Comparing Tightly-Coupled versus Loosely-Coupled Integration for GNSS and INS

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Veripos
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GNSS Technology

- GNSS satellites
  » Located approx 20,000km above surface of the Earth
  » Transmit power 50W
- Signal weak by time it reaches user antenna
- Signal susceptible to degradation through interference
  » Propagation through the atmosphere
  » Jamming (intentional or un-intentional)
- Require line-of-sight to receive signal
  » Obstructions (like platforms) will mask the signal

Result = unreliable position
Inertial Technology

• Inertial Navigation involves determining a position through dead reckoning
  » INS calculates position, velocity and attitude changes using gyros and accelerometers
  » Completely self contained and therefore inherently robust
  » Continuous output with very good short term accuracy

• But drifts with time…
  » Magnitude will depend on quality of sensor
  » High quality sensors = more cost
  » Also potential export restrictions (ITAR)
  » Integration with external sensors can constrain the drift
GNSS & INS Characteristics

INS Characteristics

• Uses rigidly mounted inertial sensors to measure acceleration and rotation
• Provides relative position, velocity, and attitude
• High solution output rate, up to 200Hz
• Accuracy is stable epoch to epoch, but drifts exponentially over time without aiding
• Drift rate depends on sensor stability & observability to estimate sensor errors

GNSS Characteristics

• Requires external input (satellite signal). Must have visibility to the sky
• Provides absolute position and velocity
• Solution rate generally limited to below 100Hz
• Accuracy is stable long term but noisy epoch to epoch within error envelope
• Accuracy dependent on satellites tracked, geometry, and positioning mode
Advantages of GNSS & INS

• High output rate (200Hz)
• Smooth solution epoch to epoch
• Full attitude solution
  » Provides full roll, pitch and azimuth solution continuously (after alignment)
• Position Solution Continuity
  » Solution bridged by INS in places where GNSS is masked or completely denied
  » Reduce impacts of scintillation and interference
• Common Forms of GNSS+INS Coupling
  » Loose
  » Tight
  » Deep
• Veripos has been using Loose Coupling but now working with Deep Coupling
GNSS + INS Integration

- Advantages over Loose Coupling:
  - No GNSS position solution required only measurements from satellites
    - Use pseudorange, carrier phase & Doppler observations to constrain inertial drift
    - Benefit of these updates is more dramatic as the IMU quality decreases
  - Intelligent measurement selection
    - Using INS to QC individual GNSS measurements from SV’s
    - Outlier observations from satellite are rejected before entering filter
  - Ability to work with a range of IMU sensors
    - Can choose IMU based on performance, cost
  - Computing 2 position solution simultaneously
    - GNSS only and GNSS/INS
  - Aids rapid satellite reacquisition and faster position convergence
Integration Architectures

Loose Coupling

GNSS Position used to aid or couple with the INS

Requires GNSS to compute a position & QC metrics for use in combined solution.
Loose Coupling

- **GNSS Receiver**
  - Signal Tracking
  - Outputs: $\Phi, \rho$

- **GNSS Positioning Algorithms**
  - Input: $\Phi, \rho$
  - Output: GNSS Position & Velocity

- **INS Filter**
  - Inputs: $\Delta \theta, \Delta v$
  - Outputs: INS Position, Velocity, Attitude

- **IMU**
  - Outputs: $\Delta \theta, \Delta v$
Integration Architectures

**Tight Coupling**

Raw GNSS observations used to aid/couple with INS

Full access to low level quality metrics with perfect timing

Less impacted by the degradation of GNSS as the combined solution is not dependent on computed position
Tight Coupling

GNSS Receiver

Signal Tracking

GNSS Positioning Algorithms

INS Filter

IMU

$\phi, \rho$

$\phi, \rho$

$\Delta \theta, \Delta v$

GNSS Position & Velocity

INS Position, Velocity, Attitude
Integration Architectures

Deep Coupling

Information from the INS filter used to aid GNSS tracking and/or GNSS solution acquisition
Deep Coupling

GNSS Receiver
  Signal Tracking
  \(\phi, \rho\)
  \(\phi, \rho\)

GNSS Positioning Algorithms

INS Position, Velocity, Attitude

INS Filter
  \(\Delta\theta, \Delta v\)

IMU

GNSS Position & Velocity

INS Position, Velocity, Attitude
Integration Architectures

**Loose Coupling**

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**Deep Coupling**

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IMU Performance Evaluation

**STIM300**
- MEMS sensor
- Non-ITAR or Export Control
- Low Cost

**Lodestar**
- Ring Laser Gyro (Honerywell)
- Export Control
- High Cost
Position Error during Complete GNSS Outages
Heading Error during Complete GNSS Outages
Test Configuration

- Objective of the trials
  - Evaluate IMU performance
  - Test Deep Coupling vs Loose Coupling

- Dynamic data capture using a van running at a variety of speeds

- Loose Coupling - Lodestar using PPP solution with DGNSS used as backup
  - 4 minute free inertial outage limit

- Deep Coupling - STIM300 using PPP solution with DGNSS used as a backup solution
Deep Coupling (1) - Westhill
Loose Coupling (1) - Westhill
Deep Coupling (2) - AECC
Loose Coupling (2) - AECC
Deep Coupling (3) – Aberdeen City Centre
Loose Coupling (3) – Aberdeen City Centre

No Solution available due to INS drift – no GNSS solution available
No Solution available as free-Inertial solution has timed out – no GNSS solution
SV Tracking
Concluding Remarks

- Deep Coupling GNSS & INS provides a robust position solution
  - Good in noisy environments where satellite tracking affected
  - Intelligent measurement selection
  - Work with range of IMU’s

- Conducting more offshore trials
  - Onboard DSV vessel in North Sea
  - Small vessel operating out of Aberdeen harbor to allow testing of failure modes
  - Data collection ongoing
Questions?