

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

sponsored by



UNMANNED SYSTEMS WEEK

WELCOME TO
GNSS/INERTIAL+ INTEGRATION FOR UNMANNED SYSTEMS



Wednesday, June 4, 2014

11 am–12:30 PDT
Noon–1:30 pm Mountain
1 pm–2:30 pm Central
2 pm–3:30 pm Eastern

Audio is available via landline or VoIP—For VoIP: You will be connected to audio using your computer's speakers or headset. **For Landline:** Please select Use Audio Mode Use Telephone after joining the Webinar.
US/Canada attendees +1 (480) 297-0022, Access 805-720-632



WELCOME TO GNSS/Inertial+ Integration for Unmanned Systems



Maarten Uijt de Haag
Cheng Professor
Ohio University



Andrey Soloviev
Principal
QuNav



Sandy Kennedy
Director of Core Cards
NovAtel Inc

Co-Moderator: Lori Dearman, Sr. Webinar Producer

Who's In the Audience?

A diverse audience registered from 42 countries, 28 states and provinces representing the following industries:

21% GNSS Equipment Manufacturer

17% Professional User

17% System Integrator

17% Product/Application Designer

28% Other



Welcome from *Inside GNSS*



Richard Fischer
Director of Business
Development
Inside GNSS

GNSS/Inertial+ Integration for Unmanned Systems



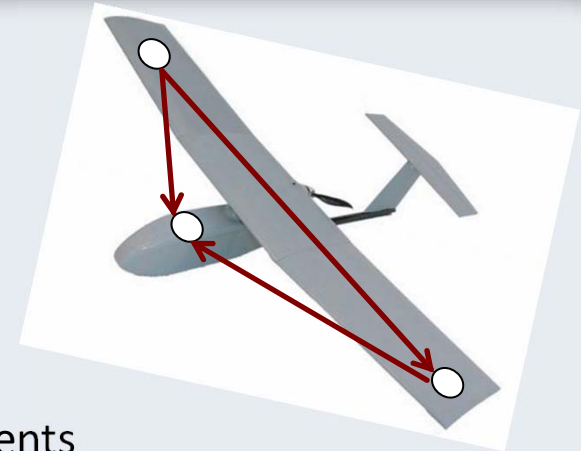
Mark Petovello
Geomatics Engineering
University of Calgary
Contributing Editor
Inside GNSS

Poll #1

What kind of environment are you most interested in operating your unmanned system in? (select top two)

- *Open Sky*
- *Indoor*
- *Underwater*
- *Urban*
- *Under foliage*

- Overview of unmanned systems
 - Applications
 - Appropriate metrics
- Positioning requirements
 - Key challenges/issues of GNSS in different environments
 - Role of multi-GNSS systems
 - Importance of having a reliable system
- GNSS accuracy requirements
 - Standalone & differential processing
 - Attitude systems
- Application to aerial and marine systems



- Role of integrated systems in unmanned applications
- GNSS + inertial + other sensors/systems
 - Role & benefit of various sensors
- Integration approaches
 - Limitations of GNSS/INS and how to include other sensors
- Product development
 - How do you actually go about selecting components and building a system



GNSS/Inertial+ Integration



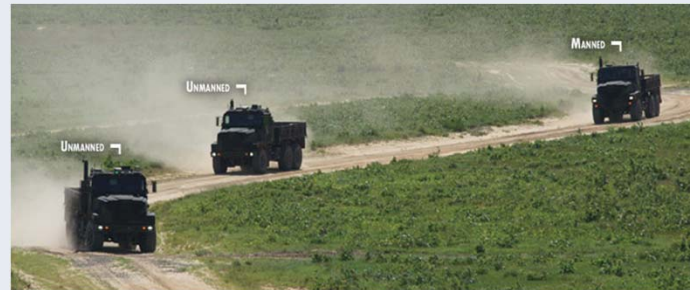
Maarten Uijt de Haag
Cheng Professor, *Ohio University*

- GNSS in unmanned vehicles summary
- Presence of additional sensor for other unmanned vehicle platform functions
- Operational requirements with respect to the required navigation performance based on GNSS
- Why GNSS inertial integration?
- GNSS/Inertial+

- Many commercial platforms rely on GNSS for various purposes:
 - Navigation
 - Surveillance
 - Conflict detection and resolution
 - Geo-referencing
 - Time-keeping/synchronization
 - Etc.



Courtesy of Amazon



Courtesy of Oshkosh Defense



Courtesy of OrbitGIS



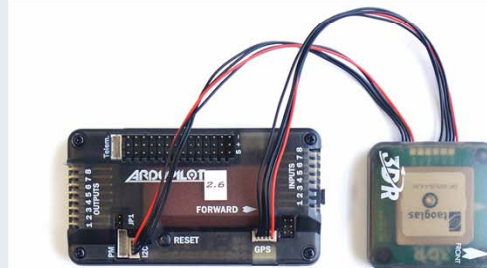
Geo-referenced LIDAR map of OU football stadium

GNSS in Unmanned Vehicles

LOA	Computer	Human
1	Offers no assistance	Does all
2	Suggests alternative	Chooses
3	Selects way to do task	Schedules function
4	Selects and executes	Consents
5	Executes unless vetoed	Has possibility to veto
6	Executes immediately	Is informed upon execution
7	Executes immediately	If informed if asked
8	Executes immediately	Is ignored by computer

Levels of Automation, LOA (Sheridan, 2002)

- Low-cost GNSS has enabled the execution of automatic UAV/UGV flight plans for even the non-professional user.



Courtesy of 3DR robotics

- Most unmanned vehicles already include an **inertial sensor** (e.g. an inertial measurement unit or IMU) to support the vehicle controller;
- Additional sensors are used for environment mapping, surveillance, conflict detection and avoidance.



Google car

3D maps, obstacles and traffic:

- Velodyne laser scanner

Fast traffic:

- Four radars (front and rear bumper)

Traffic lights:

- Camera (near the rear-view mirror),

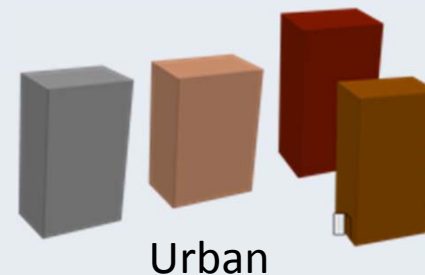
Navigation/motion:

- GPS, Inertial measurement unit (IMU),
Wheel encoder

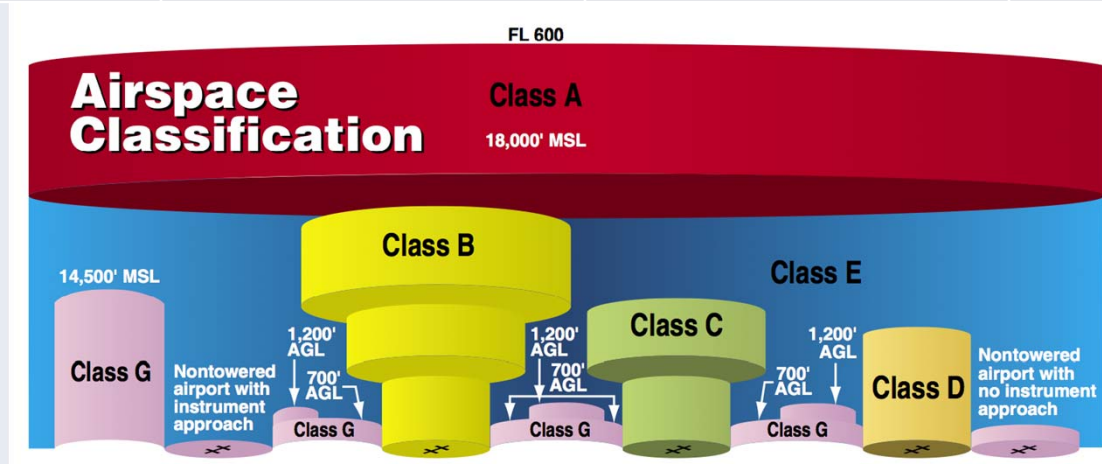
Environment	Ground vehicles	Aerial vehicles	GNSS
National airspace		X	Available
Rural, open-sky	X	X	Available
Rural, foliage	X	X	Challenged
Suburban	X	X	Available
Urban	X	X	Challenged
Indoor*	X	X	Not available/very low signal strength

Important note: where GNSS is normally available, service could possibly be denied by interference (intentionally or unintentionally) or, worse, spoofed.

*includes structured environments such as buildings and unstructured environments such as mines and caves



Environment	Ground vehicles	Aerial vehicles	GNSS
National airspace		X	Available

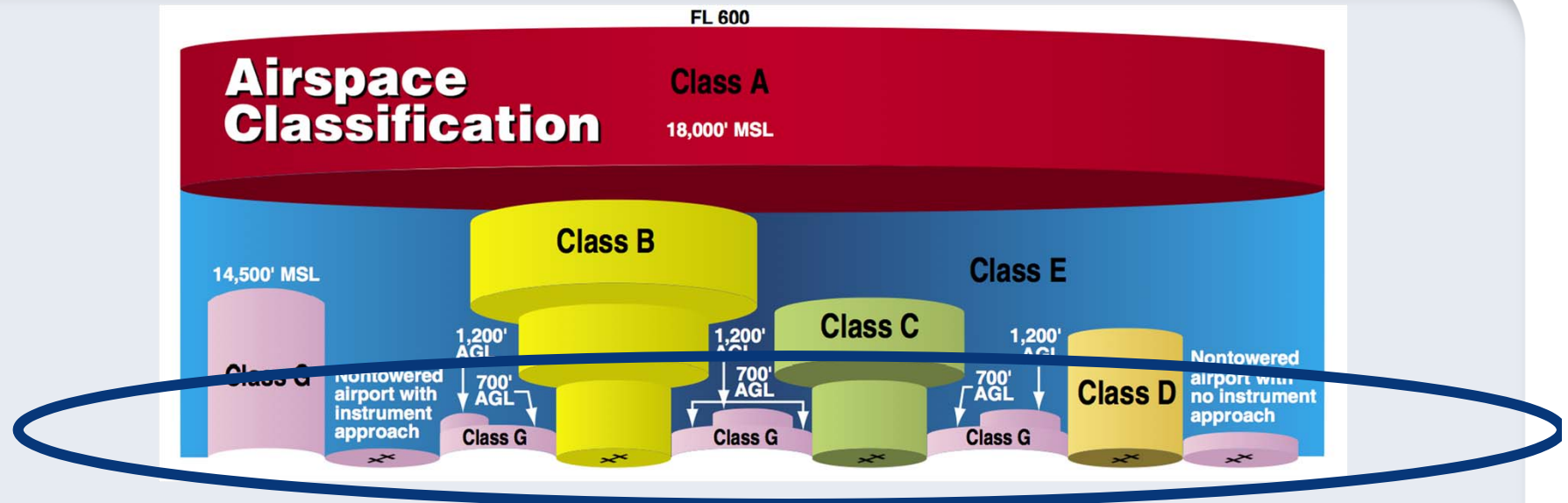


From FAA:

- Model aircraft below 400ft, away from populated areas and full scale aircraft, not for business purposes.
- Scan Eagle and Aerovironment's Puma have been certified for commercial use (only authorized to fly in the Arctic)
- Public entities (federal, state and local governments and public universities) may apply for a Certificate of Waiver or Authorization (COA)

But also:

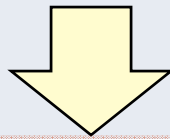
- An NTSB judge dismissed the \$10,000 fine the FAA levied against UAV operator ...



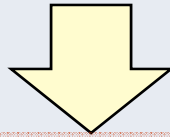
Many operations are envisioned that require (semi-)autonomous operation at low altitudes over or even in populated areas (urban/suburban)

Environment	Aerial vehicles	GNSS
Rural, open-sky	X	Available, vulnerable
Rural, foliage	X	Challenged
Suburban	X	Available, vulnerable
Urban	X	Challenged
Indoor	X	Not available/low signal strength/multipath

*Objective of a navigation system is to provide an accurate Position, Velocity, Attitude, and Time (PVAT) expressed in the coordinates of some geometric reference: **Position, Velocity, Attitude, Time***



***Required Navigation Performance:**
Accuracy, **Integrity, Availability, Continuity, etc.***



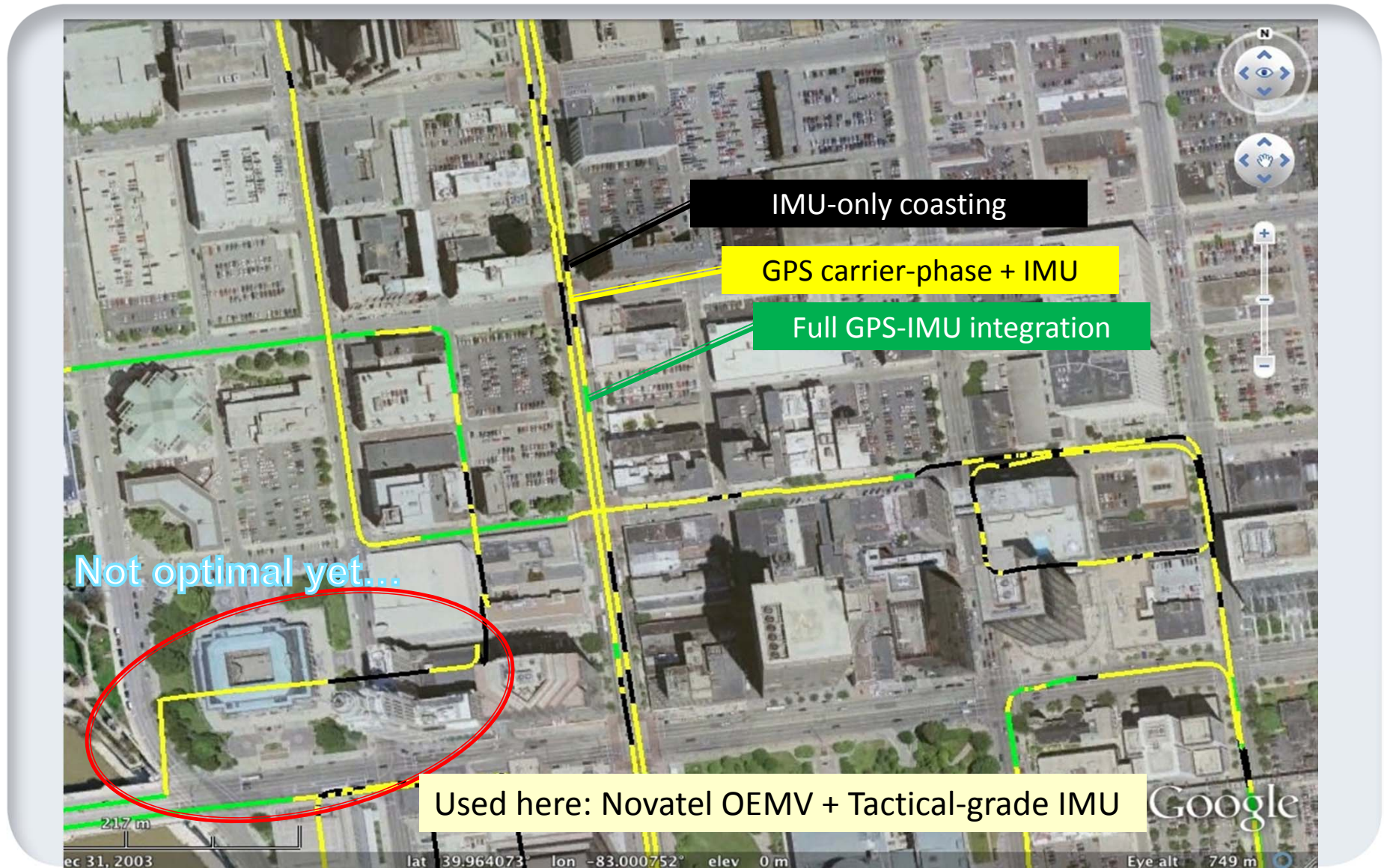
***Integrated Navigation**
Combine (integrate or fuse) data from multiple sensors (or navigation aids) in such a way that the **Required Navigation Performance** of the intended operation can be met.*

But also robust surveillance, collision avoidance, path planning, control, communication, etc.

Unmanned Ground Vehicle: Urban Operation

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

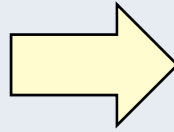
sensoror



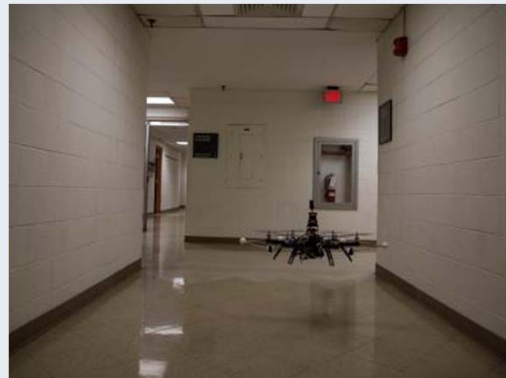
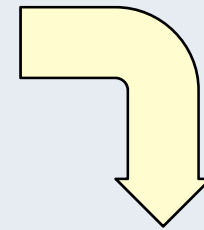
Further Limitations



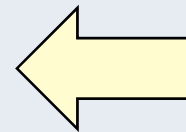
Outdoor with and without foliage



Transition to indoor



“Structured” indoor with multiple path options



Transition to indoor

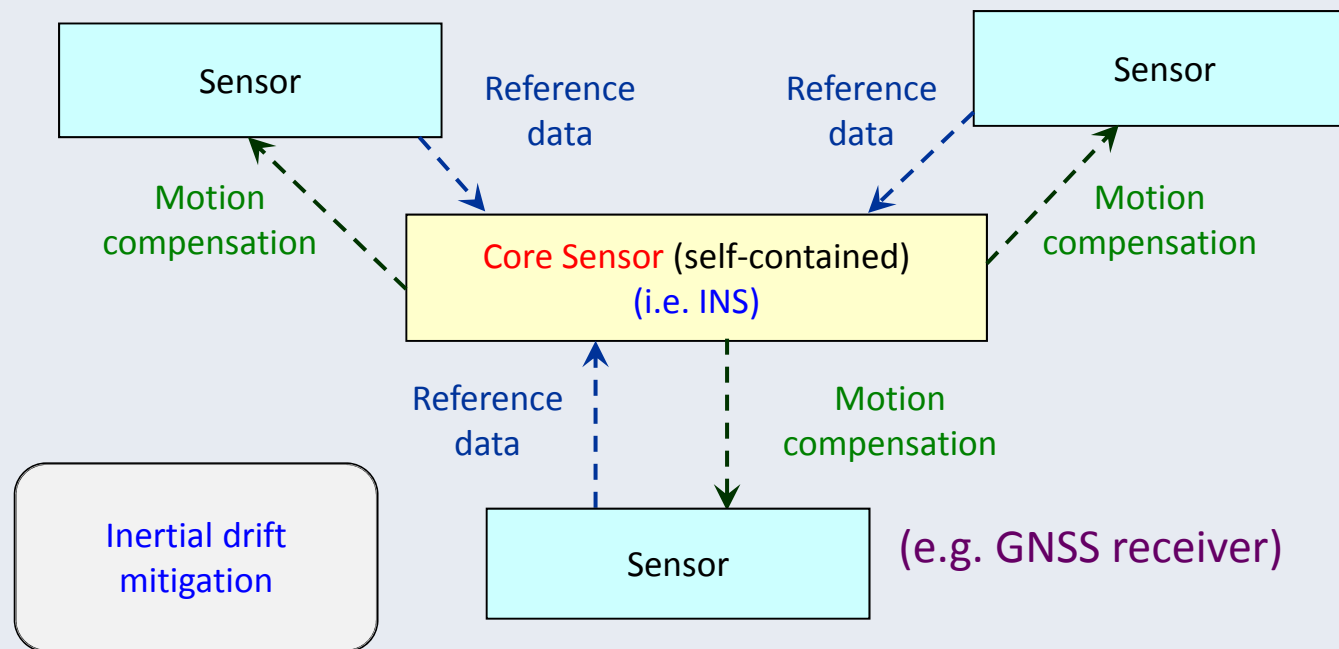
InsideGNSS sensoror

Based on: R. Siegwart et al, Introduction to Autonomous Robotics, Second Edition.



(e.g. vision sensor)

(e.g. laser scanner)



- Integrated navigation to satisfy the RNP requirements
- In addition:
 - Secondary sensors can be used for their original primary function such as 3D mapping, collision avoidance, precision agriculture, etc.
 - And exploit the robust (and in case GNSS is present absolute and accurate) position, velocity and timing solution.

GNSS/Inertial+ Example 1



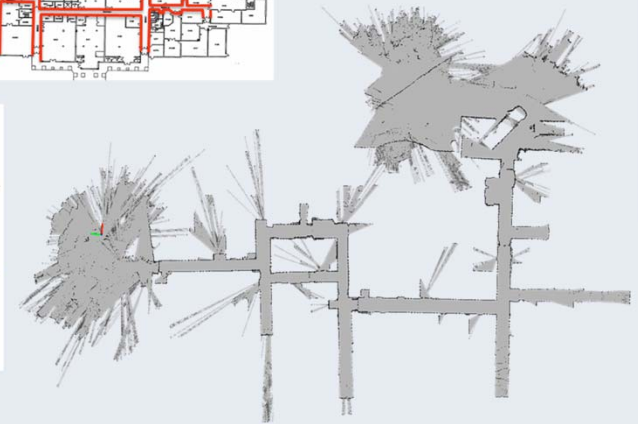
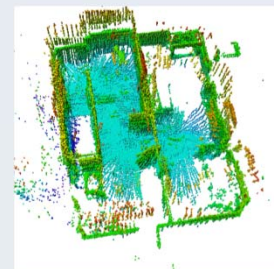
OU 3DR Hexacopter



Vision-based navigation

Payload:

- NovAtel OEMSTAR
- NovAtel L1 antenna
- Hokuyo laser scanner (3)
- Firefly MV camera
- Xsens IMU
- Atom onboard processing unit running Ubuntu and ROS
- APM 2.5 Ardupilot



6DOF SLAM

GNSS/Inertial+ Example 2

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

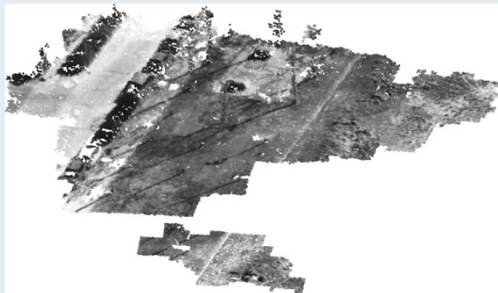
sensoror



CTAE/ASCAMM ICARUS Quadcopter



Mapping mission



3D Structure-from-motion results

*Collaboration between Ohio University and
CTAE/ASCAMM Barcelona, Spain*



3D Structure-from-motion results

GNSS/Inertial+ Integration



Andrey Soloviev
Principal, *QuNav*

- Main integration approaches:
 - *Loose integration*: solution-level data fusion;
 - *Tight integration*: measurement-level data fusion;
 - *Deep integration*: data fusion at the level of signal processing
- Main benefits
 - PNT availability (bridging over GNSS outages);
 - Redundant information to reject “bad” measurements (including potential protection against spoofing);
 - Improved robustness of signal processing (weak signals, jamming)

- Example: navigation under dense canopy

GPS-only solution



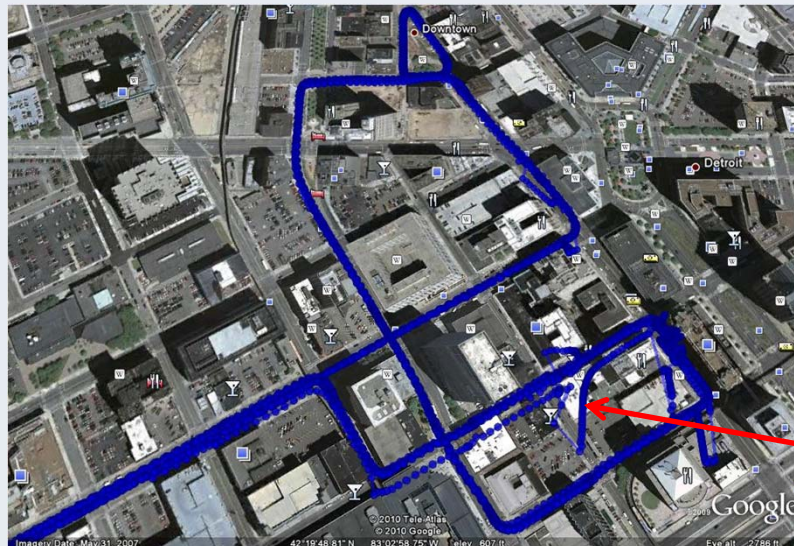
Very sparse position fixes are obtained

Deep GPS/Inertial Integration



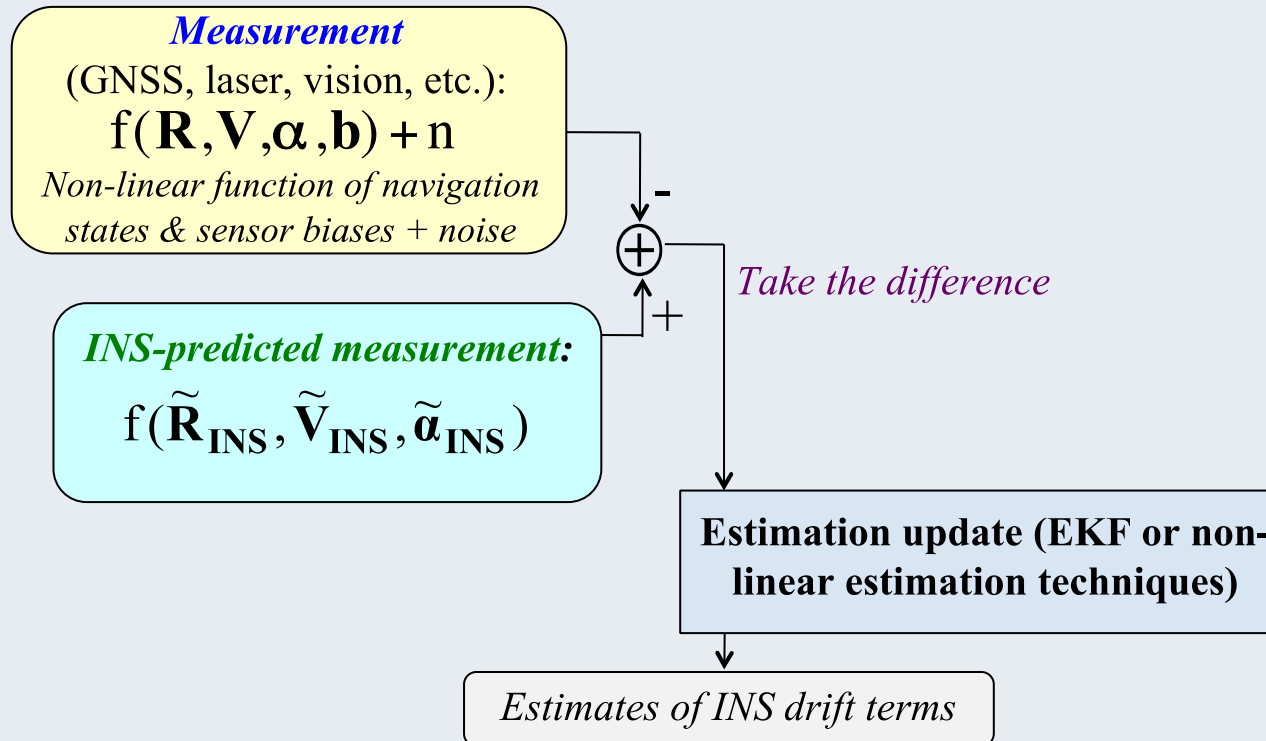
Reliable trajectory reconstruction is maintained

- GNSS/INS integration improves the solution availability, however, performance can be still limited (especially, when integrating with lower-cost IMUs);
- Example: navigation in dense urban areas

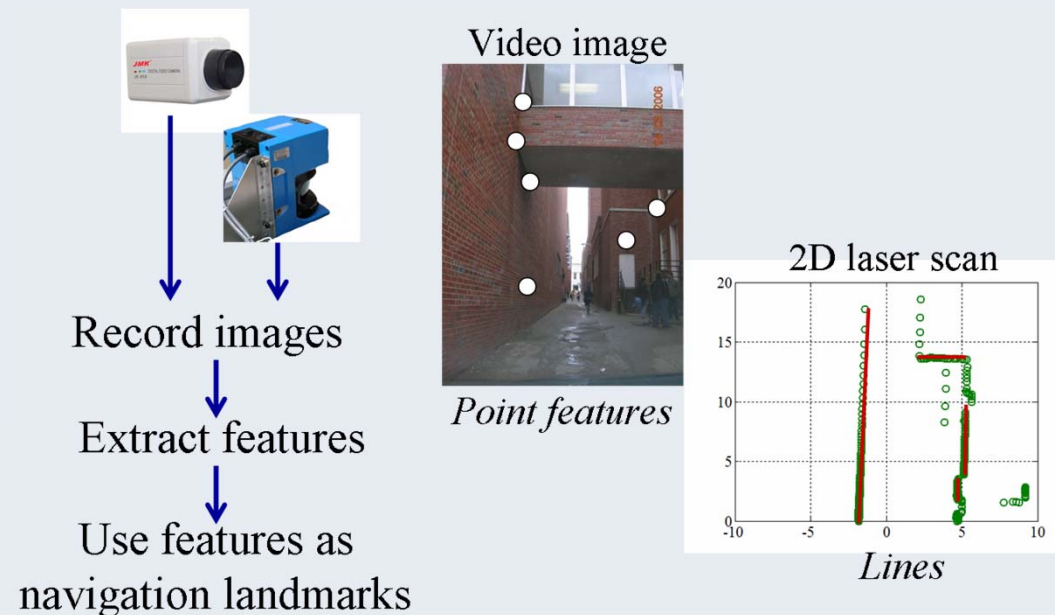


*Solution
discontinuities*

- Generic integration approach
 - INS is a core sensor;
 - Other sensors provide aiding data for the inertial drift mitigation



- o Motivation: Image-based approaches efficiently complement the GNSS navigation
- o GNSS-denied scenarios: **Natural or man made obstacles attenuate satellite signals**
- o Image-based approach: **Obstacles are used to navigate**



Example of Improved Availability

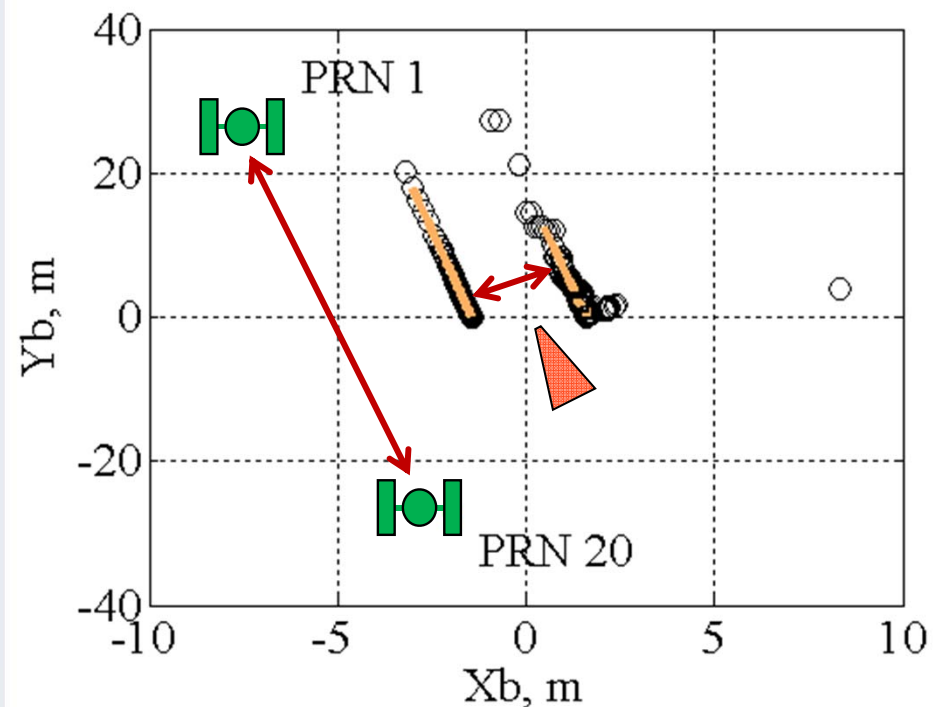


red segment of vehicle path

Laser measurements provide
cross-track position *observability*

GPS measurements provide
along-track position *observability*

Scan image and SV locations projected
onto the scanning plane

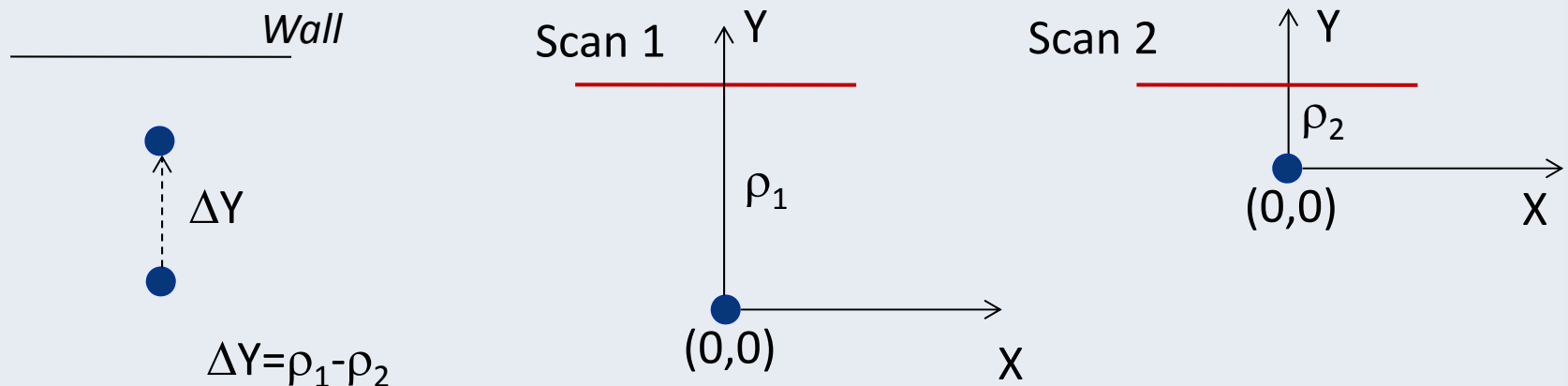


red segment of vehicle path

- **Feature-based approach:**
 - Use one or more images to observe features and apply feature parameters for navigation.
- **Correlation-based (or map-based) approach:**
 - Use one or more images to form a map of the environment; then correlate/compare this map to either an a priori map or a previously derived map to estimate the user position, velocity and attitude.
- **Integration with inertial sensors:**
 - Integrate the feature- or correlation-based approaches with the INS to obtain a solution that has a higher level of accuracy, availability, integrity and continuity.

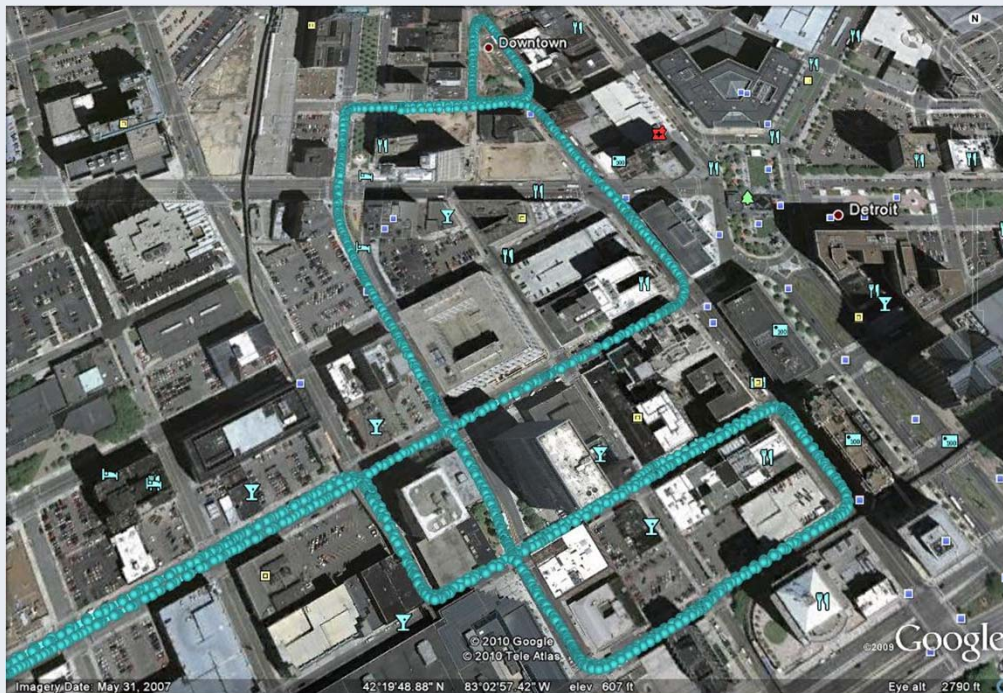
A simplified conceptual explanation

- o Line-based navigation using laser scanner
- o Measurement of displacement



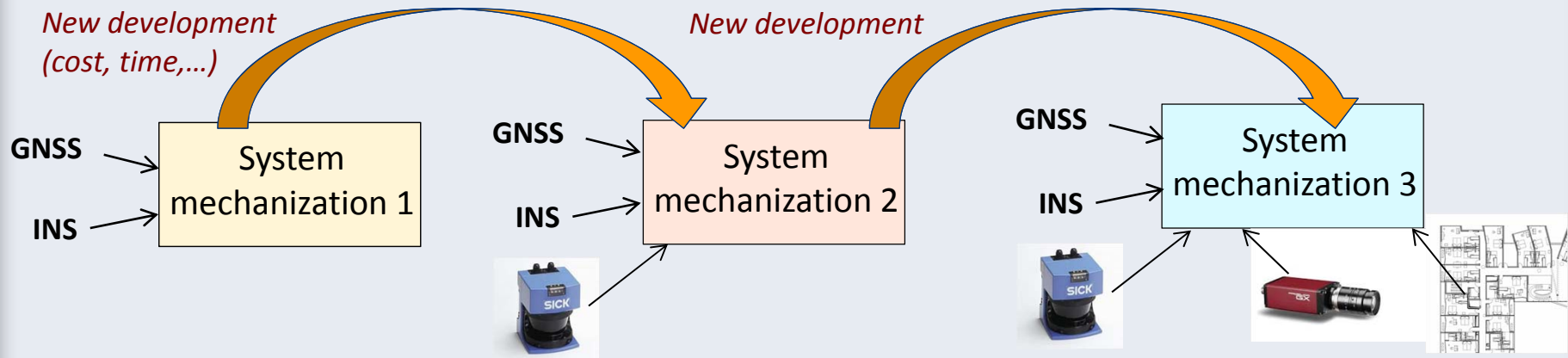
Displacement is estimated based on changes in line ranges

- Example results: GPS/Inertial/Lidar data fusion in urban canyons

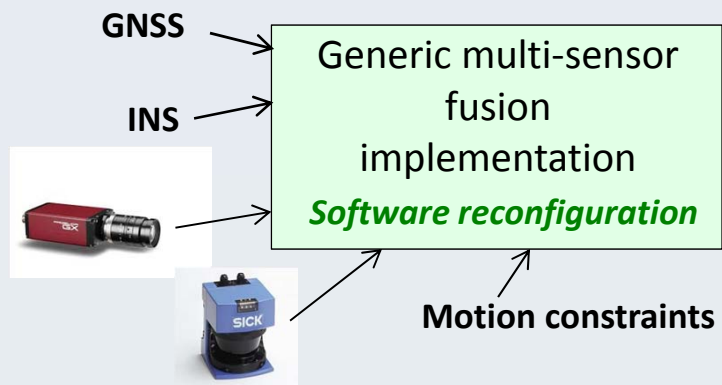


*Continuous
trajectory
reconstruction*

Current state-of-the-art multi-sensor mechanizations: *sensor specific*

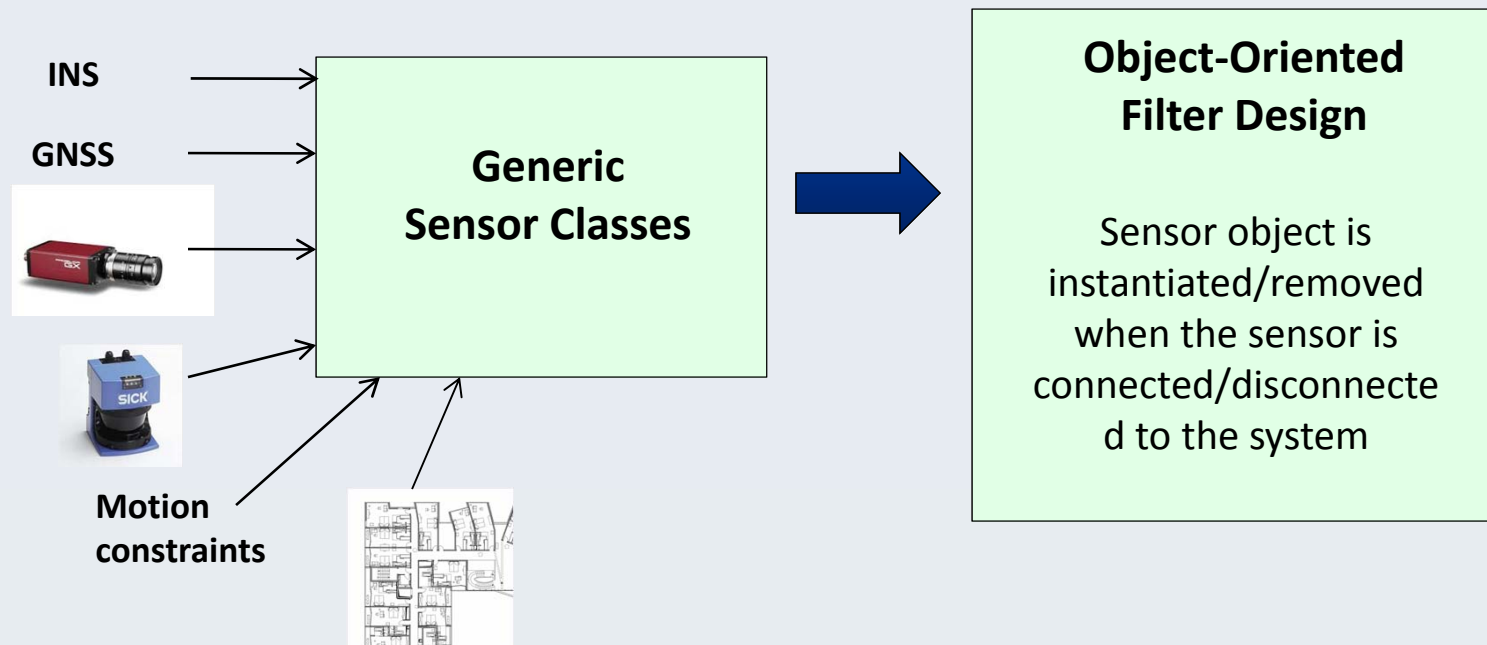


From *sensor-specific* implementations to *generic plug-and-play* navigation



- **System can be reconfigured** for a specific sensor set (prior to the mission) and/or on-the-fly as sensors are connected/disconnected;
- **No additional design efforts are required to incorporate new sensors!**

- It is difficult, if not *impossible*, to create an *exhaustive list of all aiding sensors*;
- Yet, it is *possible* to categorize *aiding measurements* into *generalized types*;
- Hence, *RIFE design is abstracted for generic sensors* that are grouped into classes according to the type of their measurements

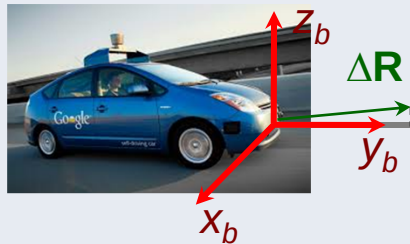


*Developed under DARPA All Source Positioning and Navigation (ASPN) program

Relative position observables: change in position vector projected onto some axis (or axes) of the navigation or body-frame

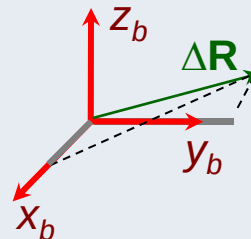
Examples

Odometer



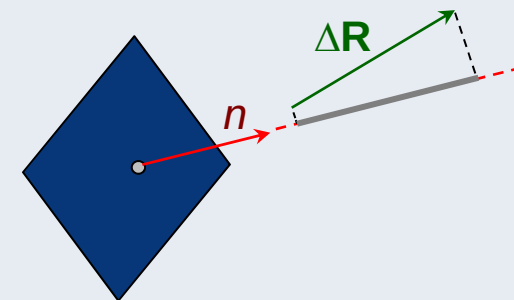
Position change projected onto forward axis

Position change from 2D lidar



Position change projected onto x and y axes of the body-frame

Planar surfaces extracted from consecutive 3D lidar images



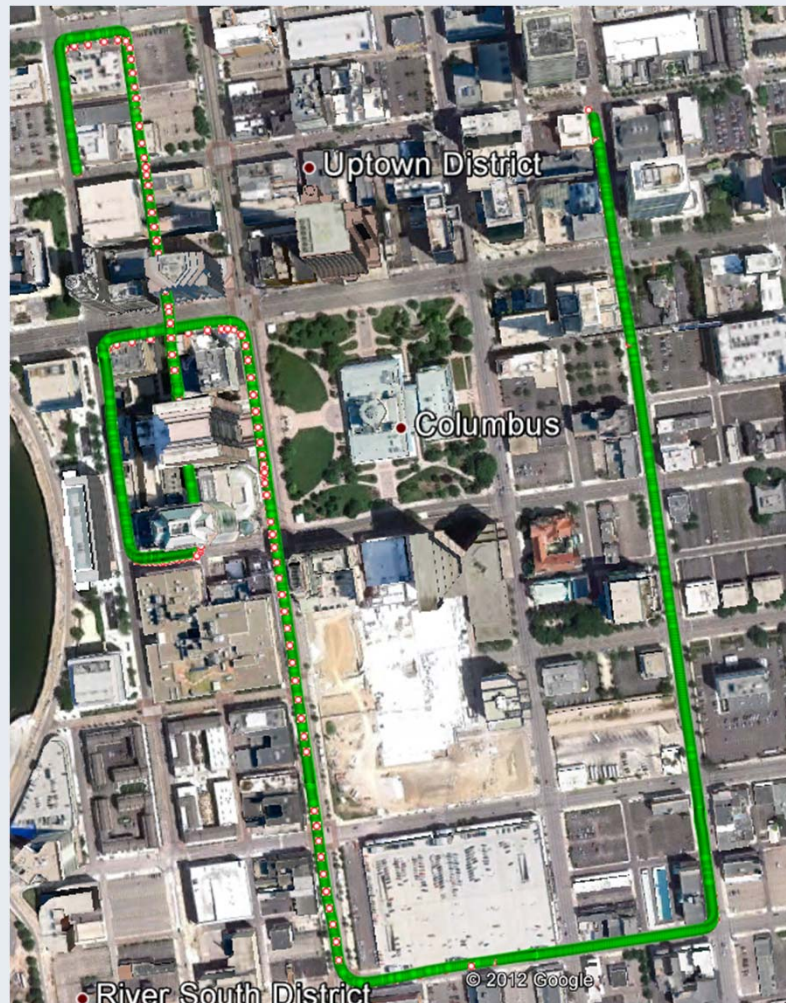
Position change projected onto the plane normal vector

Plug & Play Sensor Fusion: Example Test Results

InsideGNSS
GPS | GALILEO | GLONASS | BEIDOU

sensoror

Urban navigation



Sensors

IMU: HG764G

GPS Pos Vel: Novatel-5

Camera: Prosilica-1

Camera: Prosilica-5

Stereo: Prosilica-6-7

Stereo: Prosilica-3-4

Laser 2d: Sick360

Odometer-2

Mag compass: HMR2300-2



Reference



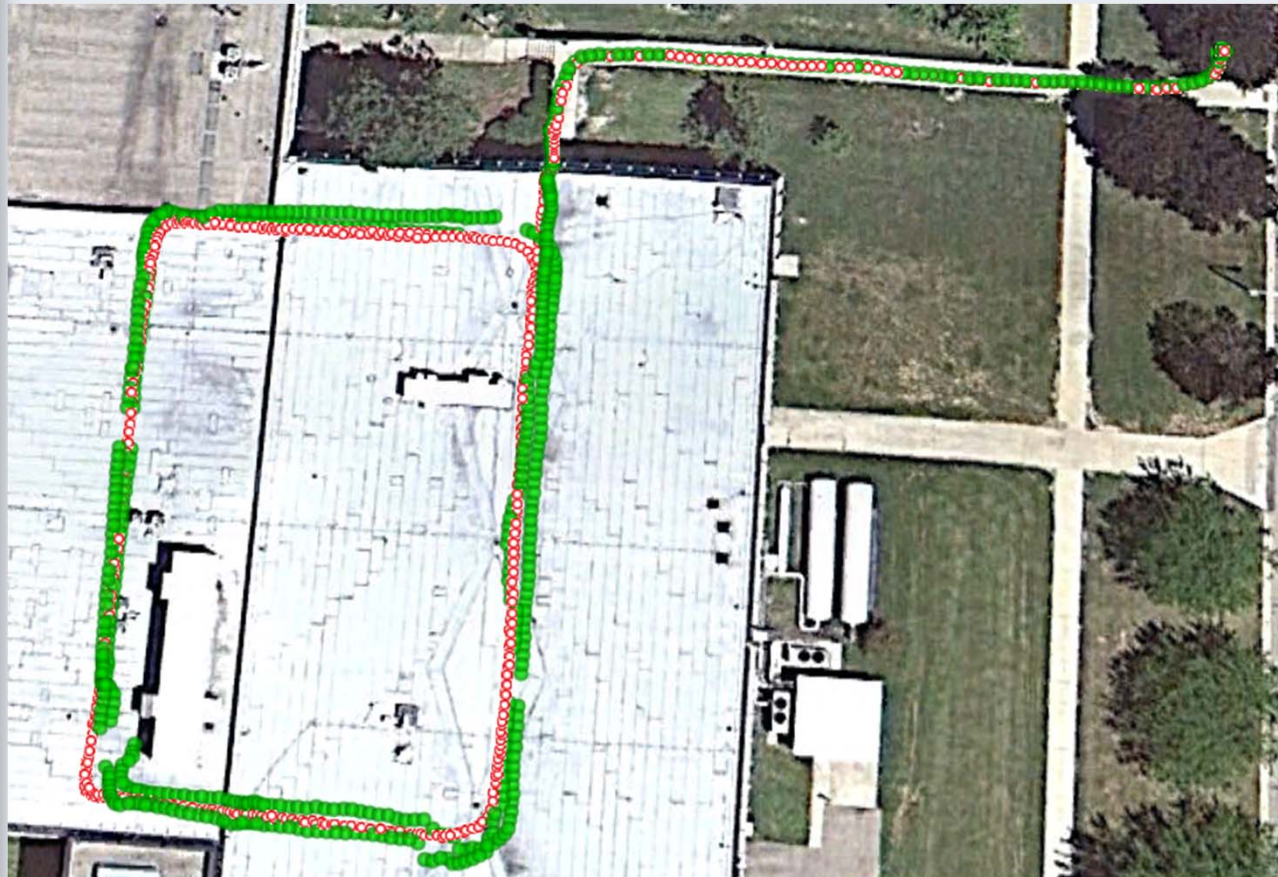
RIFE solution

Plug & Play Sensor Fusion: Example Test Results

InsideGNSS
GPS / GALILEO / GLONASS / BEIDOU

sensoror

Indoor navigation



Sensors

IMU: HG1700

GPS Pr Dr: SPAN

Camera: CasioCam

Camera: MS Kinect

Barometer

Magcompass

RFID



Reference



RIFE solution

Ask the Experts – Part 1



Maarten Uijt de Haag
Cheng Professor
Ohio University



Andrey Soloviev
Principal
QuNav



Sandy Kennedy
Director of Core Cards
NovAtel Inc

Poll #2

What other sensors are you most interested in other than using GNSS+ Inertial? (select your top two):

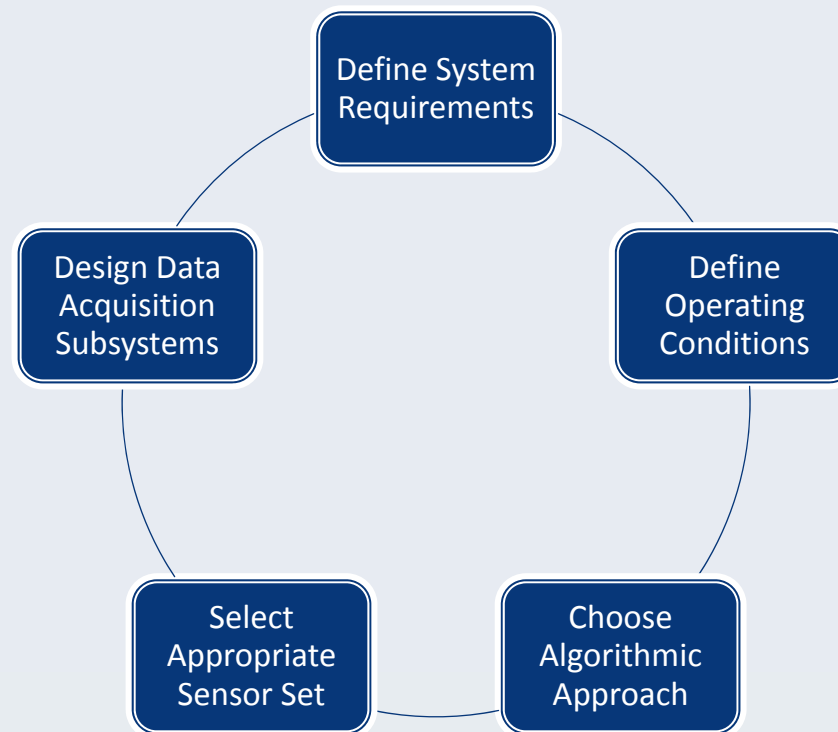
- *Odometer*
- *Vision*
- *Lasers or Radar*
- *Maps*
- *Magnetometer and Pressure Sensor*

GNSS/INS+ Product Development

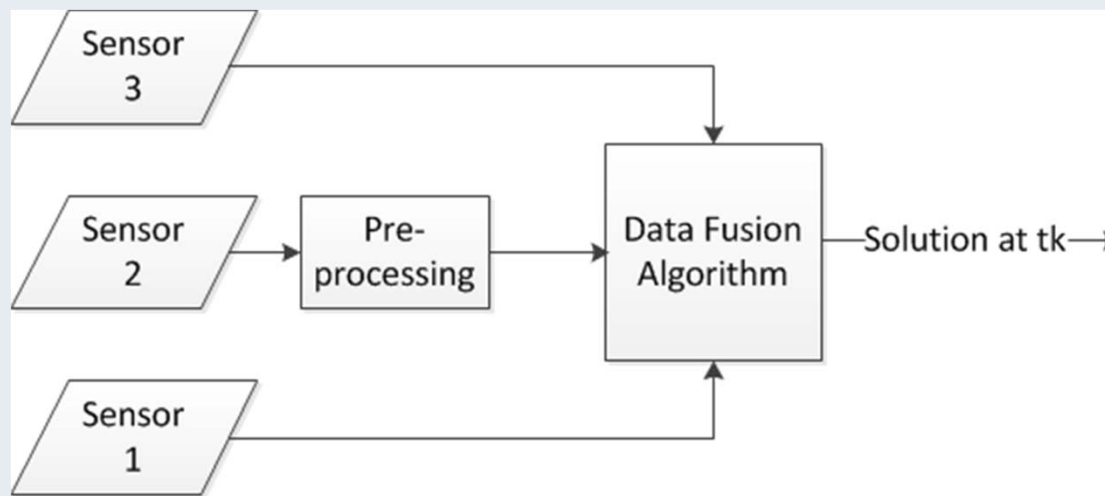


Sandy Kennedy
Director, Core Cards
NovAtel Inc.

- The benefits of a GNSS/INS+ system are clear, but how do we build it into a product that the marketplace needs?
- The system must be useful and effective
 - Needs to work within specification
 - Every time without onerous setup requirements
 - Not assured of ideal operating conditions
- Must be manufacturable and testable.
 - Low unit to unit variability
 - Repeatable build process

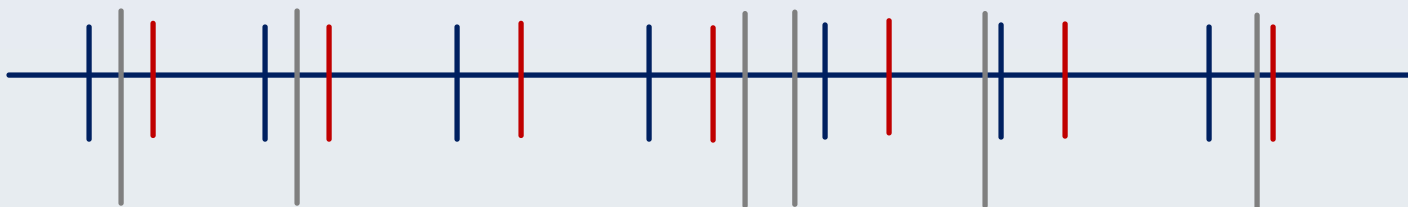


- Data Acquisition details are often glossed over when discussing algorithmic approaches
 - Reliable system operation hinges on this!

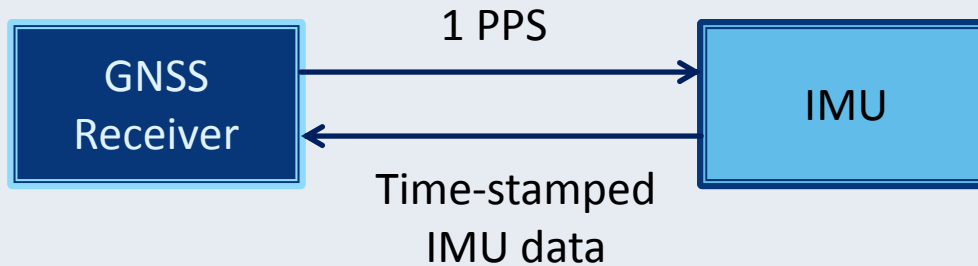


- What is the interface to each sensor?
- Associated latencies?
- Need correct time of validity on each data stream

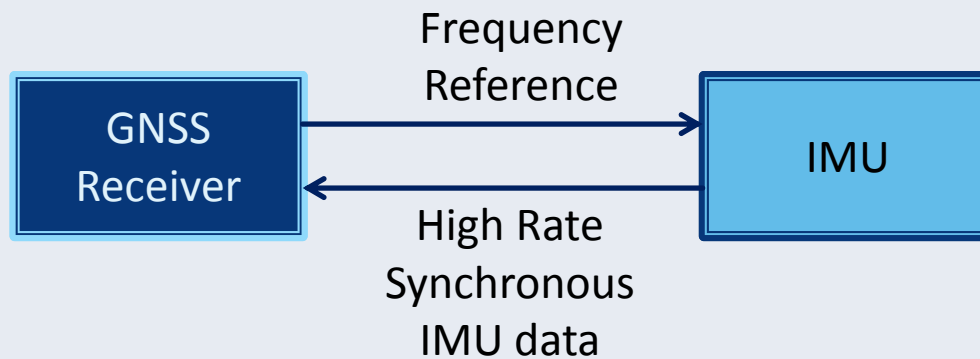
- Synchronous data
 - GNSS data and solutions (ie raw carrier phases and attitude solution)
 - Some IMUs can be synced to GPS time
- Asynchronous data
 - Some IMU data is asynchronous to GPS time
 - External events (ie camera exposure)



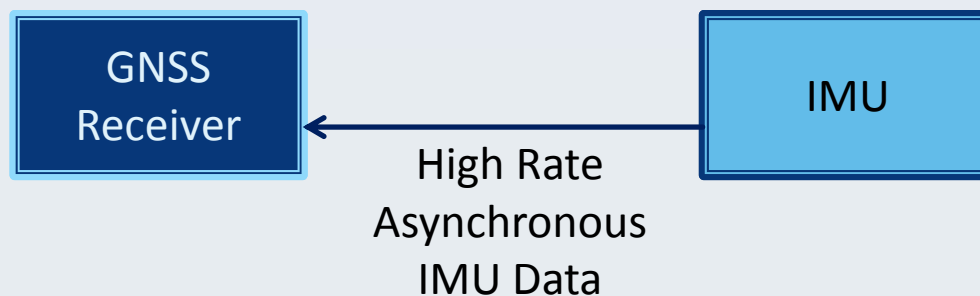
Example: IMU Data



- IMU clock interpolates between 1PPS boundaries



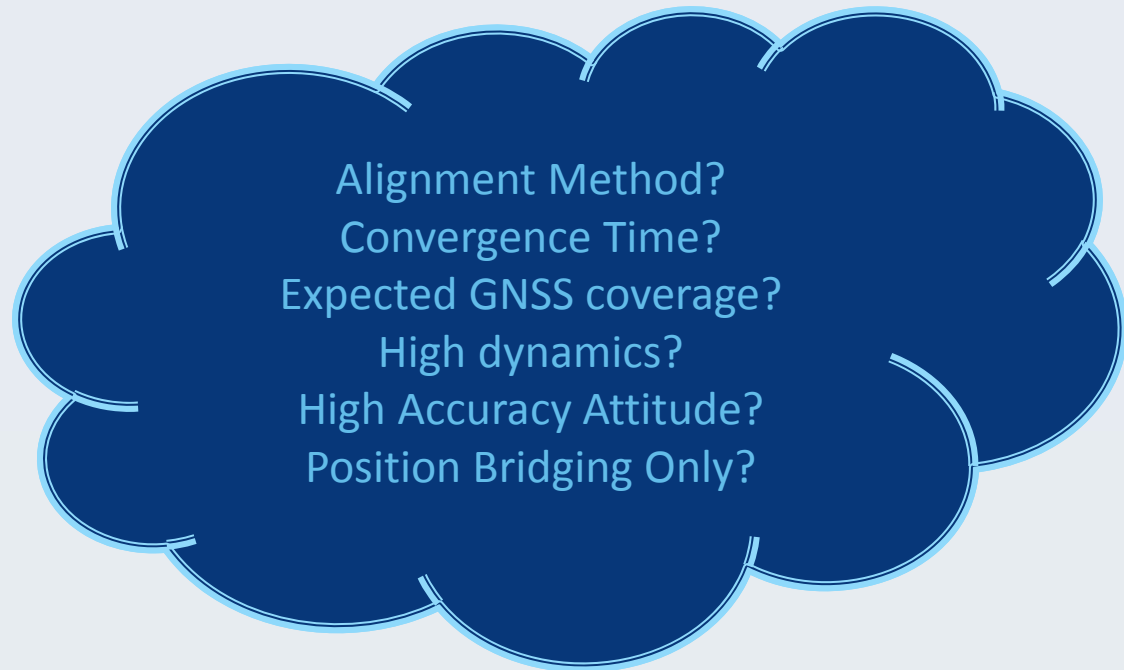
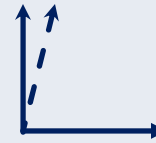
- Known offset from synchronous trigger to data ready



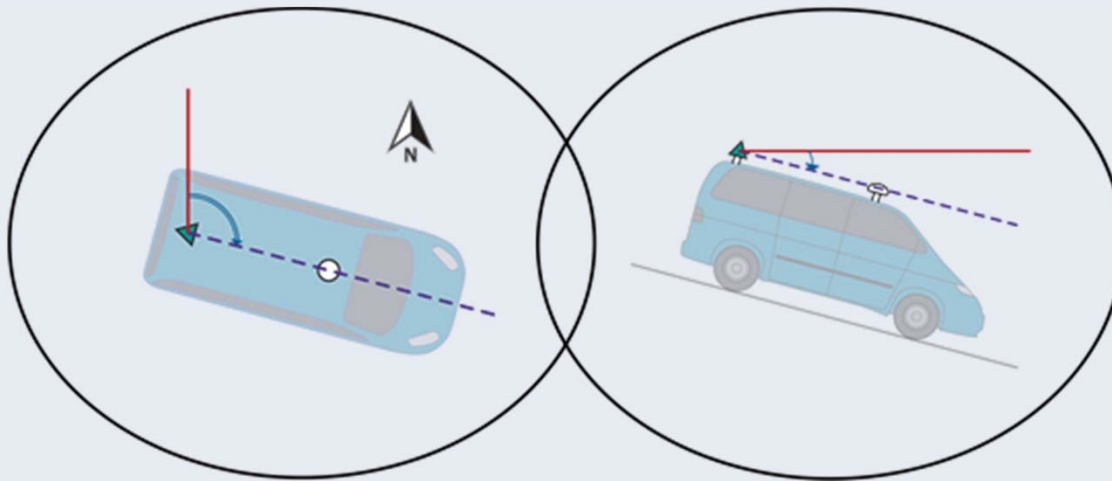
- Need leading input pulse to precisely time stamp data via a mark input

- IMU – yes!
- GNSS receiver and antenna – yes!
- Other sensors
 - Wheel sensor (odometer)?
 - Dual GNSS antenna and receiver (for attitude)?
 - Magnetometer?
- Perhaps better to think of what input measurements would be useful
 - External position
 - External attitude
 - External position displacement or range

- Bias Stability
- Non-orthogonalities/misalignments in the gyro and accel triads
- Scale factor errors
- Noise
- Size
- Cost
- Export classification
- MTBF



- 2nd GNSS antenna (and receiver)
 - Useful for alignment
 - Must measure or estimate angular offset between GNSS baseline and IMU axes
 - Attitude updates
 - Do you expect to be stationary (or constant velocity) for long periods?
 - But can the application bear the size of 2 antennas with sufficient separation?



- Wheel sensor/odometer/velocity sensor
 - Do you have wheels? Can you mount an external wheel sensor? Does an onboard odometer sensor have sufficient resolution/accuracy? Do you expect extended total GNSS outages?
 - HW input (pulses/ticks) or data record input?
 - Velocity update – instantaneous velocity measure or average over last epoch?



- Magnetometer
 - Quality control of data – are you near a lot of electricity and metal?
 - Accuracy of useful heading update
- Altimeter/barometer
 - Can you expose the sensor to the ambient air? Does your vehicle change height rapidly? (ie what is response time of sensor to changes)

- Instead of interfacing to various sensors, you can accept a generic input that the overall system user has derived
 - External position (of the IMU or known point)
 - External attitude (of the IMU or known frame)
- Provided this external input data can be time stamped correctly and provided to the GNSS/INS fast enough
- Provided this external input data has a correct quality indicator with it
 - A standard deviation that truly reflects the error
 - Doesn't add any more unknowns to be modeled
- If these criteria are not met, you can get sub-optimal performance
 - Which means customer support calls

- Select the appropriate sensor set
 - Know the requirements of your target application
 - Understand how individual sensor errors impact the overall system error budget
- Make a reliable data acquisition sub system
 - HW and FW
- Implement reliable/robust data processing algorithms
- Test, test, test!

Visit www.insidegnss.com/webinars for a PDF of the presentations

Register for Unmanned Systems Week Sessions 3 at www.insidegnss.com/webinars

- Fri, June 6th : Unmanned Solutions & Applications Day

Contact Info:

- Sensoror – www.sensoror.com/
- Sandy Kennedy – sandy.kennedy@novatel.com
- Andrey Soloviev – soloviev@qunav.com
- Maarten Uijt de Haag – uijtdeha@ohio.edu

Poll #3

Which best describes your GNSS+ Inertial application?

- *Low dynamic and High accuracy*
- *Low dynamic and low accuracy*
- *Highly dynamic and high accuracy*
- *Highly dynamic and low accuracy*

Ask the Experts – Part 2



Maarten Uijt de Haag
Cheng Professor
Ohio University



Andrey Soloviev
Principal
QuNav



Sandy Kennedy
Director of Core Cards
NovAtel Inc

www.insidegnss.com
www.sensoror.com