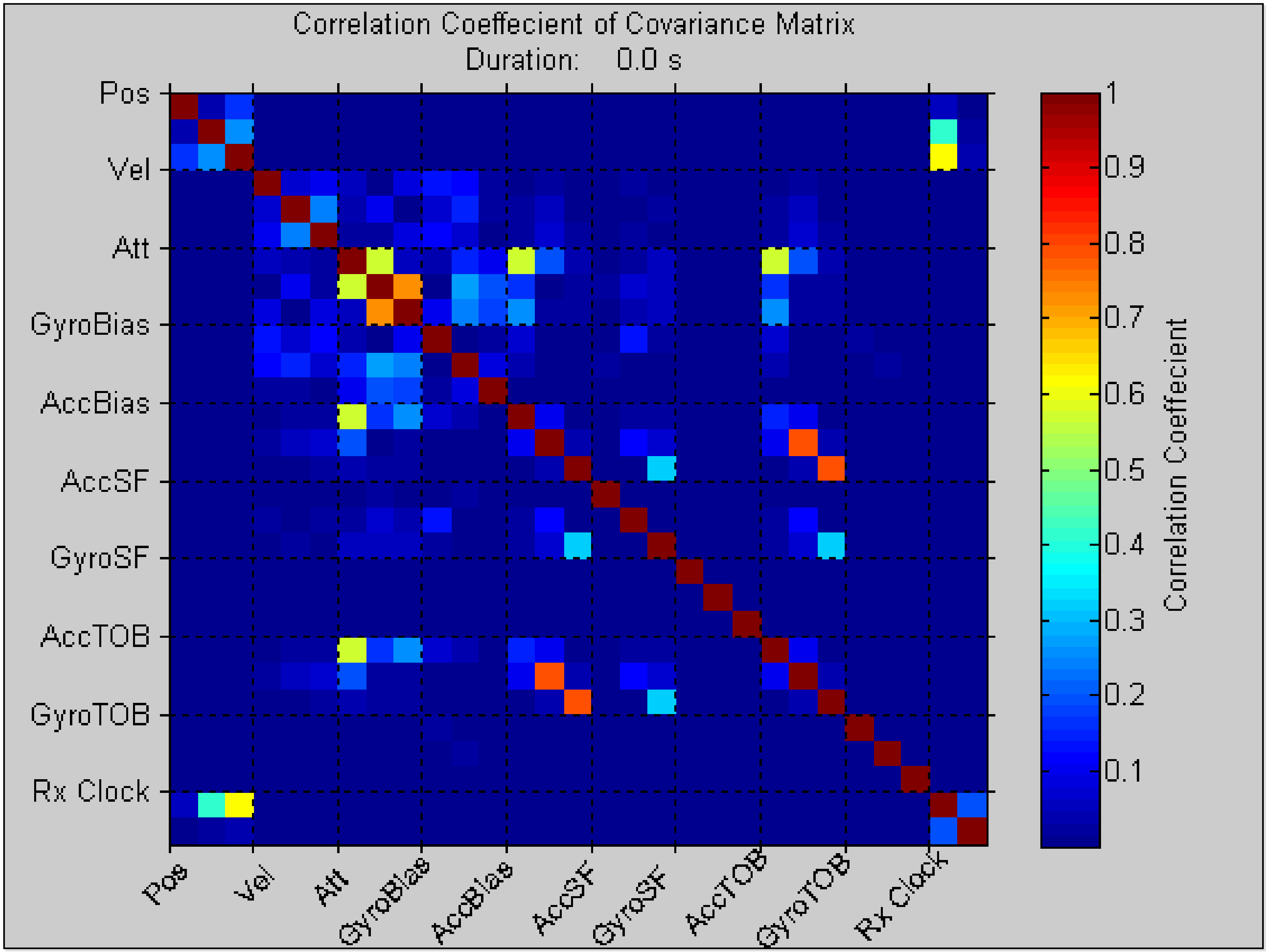
- Different processing strategies provide different results, RDUPT providing the lowest error
- Second time around loop errors increase

Twin IMU Navigation Error

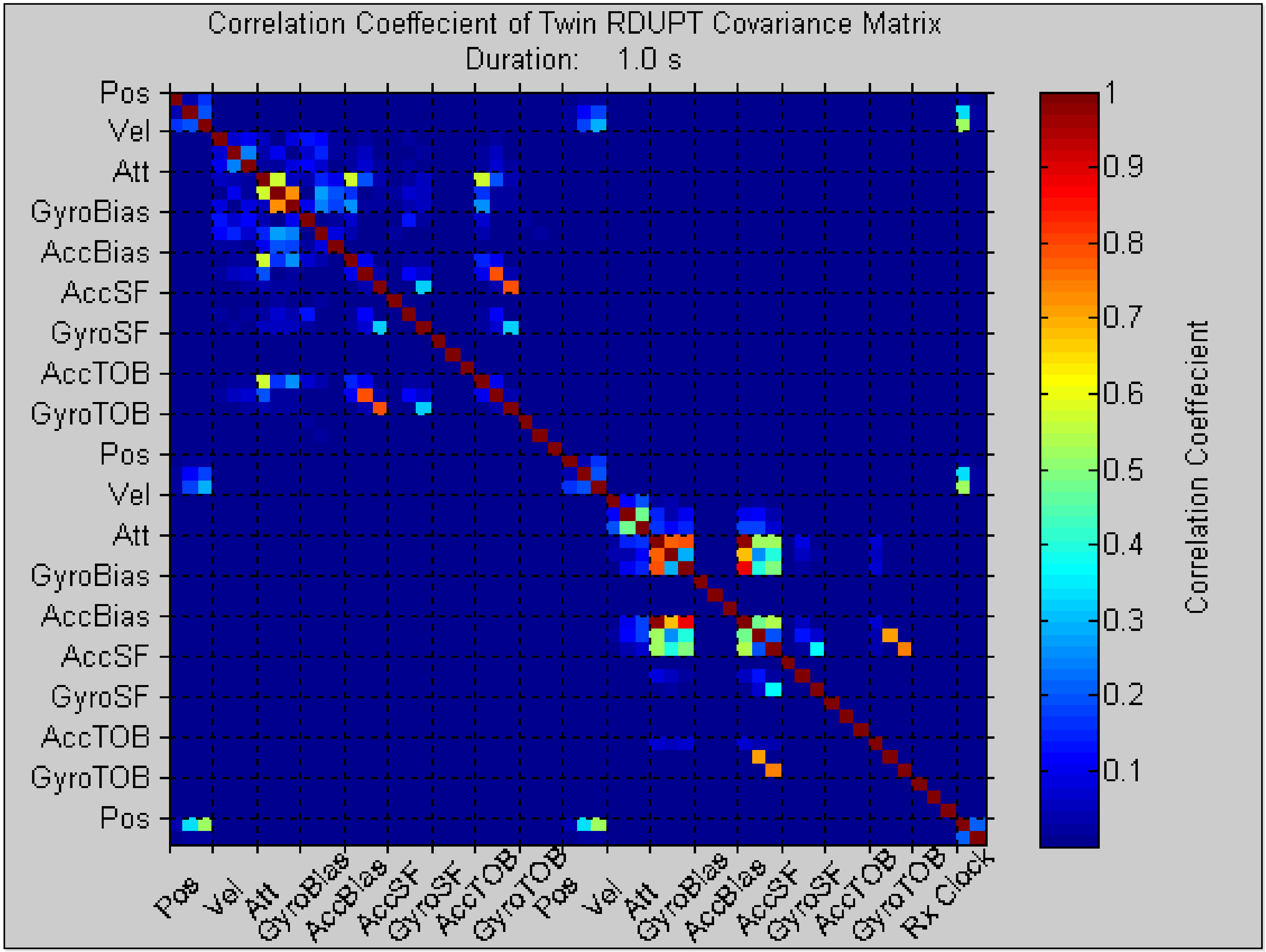


Processing Strategy	Loop 1	Loop 2	Loop 3	Improvement Factor
	Max Error (m)			
RDUPT	15	19	32	3.5
RVUPT	50	39	38	2.9
Single IMU	40	80	120	1.0

Correlation of Single IMU



Correlation of RDUPT Twin IMU



Conclusions

- Implementing a twin IMU filter for pedestrian navigation was shown improve navigation in GPS reduced areas by a factor of 2.9 - 3.5
- Two methods were used to relate the IMUs relative position and provide an update to the filter
  - Relative distance (RDUPT)
  - Relative vector (RVUPT)
- Correlation induced from relative updates between IMUs is negligible