Use of Image-aided Navigation for UAV Navigation and Target Geolocation in Urban and GPS-denied Environments

Precision Strike Technology Symposium

Alison K. Brown, Ph.D.
NAVSYS Corporation, Colorado

Phone: 719-481-4877 email: abrown@navsys.com
www.navsys.com

Problem Statement

- Small, low cost UAVs are becoming prevalent on the battlefield
  - E.g. Shadow, Silver Fox, Aerosonde
- Small low cost GPS/inertial navigation solutions are needed
  - Can use MEMs accelerometers and gyroscopes
  - But … MEMs instrument accuracy is 100x worse than tactical IMUs
  - Challenge is to integrate low grade instruments to still provide navigation quality information

Comparison of Inertial Measurement Units

Tactical Grade
Honeywell HG1700 (RLG)

MEMs
Cloud Cap Crista

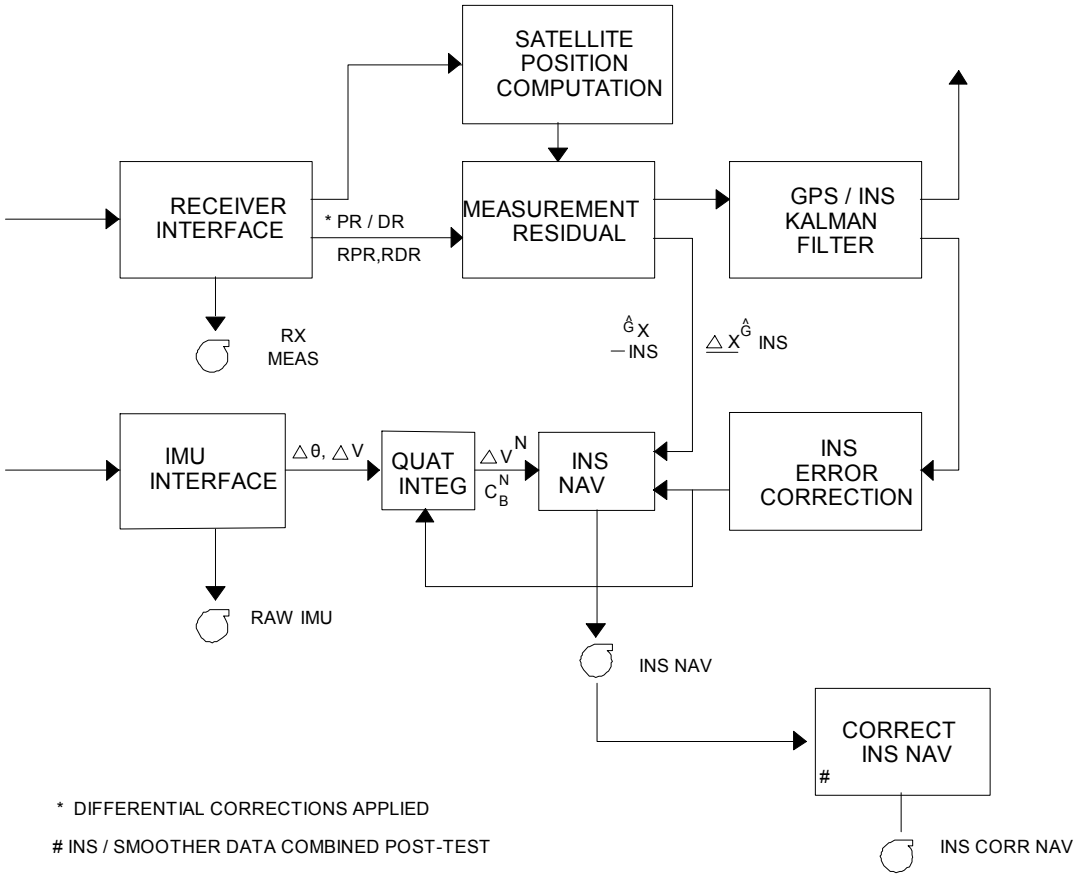
IMU Gyroscope and Accelerometer Parameter Comparison

Parameters	UNITS	HG1700[i]	Crista[ii]
	Type	*Ring Laser Gyro*	*MEMS*
Size		33 cu in	1.6 cu in
Weight		32 oz	0.7 oz
Power		8 w	0.7 w
Gyroscopes			
Operating Range	±°/s	1000	300
Scale factor accuracy (1 σ)	ppm	150	25000
Scale factor linearity 1 σ to ± 800 °/s	ppm	150	N/A
Bias (1 σ)	°/hour	2	500
Axis alignment stability (1 σ)	µrad	500	3000
Axis alignment stability, non-orthogonality (1 σ)	µrad	100	N/A
Output noise (1 σ of 10,000 samples)	µrad	80	80
Angular random walk max.	°/Rt-hr	0.1	5
Accelerometers			
Operating Range	±g	50	10
Scale factor accuracy (1 σ)	ppm	300	25000
Scale factor linearity (1 σ)	ppm	500	N/A
Bias (1 σ)	mg	1.0	15000
Axis alignment stability (1 σ)	µrad	500	3000
Axis alignment stability, non-orthogonality (1 σ)	µrad	100	N/A
Output noise (1 σ of 10,000 samples)	m/s	0.0024	0.0003_1
Velocity random walk	(ug/Rt-Hz)	150	450

1. Accelerometer includes filtering in sampled signal

[i] HG1700 Specification http://content.honeywell.com/dses/assets/datasheets/ds7_hg1700_imu.pdf
[ii] Crista IMU Specification http://www.cloudcaptech.com/crista_imu.htm

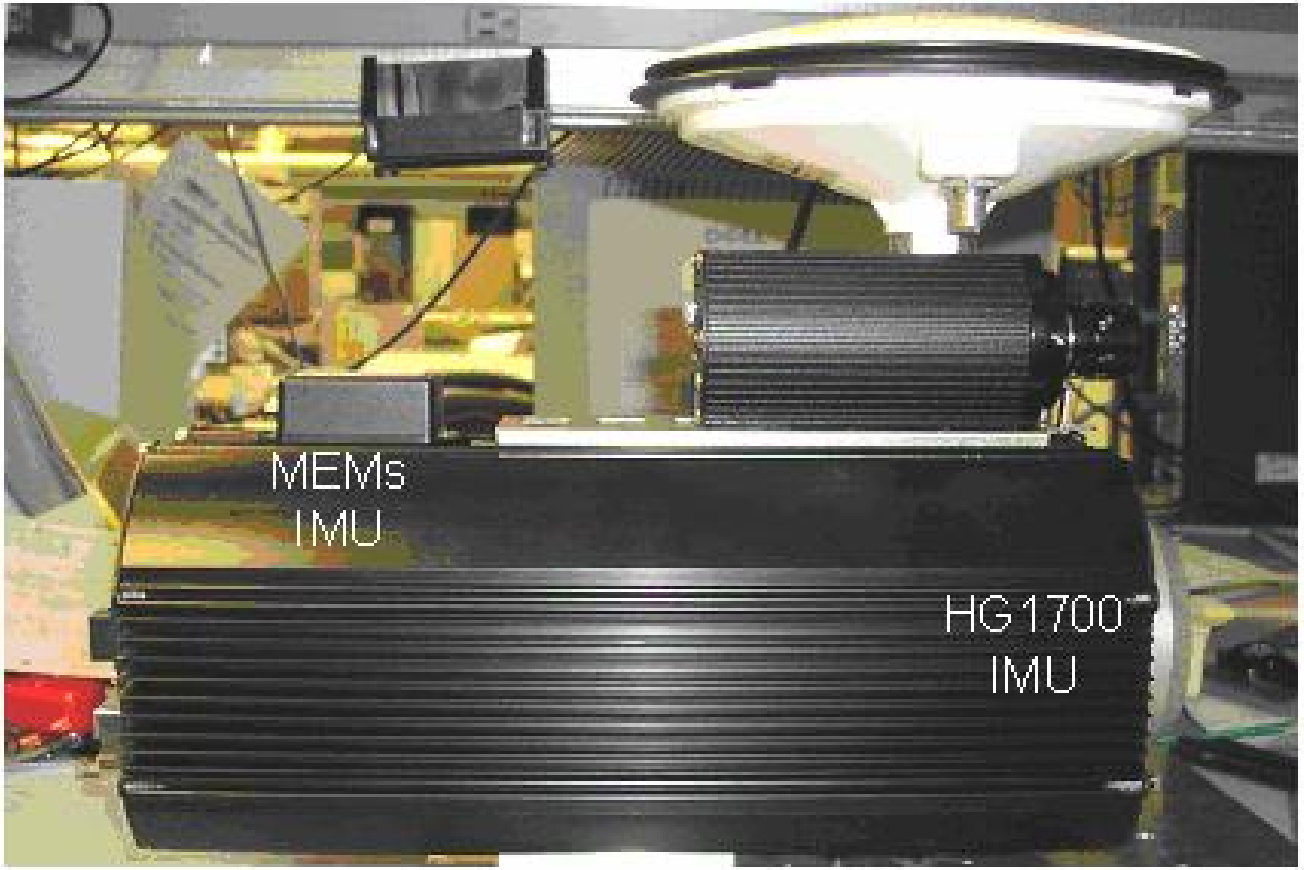
GPS/Inertial Integration using InterNav Kalman Filter allows for IMU Calibration



GPS/INS Correction States
Position Error (navigation frame)
Velocity Error (navigation frame)
Body Attitude Error (navigation frame) (T_x, T_y, α)
Accelerometer bias error
Gyro bias error
GPS Clock bias error
GPS Clock frequency error
Accelerometer misalignment & scale factor error
Gyro misalignment & scale factor error

States allow for calibration of inertial instrument errors

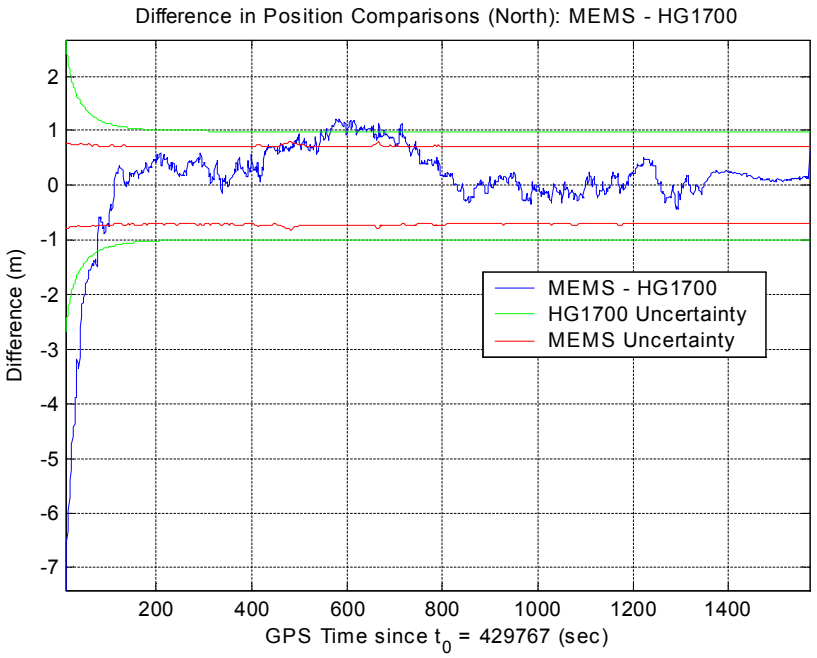
GI-Eye Test Fixture

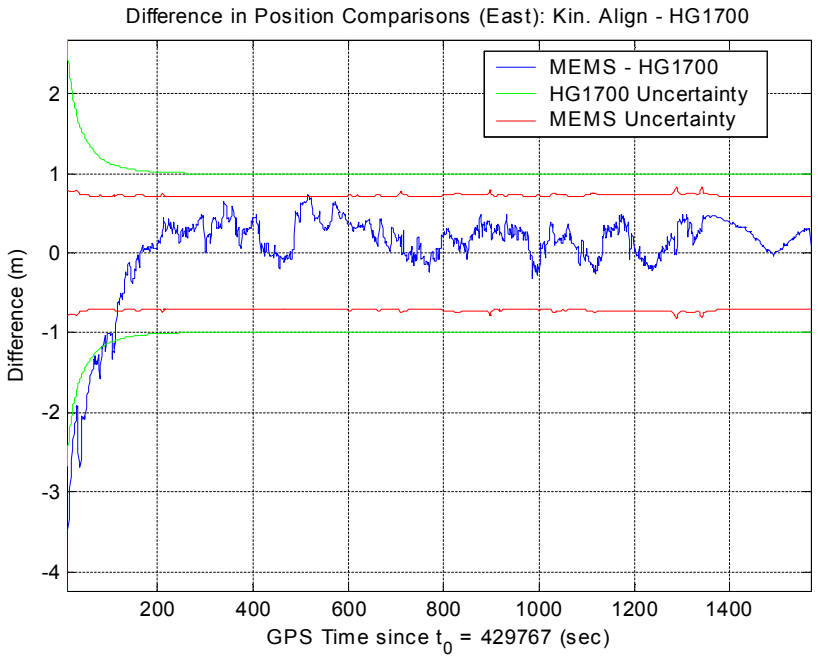


Truck Testing performed to compare HG1700 and MEMs Performance

North position diff
HG1700-MEMs

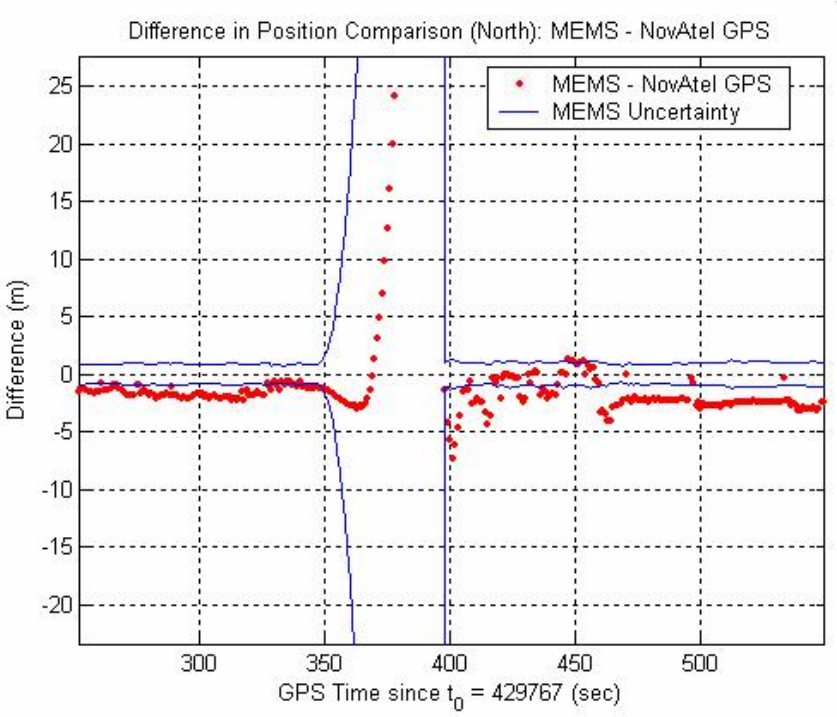
East position diff
HG1700-MEMs



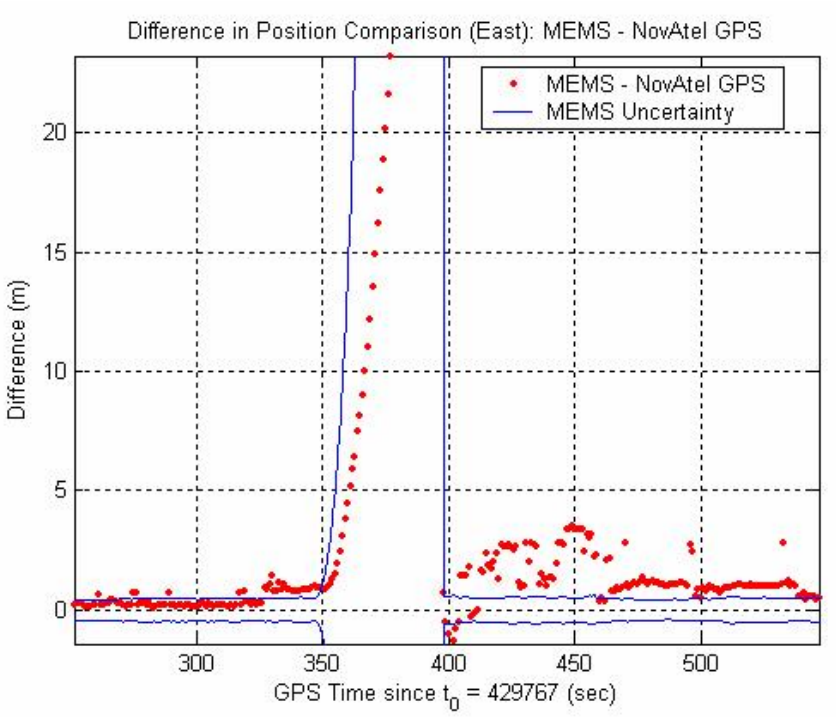


MEMS inertial position errors grow rapidly during GPS drop-out

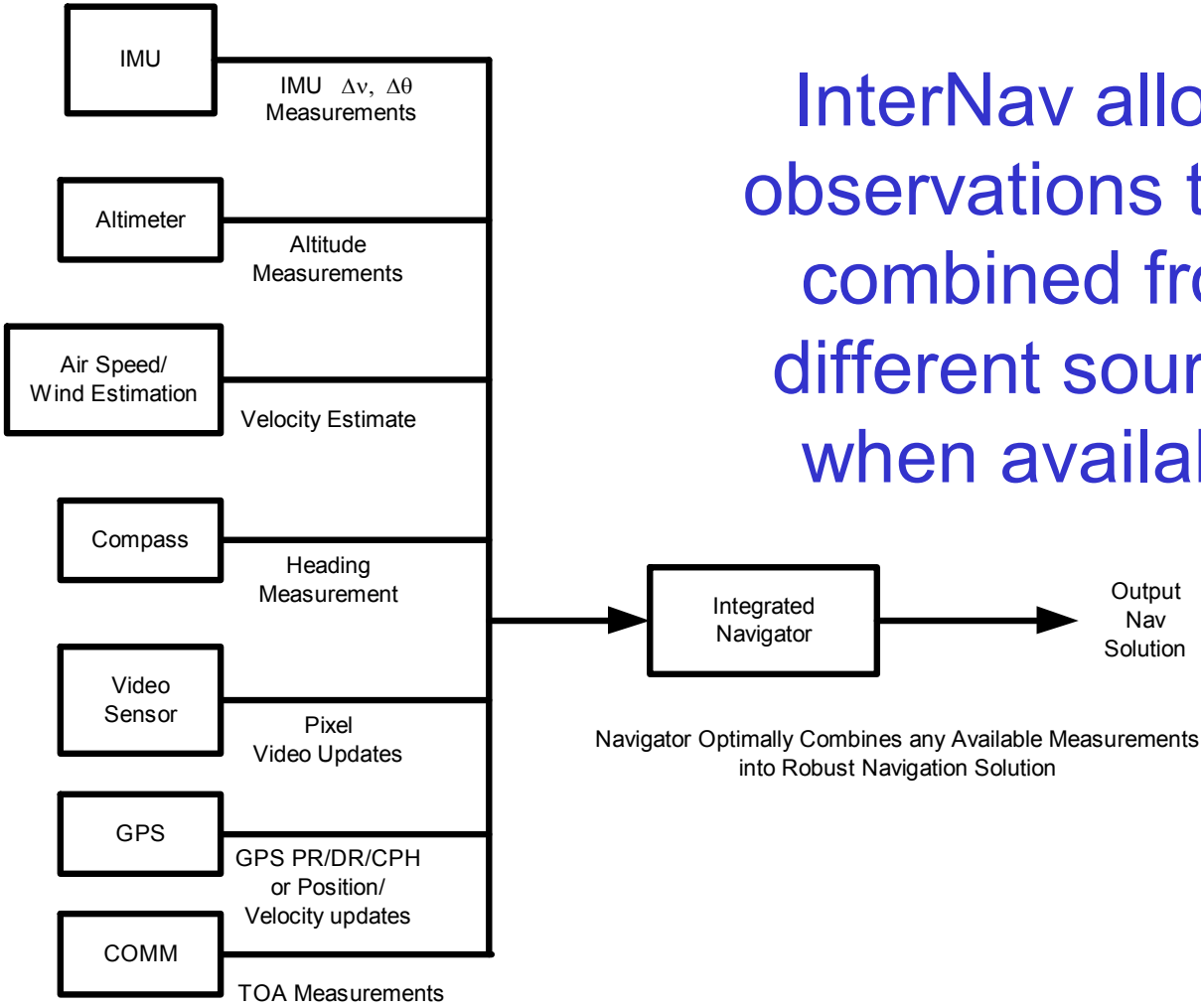
North Error



East Error



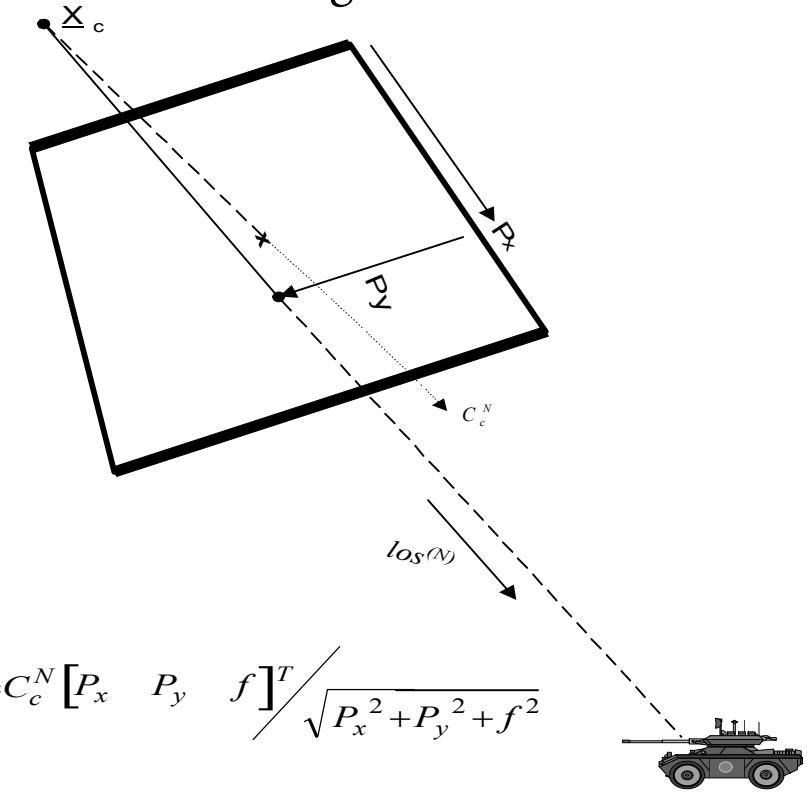
Back-Up Inertial Aiding is needed with MEMs IMU during GPS drop-outs



InterNav allows observations to be combined from different sources when available

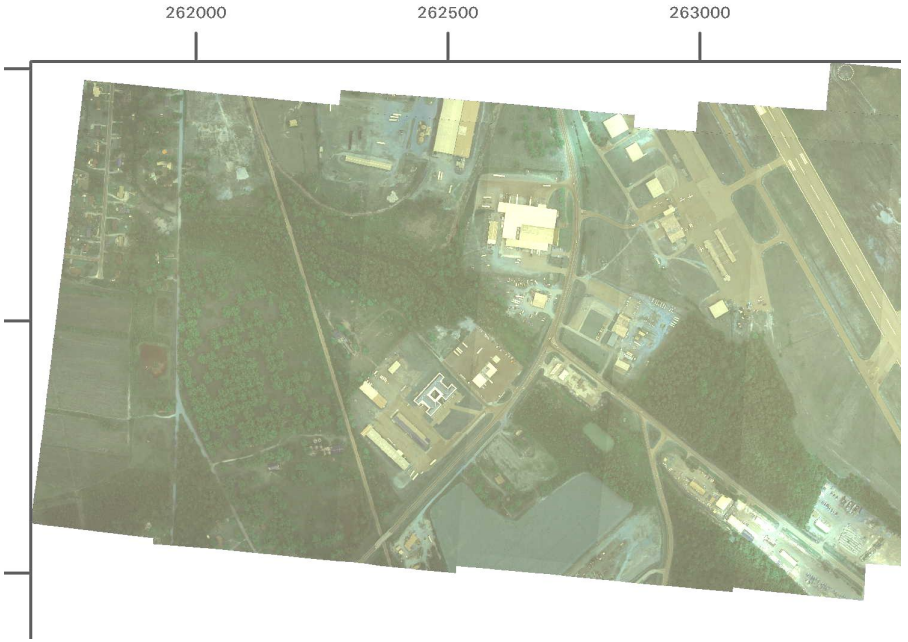
GI-Eye Auto-Georegistration
"Every pixel is a coordinate"

- GI-Eye Payload
  - GPS gives position
  - Inertial gives attitude

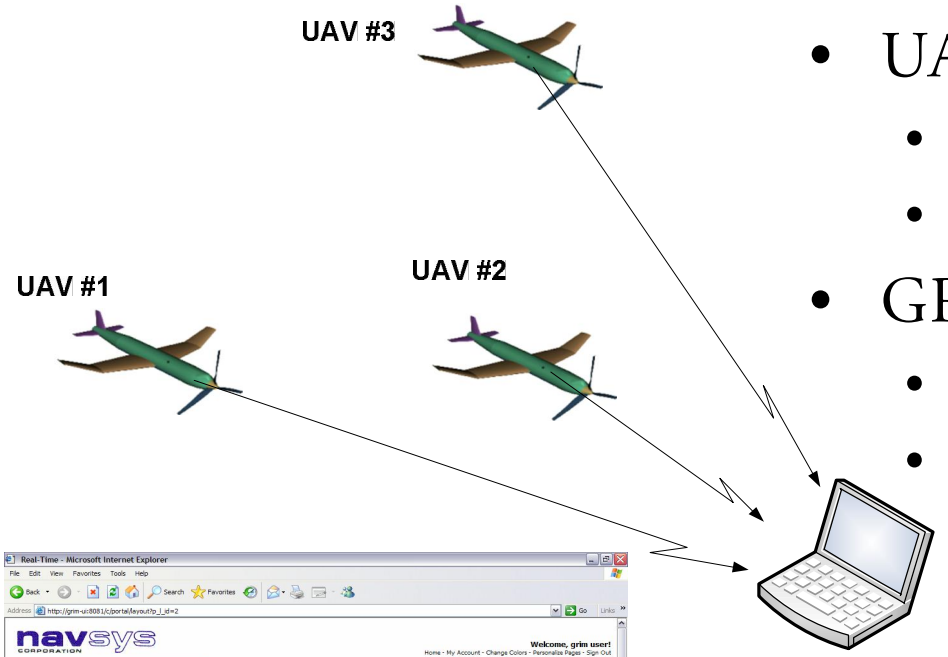


$$los^{(N)} = C_c^N \begin{bmatrix} P_x & P_y & f \end{bmatrix}^T \Big/ \sqrt{P_x^2 + P_y^2 + f^2}$$

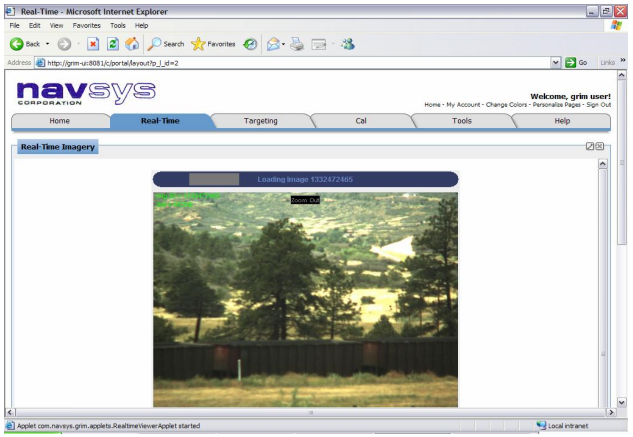
- UAV Sensor Registration
  - Real-time registration for target location
  - Auto-mosaic generation



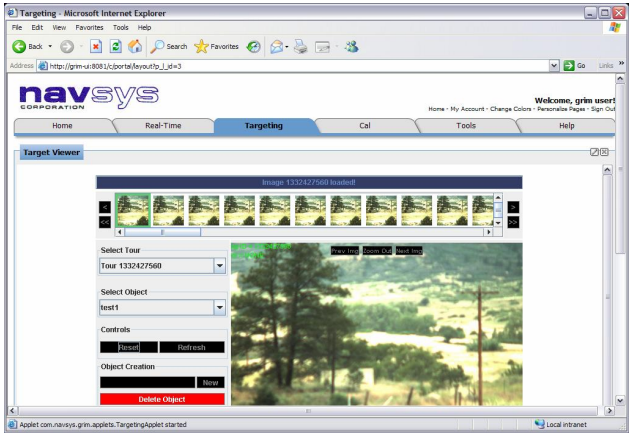
GRIM – Provides access to Sensor data through WLAN and Web Browser



- UAVs with GI-Eye
  - Airborne Server
  - Store Images with MetaData
- GRIM Ground Station
  - Web Browser User Interface
  - Targeting using MetaData



Real Time Viewer

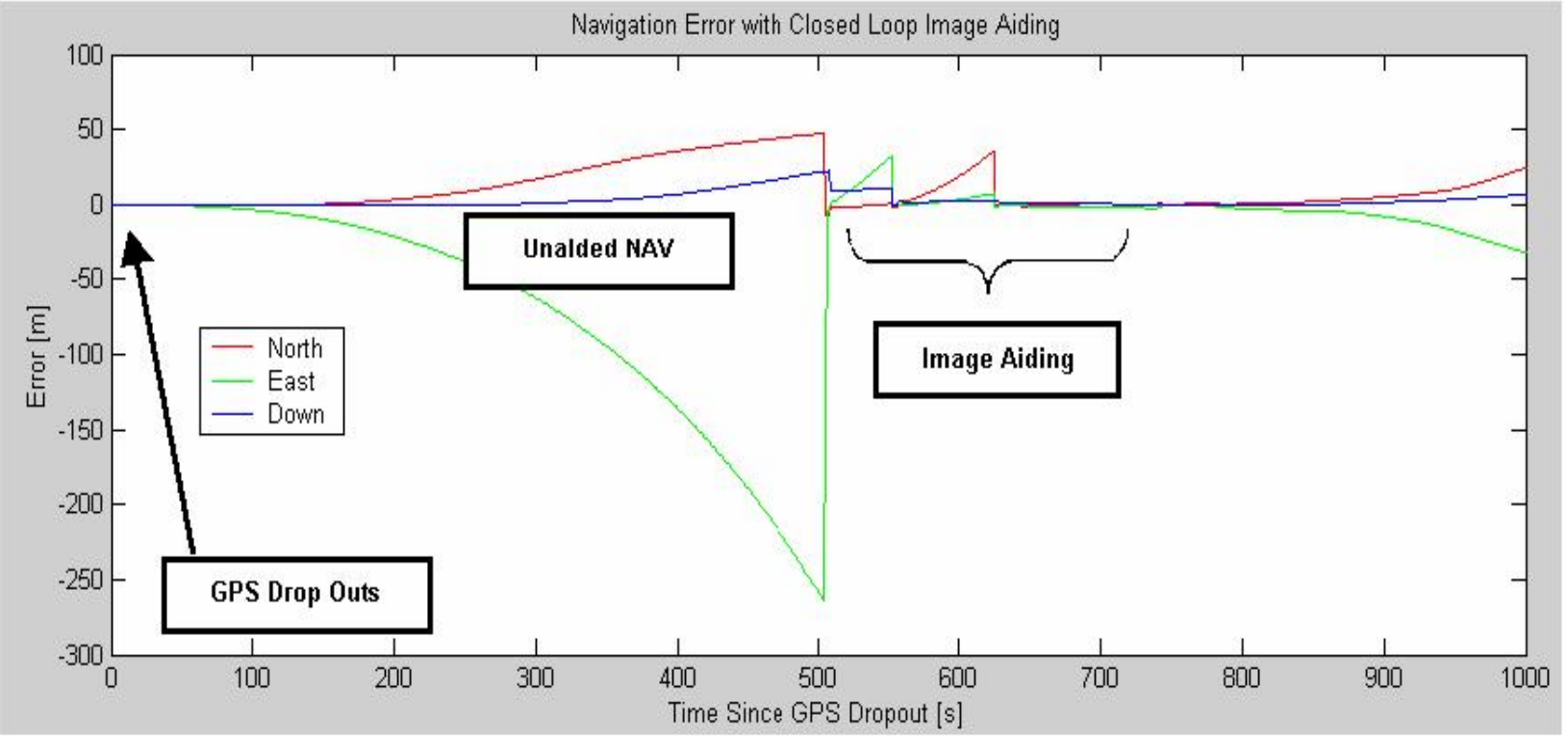


Targeting Page

GRIM Video-inertial Updates

- GRIM Ground Station
  - Used for navigation aiding during GPS drop-outs
- Video updates
  - Model provides reference location
  - Correlation provides pixel centroid location
  - Delta pixel offset expected model location (using inertial soln) observed inertial error
- InterNav on UAV
  - Applies Video Updates from ground station

Airborne Navigation Performance with Image Aiding (Forced GPS drop-outs)



Steady-State Nav Error < 5 m with 2 updates per minute

Conclusion

- A low cost, low grade MEMs IMU can be used as a UAV inertial navigation system
  - Calibration of the MEMs inertial instruments is essential
  - Solution rapidly degrades within minutes without aiding data for GPS or another source
- Applying GPS/Inertial Metadata to Imagery
  - Allows real-time targeting and mosaic generation
  - Allows Video Updates (VUPT) to be applied to UAV using known reference points
  - Inertial VUPT aiding allows robust navigation with low grade MEMs IMUs following GPS drop-outs