Dynamic Positioning Committee
Marine Technology Society

Sensors

Combining GNSS and Inertial Navigation Systems in Improved DP Position Reference Systems

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We maximize marine performance by providing

THE FULL PICTURE

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Combining GNSS and Inertial Navigation Systems in Improved DP Positioning Reference Systems

Dynamic Positioning Conference 2007

by

Arne Rinnan, Kongsberg Seatex AS

Presentation Outline

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- Track record, 1990 - 1997
- The future of GNSS
- GNSS error sources
- Integrated GNSS/IMU for DP Operations
- GNSS/IMU Solution architecture
- Test flights, 2007
- Conclusion

Track Record

1990 - 1997

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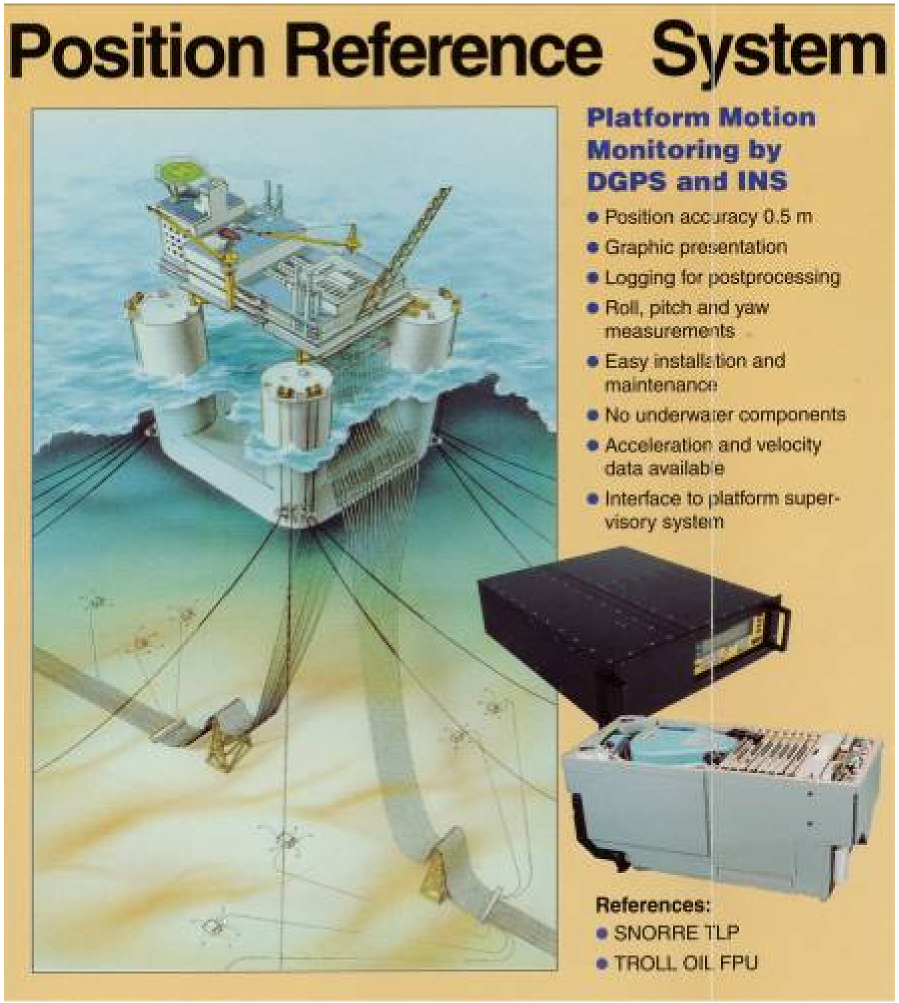
2 x Platform Position Monitoring System

- Delivered to Snorre TLP and Troll B
- Used for precise monitoring of platform dynamics
- Carrier aided DGPS combined with Honeywell ring laser gyro
- “Tight coupling” GPS/IMU solution



5 x Flight Inspection and Calibration Systems

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- Delivered to Civil Aviation authorities
- Used for inspection and calibration of ILS systems
- GPS RTK combined with Honeywell ring laser gyro
- “Tight coupling” GPS/IMU solution

1 x Road Surveying System

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- Delivered to the Norwegian Mapping Authority
- Used for road surveying in Norway and Sweden
- Cost-effective compared to airborne photogrammetry
- DGPS combined with Honeywell Ring Laser Gyro
- “Tight coupling” GPS/IMU solution

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The Future of GNSS

GNSS Compatibility and Interoperability

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- Compatibility: different systems and services can live together
- Interoperability: combined use of systems and services will provide a better solution than individual systems/services
- There are strong drivers for compatible and interoperable Open Service solutions

Existing and Future GNSS(*)

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GNSS	Satellites	Frequencies	FOC	Nationality
GPS	24	2-3	Now	US
Glonass	24	2-3	2009?	Russia
WAAS	3	1-2	Now	US
EGNOS	3	1	2009	EU
Galileo	30	3	2012?	EU
Gagan	2	1	2010?	India
IRNSS	7	2	2011?	India
Compass	35	3	2010?	China
MSAS	2	1	2010?	Japan
QZSS	3	4	2010?	Japan
Combined	**133**	**2-4**		

(*) Specifications and plans subject to change without notice...

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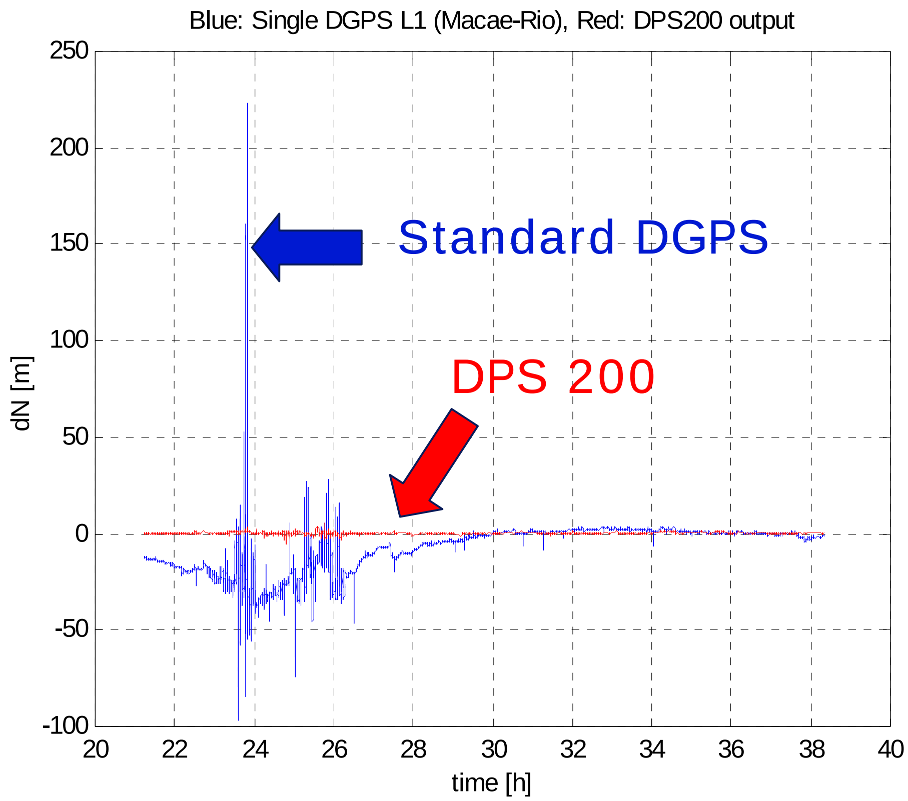
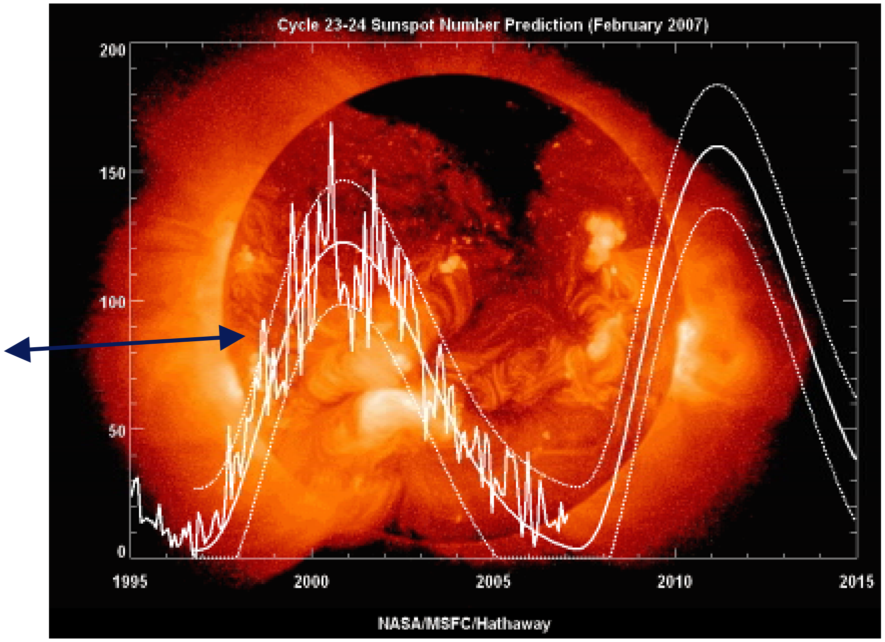
GNSS Error Sources

GNSS Common Mode Failures

- Ionosphere
- Troposphere
- Electromagnetic environment
  - On purpose
  - Accidental
- Multipath
- Signal obstruction
- Hardware faults
- Software bugs

Example: Ionospheric Plasma Bubble Depletion





Current GNSS Error Protection Strategies

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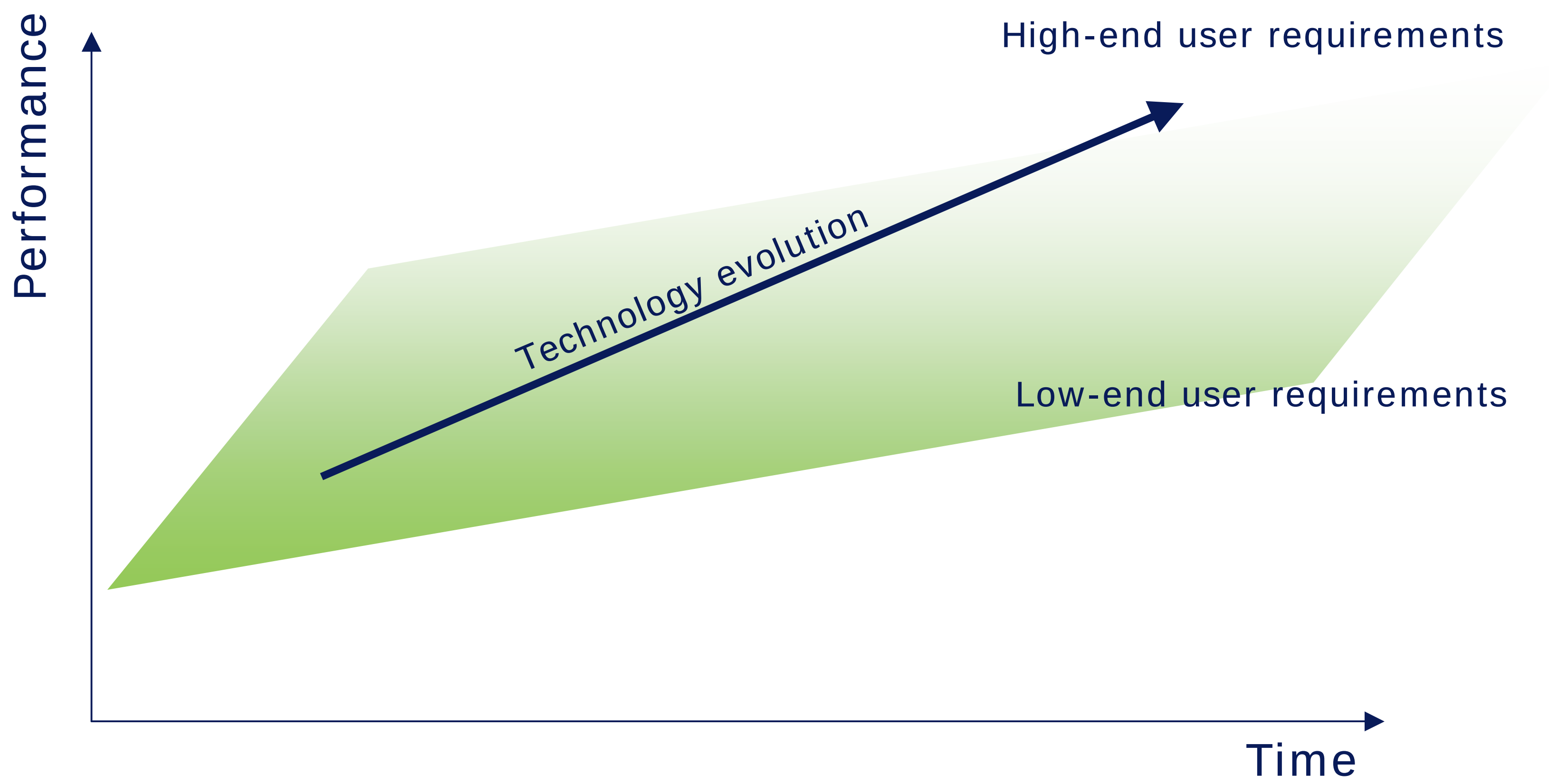
Error source	Protection Strategies	Vulnerability
Ionosphere	Differential corrections Multiple frequencies Multiple satellite constellations	High
Troposphere	Differential corrections Model compensation	Low
Hostile EM interference	Multiple frequencies	Medium
Accidental EM interference	Multiple frequencies Antenna installations	High
Multipath	Signal correlator techniques Code-carrier filtering Multiple frequencies	Low
Signal obstruction	Multiple satellite constellations Antenna installations	Medium
Hardware faults	Redundant installations	Medium
Software bugs	Development standards Signal simulation SW architecture Testing, testing, testing…	Medium

Still Need for Improvements



GNSS Technology Limitations

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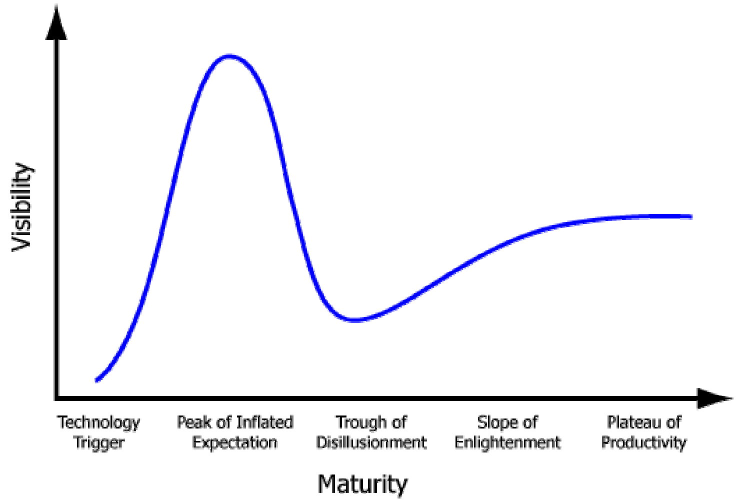
- There will be limits to the level of performance of GNSS solutions - like every other technology – constrained by underlying fundamental principles
- Fusion between different principles might have the potential to overcome these limitations
- There is a long tradition for integrating GNSS and Inertial technology



Gartner's hype curve – a reminder…

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Integrated GNSS/IMU for DP Operations

Advantages for DP Operations

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1. Improved availability of GNSS signals
   - Re-acquisition of satellite signals
   - Reduced risk of re-initialization for high precision solutions
2. Improved reliability of Position and Velocity
   - RAIM
   - Integrity check of GNSS data
3. More reliable and accurate lever arm compensation of Position and Velocity
4. Back-up Position and Velocity for a limited period of time during periods when no GNSS signals are available

Challenges/Pitfalls

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- Cost of IMU/INS technology
  - Utilize emerging, “low-cost”, technologies (MEMS, FOG)
  - Focus on real performance requirements – avoid over specification
- Complexity of installations and maintenance
  - Training and awareness
  - Toolbox
- Complexity to DP operator
  - Careful Design of User Interfaces
- Export licenses
  - Adapt technical solutions to regulative categorization
- Processing power requirements
  - CPU utilization
  - Software architecture
- Regulations?
  - Needs clarification

Regulatory Positions

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”Two of the position reference systems may operate on the same principle. A Single failure is not to affect simultaneously more than one position reference system, i.e., no common mode failures.”, ***ABS (4-3-5) Section 15.7.2***

”When more than one position reference system is required, at least two shall be based on different principles.”, ***DNV (6-7-3) Section C101***

”At least three position reference systems incorporating at least two measurement techniques as defined in 4.3.2 are to be provided and are to be arranged so that a failure in one system will not render the other system inoperative.”, ***LRS (7-4) Section 5.3.4***

”When two or more position reference systems are required, they are not all to be of the same type, but based on different principles and suitable for the operating conditions.”, ***BV Section 4.43.14***

”When two or more position reference systems are required, they are not both (all) to be of the same type, but based on different principles and suitable for the operating conditions.”, ***CCS Section 6.8.1***

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A Regulatory Challenge

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What about hybrid systems, like integrated GNSS/IMU, based on at least two completely different physical principles?

Standards are always out of date.

That is what makes them standards.

Alan Bennett

GNSS/IMU Solution Architecture

Traditional Approach I – Easy…

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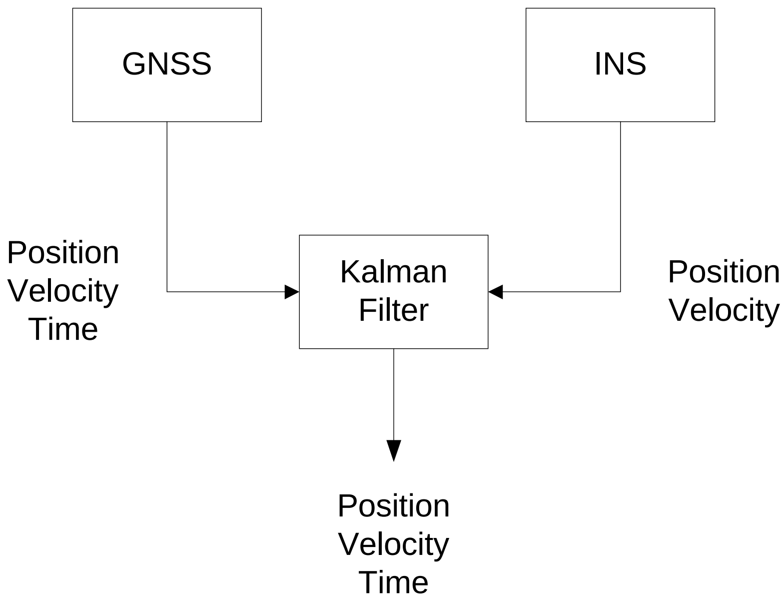
"Loose Coupling"



- Combining position and velocity from GNSS and INS
- Lever arm compensation of position and velocity possible
- Position available during short GNSS outages but requires high grade INS
- "Sensor" aiding not possible
- Advanced GNSS processing capacity wasted

Traditional Approach II – a Little More Complicated...

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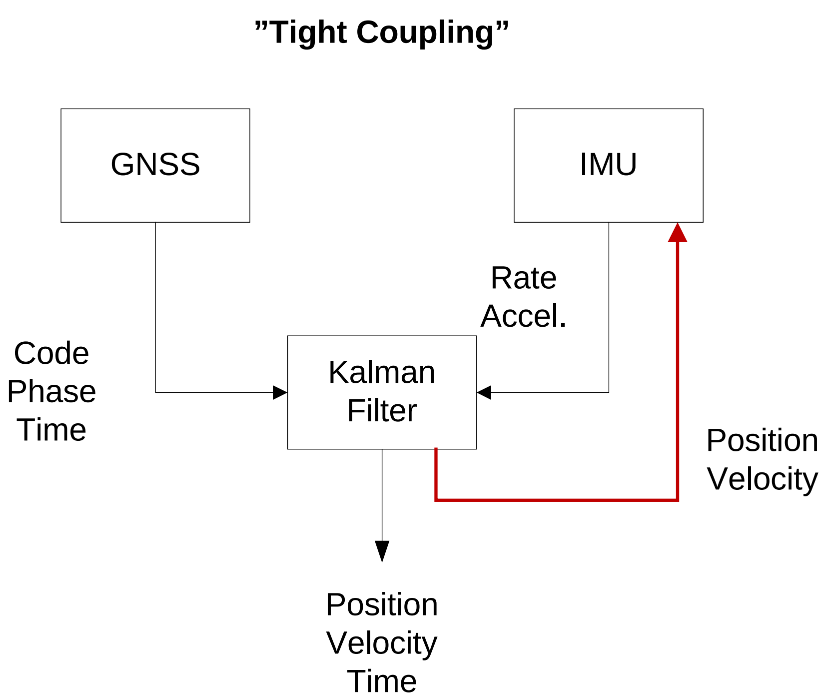

- Utilizing raw measurements rather than positions
- Aiding the IMU with position and velocity data to compensate bias and noise
- Increased processing power requirements

Traditional Approach III – Even More Complicated...

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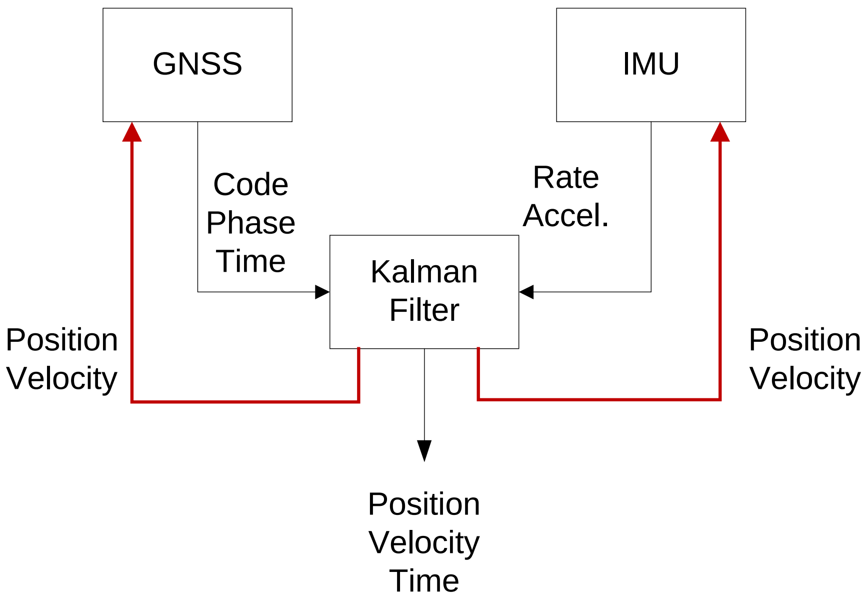
”Deep Coupling”



- Feed-back loop both to IMU and GNSS receiver
- Aiding of tracking loops
- Improves Time-To-First-Fix (TTFF) and re-acquisition time
- GNSS receiver design needs to allow feed-back to core signal processing

The Advanced Approach

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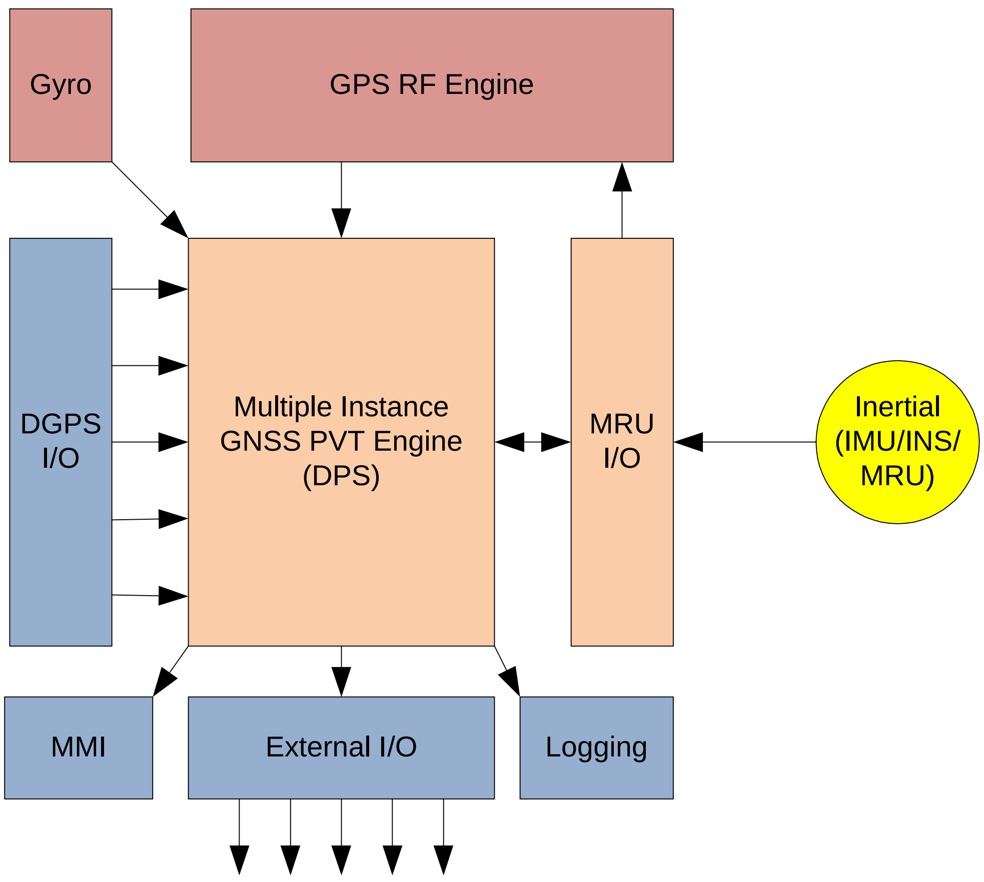

- Taking advantage of powerful processing capacity
- Multiple instance architecture enables improved reliability and stability
- Inertial data for aiding GPS tracking loops, and reducing re-acquisition time
- Inertial data for enhanced RAIM capabilities
- Reducing the requirements of the IMU/INS and enables "the right solution for the job"

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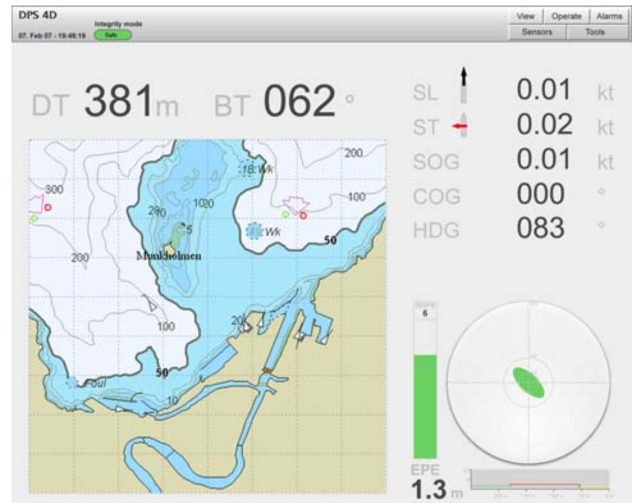
Test Flights

2007

Test Platforms



Vehicle Platforms

Behind the Scene

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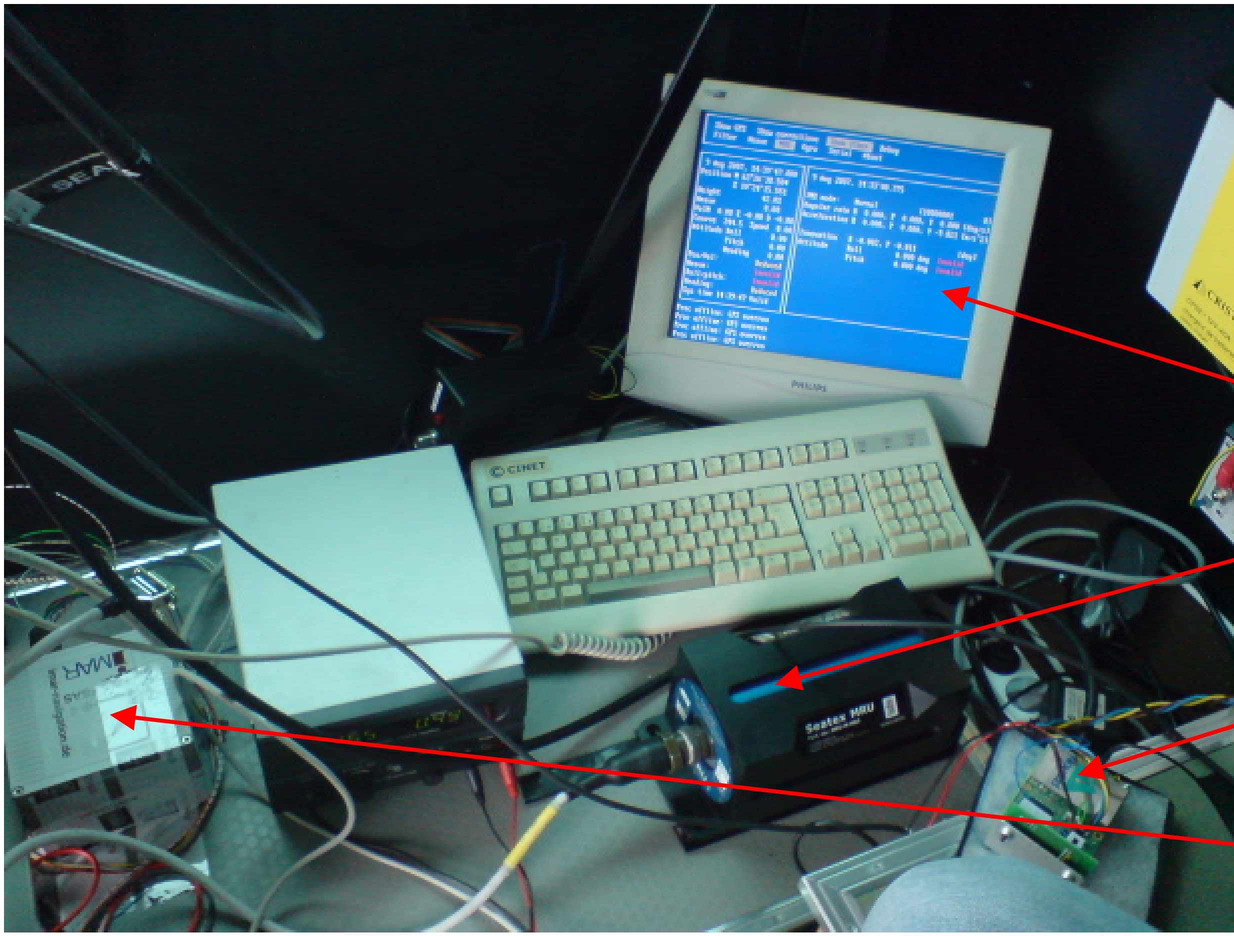


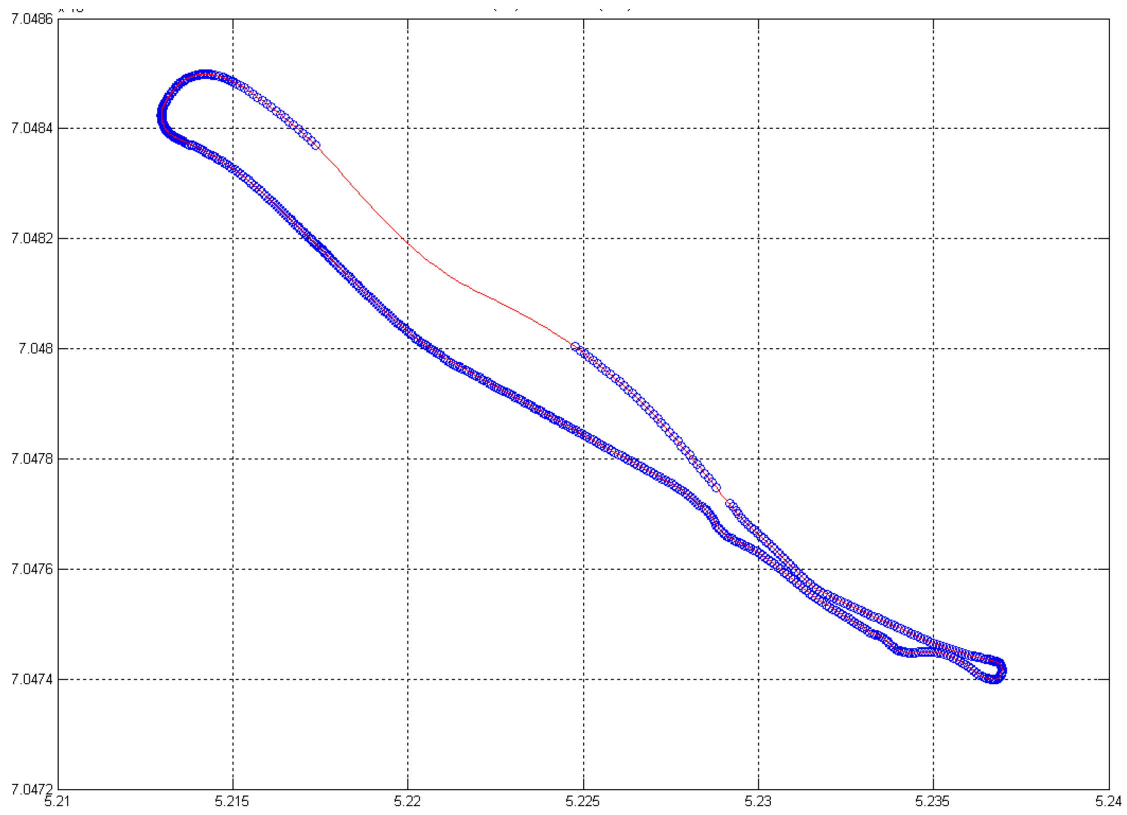
Test software

MRU 5 (INS)

GPS Engine

iMAR IMU

Some Test-Results



Scenario:

Tunnel driving outside Trondheim

Blue – GPS position

Red – GPS/IMU position

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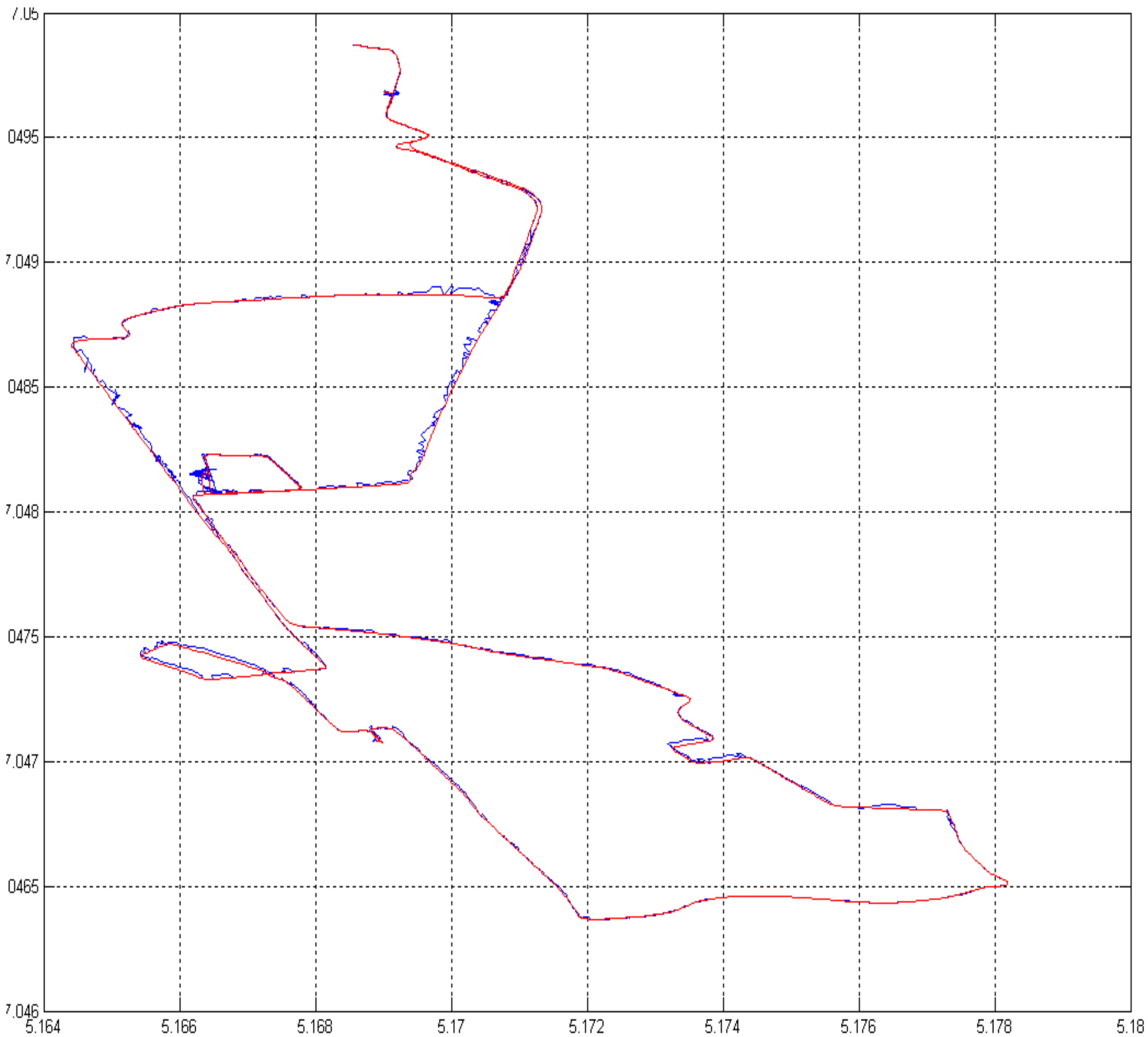
Some More Test-Results



Scenario:

Driving down-town Trondheim

Blue – GPS position

Red – GPS/IMU position

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Graphical User Interface Snap-Shot

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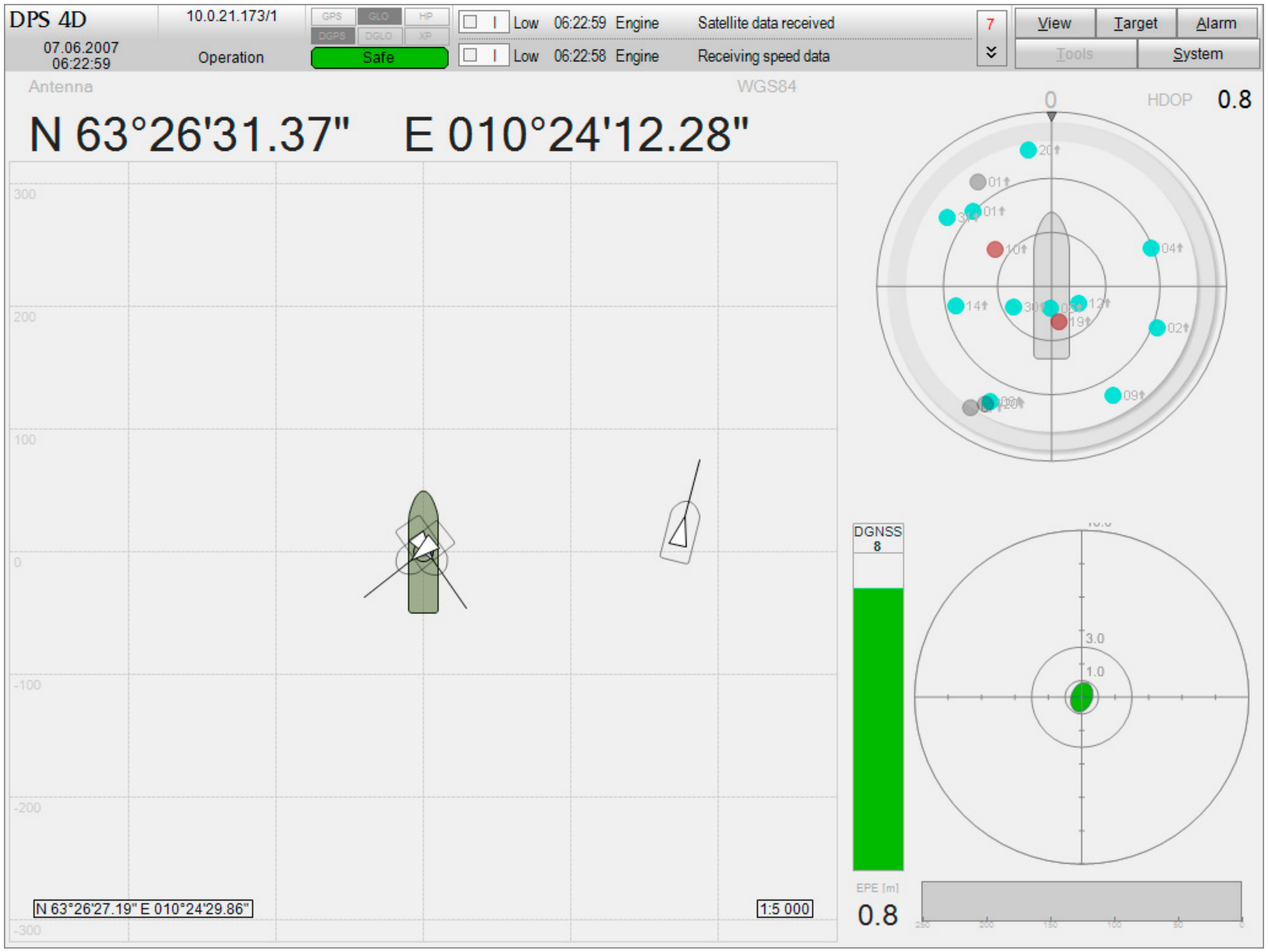
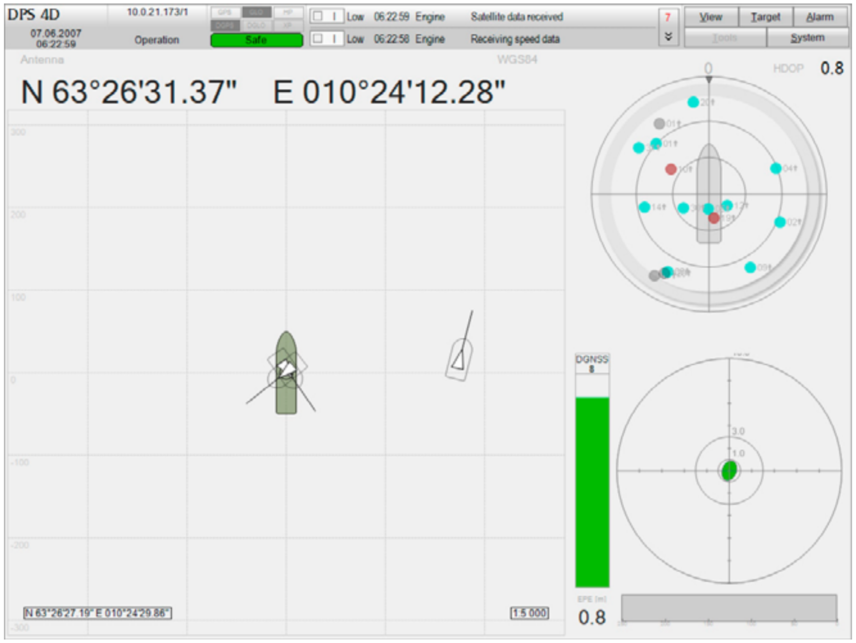


- User interfaces should focus on <u>operational</u> efficiency
- Complex functionality should not lead to complex user interfaces
- User interfaces should be harmonized across applications and instruments

Conclusion

- An optimal hybridization between GNSS and inertial technology for DP Position Reference Systems requires modifications to both technologies
- "One size doesn't fit all"
- Systems should be carefully designed to avoid added complexity to the DP operator



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