Retooling GPS, the Global Positioning System

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This talk includes the thoughts of many people at Stanford and in the wider navigation community.

But the opinions may be mine alone & and the mistakes certainly are!
Modernization of GPS

• GPS Basics
• Today’s Accuracy (2003)
• Tomorrow’s Accuracy
  (2004 & even more in 2010)
• Beyond Accuracy
  • Real time error bounds (WAAS & LAAS)
  • Indoors & downtown (television signals)
  • Hackers (civilian anti-jam)
Today’s GPS Serves Over 20 Million Users

1973: DoD approval
1975: first satellite
1995: 24 production satellites
2003: 28 satellites

military, aviation
maritime, space,
auto-farming,
precision construction,
telecommunications,
E-911, car navigation,
animal tracking, etc.
GPS Ranging
Present GPS Signal Spectrum

- Received power density: $10^{-13}$ W/m$^2$
- Received power: $10^{-16}$ W into a reasonably sized hemispherical antenna
- Spread spectrum for:
  - ranging
  - discriminate reflections
  - multiple access without time or frequency multiplexing
  - modest rejection of radio frequency interference
Scatter Plots (cartoons actually) for Today’s GPS

“Stand Alone”

GPS

DGPS
at 10 km

DGPS
at 100 km

DGPS
at 1000 km
Present and Future Spectra of GPS Signals

Today’s satellites

New satellites launched beginning in 2004

New satellites launched near the end of the decade
Tomorrow’s Accuracy

Stand-Alone vs. DGPS to 1000 km?
Beyond Accuracy
Part I: Integrity

• Accuracy
  • measured at the 95% level
  • after the fact
• Pilots need a guaranteed bound on error size
• Pr(true error exceeds bound)<10^{-7}
• *Independent* monitor networks deliver error bounds in real time
  • On airport monitoring provides 2 s TTA
  • Continental monitoring provides 6 s TTA
• Military recently recognizes need for error bounding
Runway 11 at Sitka (from Alaska Air)
Runway 25 at Kodiak, Alaska (from Alaska Air)
Multiple GPS receivers used for cross-checking & redundancy

Central processor to generate corrections & error bounding data

On-Airport Monitoring (LAAS)

VHF data broadcast of:
- airport corrections
- data for error bounding

GPS constellation
Continental Monitoring Networks (WAAS)

Geostationary broadcast of:
1.) Continental corrections
2.) Data for error bounds
3.) Ranging signal

WAAS: Operational on July 10, 2003!
Beyond Accuracy
Part II: Continuity

• Indoors & downtown
  • assisted GPS (supplant GPS nav. message)
  • ranging from cell towers or television signals
• Hackers motivate civilian anti-jam
  • basic backup network (BBN) of traditional nav. aids (Loran, DME, etc.)
  • inertial aiding to extend averaging time
  • ring nulling & beam steering antennas
• New signals help, but we need more.
Television Signals Are Designed to Go Indoors and Downtown (from Rosum Inc.)
Dual-Element Stacked Patch Antenna
(from Dr. Frank Bauregger)

Prototype Antenna

RF and Switching Circuitry
- LNA
- BPF
Flight Results for Ring Nulling Antenna
Last Thoughts

- Galileo
- Quasi-Zenith Satellite System
- Glonass

- Spectrum vigilance.
  - GPS noise floor is set by Mother Nature
  - WiFi band is loud in Yosemite, never mind the Bay Area
  - Continued institutional help is needed.
Assured Ionospheric Measurement & Wide Laning

\[ \lambda_{ML} = 75 \text{ cm} \]

\[ \lambda_{WL} = 86 \text{ cm} \]

\[ \lambda_{EWL} = 5.87 \text{ m} \]
Theoretical Radiation Patterns

- Roll Pattern for Antenna Mounted on Cessna Caravan
Flight Results for Ring Nulling Antenna