New Interface Requirements – Implications for the Future

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Senior Engineer, Engineering Development Laboratories
Chairman SAE International’s Aerospace Avionic Systems Division and PNT Committee

James L. Farrell:
VIGIL, Inc.
Phase Residuals

Residual (cm)

Time after start (sec)

SV Below Mask
Flight Test Results – Error Plots

Separation Vector Errors (East, North, Up) – Carrier-smoothed Code (T-20s) on

Relative Velocity Errors (East, North, Up)

Head-on Traffic

Overtaking Traffic

Crossing Traffic

Flight Test Setup and Scenarios

GPS Equipment: NovAtel OEM V

Head-on Traffic

Overtaking Traffic

Crossing Traffic

UAS Test with Low-cost GNSS

*Ublox M8T*
SOME GRADE-SCHOOL ARITHMETIC

10 meter/sec × 100 sec = 1000 meters

Two Horizontal Directions (e.g., North & East) – Area:
1000 meters × 1000 meters = 1 MILLION square meters

0.01 meter/sec × 100 sec = 1 m

1 meter × 1 meter = ONE square meter area

PRECISION IS NEEDED IN VELOCITY
– NOT INSTANTANEOUS POSITION
1-sec Changes in Carrier Phase

- Ambiguity forever OK
- No mask
- Discontinuities OK
- Immediate reacq
- Flight validated
- Any channel any constellation
- Insensitive to
  - SV mislocation
  - nonuniform ellipsoid models
  - nonuniform time ref
- Geometry benefit
About SAE International

- SAE International “is a global body of scientists, engineers, and practitioners that advances self propelled vehicle and system knowledge in a neutral forum for the benefit of society.”

- SAE is the largest automotive and aerospace standards-setting body in the world.

- SAE is able to harness the intellectual property found with subject matter experts from various industries across the globe to address the needs associated with the rapid advancement of technology.
• SAE has a long and successful history of working with Government agencies on standards for a broad spectrum of applications.
• Over 400 SAE standards are referenced in FAA certification requirements and other regulatory material.
• Over 320 SAE standards have been formally adopted by US DoD.
• Over 140 SAE standards are referenced in EASA (European Aviation Safety Agency) certification and regulatory material.
• There are over 30 references to SAE standards in ICAO (International Civil Aviation Organization) Manuals and Documents.
The need for PNT Standards

• The global economy is highly dependent on power grid systems, banking operations, transportation systems, and communications systems.
• This immense critical infrastructure primarily relies on GNSS for PNT information.
• The easy access to GNSS signals has allowed manufacturers to incorporate PNT technology into virtually every device and vehicle on the planet.
The need for PNT Standards

- PNT technology is experiencing unprecedented growth, thereby generating the need to develop and publish standards that define architectures, sensors, interfaces, training, and certification.
- PNT standards will ensure that the future is not stalled by a lack of effective methods to marry computers and networks with timing systems.
- PNT standards will accelerate the development of driverless vehicles, smart electrical grids, reliable communications systems, secure banking systems, and the Internet of Things (IoT).
The need for PNT Standards

- The rapid advancement of PNT technology is placing great challenges on governments, managers, engineers, technicians, and educators.
- The intellectual property associated with it can only be found within a small group of subject matter experts scattered across the globe.
- It is the mission of SAE International’s PNT Committee to bring these experts together and create standards to maintain the uninterrupted operation of the world’s critical infrastructure.
# SAE Standards Works

## PNT Position, Navigation, and Timing

**WIPs Older Than 5 Years.**

<table>
<thead>
<tr>
<th>Project</th>
<th>Title</th>
<th>Sponsor</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE1002</td>
<td>U.S. National Grid (USNG) Standard</td>
<td>Doug Taggart</td>
<td>Oct 31, 2017</td>
</tr>
<tr>
<td>SAE6419</td>
<td>Specification of The Transmitted Loran-C Signal</td>
<td>William R. Woodward</td>
<td>Sep 12, 2017</td>
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<td>SAE9990</td>
<td>Transmitted Enhanced Loran (eLoran) Signal Standard</td>
<td>William R. Woodward</td>
<td>Sep 12, 2017</td>
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<tr>
<td>SAE9990/1</td>
<td>Transmitted Enhanced Loran (eLoran) Signal Standard for Tri-State Pulse Position Modulation</td>
<td>Doug Taggart</td>
<td>Sep 21, 2017</td>
</tr>
<tr>
<td>SAE9990/2</td>
<td>Transmitted Enhanced Loran (eLoran) Signal Standard for 9th pulse modulation</td>
<td>Doug Taggart</td>
<td>Sep 21, 2017</td>
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<tr>
<td>SAE9991</td>
<td>Introduction to the Operation and Use of the Transmitted Enhanced Loran (eLoran) Signal</td>
<td>William R. Woodward</td>
<td>Sep 12, 2017</td>
</tr>
<tr>
<td>SAE9992</td>
<td>A Guideline for Using the Transmitted Enhanced Loran (eLoran) Signal for Timing, Phase, and Frequency</td>
<td>Steve Bartlett</td>
<td>Sep 12, 2017</td>
</tr>
</tbody>
</table>

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New Project

• Improving Blended Navigation Solutions Using Raw GNSS and Inertial Sensor Measurements
  - Sponsor, James Farrell
Next PNT Committee Meeting

- Baltimore, Maryland May 7-10, 2018
  Holiday Inn Inner Harbor
  301 West Lombard Street
  Baltimore, Maryland 21201
  Phone: 877.834.3613
  http://www.innerharborhi.com/
Contact Information

- If you have any questions, please contact:
  - Dorothy Lloyd, Aerospace Standards Specialist
  - 724-772-8663
  - dlloyd@sae.org
  - Bill Woodward, PNT Committee Chair
  - bill@edli.com
TRANSMITTED COORDINATES

- Data acceptance conditional (quality)
- Loss of partial data
- Very poor velocity accuracy
- Correlation between coordinate errors
- Unequal amt of error in different directions
- Nonuniform coordinate error statistics
- Nonuniform coordinate error sensitivities
- Sensitivity to nonuniform datum

To remove *all* these limitations:
Transmit measurements

SEPARATION is *INHERENTLY* RELATIVE
TRANSMITTED MEASUREMENTS

- **Major** accuracy improvement,
- Increased observability,
- Independent of Datum Reference,
- Intrinsic quality indication (Covariance matrix),
- Coordinates always computable,
- Data always usable if deemed valid,
- **Correlations always accounted for,**
- Optimum weighting,
- Uncorrected C/A fully adequate
  - 1030 MHz COMM savings
- Pseudorange double differences,
- Carrier sequential differences,
- **Integrity capability.**
From Collision Course to 1 Kilometer Minimum Separation

TIME TO CLOSEST APPROACH

Initial Evader Speed [kt] = 500

<table>
<thead>
<tr>
<th>Intruder Hdg [deg]</th>
<th>Time to Closest Approach [sec]</th>
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<tr>
<td>120</td>
<td>95</td>
</tr>
<tr>
<td>130</td>
<td>90</td>
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</table>
From Collision Course to 1 Kilometer Minimum Separation

**EVADER SPEED ADJUSTMENT**

- **Initial Evader Speed [kt] = 500**

<table>
<thead>
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<th>Speed Change [kt]</th>
<th>Intruder Hdg [deg]</th>
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<tr>
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<td>30</td>
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<td>120</td>
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<td>130</td>
<td>130</td>
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</tbody>
</table>
CURRENT POPULAR APPROACHES

Full fix + RAIM "on silver platter" every time
No access to data that would enable flexibility
No hooks to enable ultratight coupling
Proprietary
Integrity monitor + tight coupling + diff:
  INTERNAL (if at all)

EVERY CHANGE INCURS FULL COST
NO SUCH THING as a

• Latitude & Longitude meter
• Velocity vector meter

Ancient mariners knew, as we do – DEDUCE coordinate HISTORY from measurements

IONJ99 opens with 8 reasons for Measurements of Satnav (pseudorange, carrier phase) applicable to DME, eLoran, radar, … all

GPSWorld Dec 2009, pp. 8, 10, 12: "The industry can either adopt changes or continue to settle for performance levels at a minor fraction of the intrinsic capabilities available from our present and future systems."

Dixon et. al., "GNSS Vulnerabilities: Testing the Truth," Coordinates v VIII n3, March 2012, pp. 13-20: "Do we really need to wait for a catastrophe before taking action against GNSS vulnerabilities?"
SOMEx 21st-CENTURY HAPPENINGS

2001 Volpe report
5-Year LORAN shutdown
1000-response *Save Loran* campaign (Narins)
Destruction of towers
Increasing instances of jamming
Panel at ION-GNSS-11
1st Spoofing Event (Austin, TX)
GPSW


Increasing instances of spoofing
Focused attention on robustness/resilience

[https://www.gps.gov/governance/advisory/meetings/2015-06/farrell.pdf](https://www.gps.gov/governance/advisory/meetings/2015-06/farrell.pdf)
Raw Data

to Improve

• Accuracy
• Integrity
• Availability
of Satellite Navigation

National Space-Based Positioning,
Navigation, Timing Advisory Board

June 11-12, 2015    Annapolis MD

James L. Farrell

VIGIL, Inc.
PARTIAL HISTORY of ADVOCACY

NAECON 77
JLFvG GPS-90
NAECON 93
AESEC
GPSWorld, InsideGNSS
BigBook
C-A seminar, ION-GPS-2000
FAA/ SC 186
ION (e.g., IONJ Fall `99)
Coordinates zine
IJUSENG – v1 n1, pages 1-8
YouTube

http://jamesifarrell.com/whats-new-a-pledge-fulfilled/
http://jamesifarrell.com/surveillance/
http://jamesifarrell.com/wanted-precise-velocity-manned-and-unmanned/
http://jamesifarrell.com/how-reliable-is-reliable-enough/
http://jamesifarrell.com/how-its-all-flight-validated/
http://jamesifarrell.com/1-sec-carrier-phase-again/
http://jamesifarrell.com/eloran/
http://jamesifarrell.com/check-list-for-designers/
http://jamesifarrell.com/runway-incursions/
http://jamesifarrell.com/in-air-collision-avoidance-moving-forward/
http://jamesifarrell.com/book-on-tracking/
http://jamesifarrell.com/single-measurement-raim/
http://jamesifarrell.com/gpsfft/
http://jamesifarrell.com/kalman-filter-or-suboptimal-does-it-matter/
http://jamesifarrell.com/collision-avoidance/
http://jamesifarrell.com/cartesianvsspherical/
http://jamesifarrell.com/the-pace-of-change-in-the-industry/

**PDFS**


**COLUMNS AND MANUSCRIPTS**

http://www.insidegnss.com/node/3492
http://www.insidegnss.com/node/842
http://mycoordinates.org/more-gps-or-smarter-gps/
"ADDITIONAL ADDITIONS"

"AI" (Misnomer?) –
(CASSCA) Steven Rogers: F-15 crash prevention
Genesis of automated responses traced to human experience
Application to civil aviation: *gradual* (Mitch Narins)

UAS

VDM

EVT


VIoT

For insight:  https://youtu.be/9UKuOTnQa5w

STANDARDS
CONCLUSIONS

Accuracy and Integrity + Availability + Versatility •

Common Provisions (Measurements, Messages, Diff)

Resilience with No Strings, No New Inventions

Change traditional methods and procedures
• Oversimplification (Loose Coupling, Position Reports, Instantaneous Accuracy)
• Separate Nav/Surveillance, Wishful Thinking (Free-Inertial Coast, 1/2/3 sigma), "GPS Vacation"

Approach steps have been offered

Industry has been unresponsive over recent decades

Events outpacing refinements and regulation

Golden opportunity: with added encryption, change content
The best humanly possible strategy is to deliver whatever performance is reachable from all available information, incomplete as it may be. For decades it has been feasible to combine intermittent partial data – of different types at varying accuracies with different sensitivities from different directions at different times – and extract all benefit offered. Decisions adopted herein offer no more and no less than that.