A New Centimeter-Level Real-Time Global Navigation and Positioning Capability with GPS

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Overview

- NASA/JPL has developed a new, very precise, global, GPS-based capability for real-time terrestrial and space platform navigation
- The system has been demonstrated on Earth's surface
  - x10 more accurate than other real-time GPS-based systems
  - Space demo likely within one year
- Advantages of the new system for Earth science remote sensing
  - Enables new science products
    - Onboard generation of science data products in real-time
    - Sensor control and reduction of data transmission bandwidth
  - Enables improved environmental forecasting
  - Autonomous and intelligent platform control
  - Operations cost savings -- reduce/eliminate ground processing costs
  - Technology transfer and commercial partnership -- new paradigm for global GPS network
Global Positioning System (GPS) Measurements Applied to Geophysics and Natural Hazards

- NASA contributes about one-quarter of the ≈ 250 GPS tracking stations in the International GPS Service (IGS) global network.
- Analyses of their data (non real-time) is interpreted in terms of tectonic plate motions and geodynamics.
- High density deployment of GPS sites contributes to the assessment of earthquake hazards (southern California map).

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GPS tracking maintains constant and precise knowledge of relative spacecraft positions & clocks
Demonstrated Orbit Accuracies With GPS

Geostationary
36000 km altitude
(TDRS, INMARSAT)
15 m
ground-based tracking

GPS
20000 km altitude
8 cm (< 40-cm real-time)
operational automated processing

MicroLab/GPSMET
730 km altitude
With GPS < 10 cm

TOPEX/POSEIDON
1336 km altitude
With GPS: < 2 cm radial accuracy
operational automated processing

Recent (2000) JPL Blackjack Flight GPS Receiver Results

Shuttle Radar Topography Mission (SRTM): 230-km alt
45-cm orbit accuracy

CHAMP: 470-km alt
< 10-cm orbit accuracy

SAC-C: 705-km alt
< 10-cm orbit accuracy

FUTURE GOAL: < 1-cm Orbit Accuracy for LEOs
GPS and/or LEO cross-link tracking maintain constant and precise knowledge of relative spacecraft positions & clocks
JPL Spacecraft Cross-Link Sensors Under Development for Space Deployments in 2001-2005

GRACE: JPL GPS Receiver with integrated camera and K-band spacecraft-spacecraft tracking, to provide 1-micron accuracy measurement of range change to improve knowledge of the Earth's gravity field by several orders of magnitude.

ST-3: Precision (1-cm) formation flying

Mars Network Node: Integrated Navigation and Telecommunications

ST-5: GPS-based Constellation Communications and Navigation Transceiver (CCNT) for cross-link ranging and inter-spacecraft telecom in constellation of spacecraft in GEO-transfer elliptical Earth orbit.
Novel Science Applications

Atmospheric and Ionospheric Remote Sensing and Science

Bi-Static Ocean Reflectometry
Motivation for Real-Time GPS

- New operations paradigm for remote sensing with individual spacecraft and/or constellations
  - Old: track spacecraft one by one, downlink sensor data sets to ground, analyze and process data in extensive ground operations
    - Relatively costly; significant latencies to science products
  - New: treat spacecraft & ground receivers as an extended sensor network, with real-time onboard processing/operations enabling high level of autonomy
    - Dramatically reduces recurring costs and downlink requirements

- Enables new science products and capabilities
  - Real-time onboard science instrument pointing/control in response to events (volcanoes, earthquakes, storms, floods etc.)
  - Precise orbit control
    - Ground track repeats, SAR navigation, cooperative sensor pointing from multiple spacecraft or aircraft (formation flying or platform ensembles)
  - Enables improved environmental forecasting
    - Tactical oceanography (science, agriculture, fishing, marine navigation, and natural hazard monitoring)
    - Atmosphere occultation processing for weather nowcasting
    - Natural hazard monitoring (volcanic inflation, earthquakes)
Motivation for Real-Time GPS (cont.)

- Example: orbit determination operations for Topex/Poseidon
  - $100K/yr for GPS-based precise orbits (1-day latency)
  - $Millions/yr for formal ephemeris operations (laser ranging etc.)
  - Delay to get science products: days to weeks
- New concept: real-time cm-level orbit knowledge available for onboard science data record generation
  - Finished or preliminary science products available in real- or near-real time
  - Exploits powerful embedded processor in Blackjack GPS receiver (PowerPC)
- Operational processing of GPS occultation data from LEOs a key beneficiary due to huge raw data volumes and need for minimal latency for assimilation into operational weather forecasting models
Task: GPS Wide Area Augmentation System (WAAS) Implementation

Task Purpose/Objectives:
- Deliver real-time software prototype to DOT/FAA for new GPS-based precision navigation system (WAAS) for aviation.

Major Products and Deliverables:
- Real-time software for GPS orbits, clocks, and ionosphere maps
- New GPS and safety algorithms

Customer Relevance:
- Improve airline navigation accuracy by orders of magnitude; enhance aviation safety in U.S.
- Save $12B+ in next decade in fuel and airport costs

NASA Relevance:
- Real-time, autonomous space navigation
- Onboard science data product generation
- Real-time natural hazard monitoring
- Pathfinder for the Mars Network Infrastructure.
Real-Time GPS Technology Development
Progression at JPL

1995
- White Paper (WADGPS)
- Real Time GIPSY (RTG)

1996
- RTG is licensed to SATLOC
- RTG is licensed to Raytheon (WAAS)
- NASA-FAA Inter-Agency Agreement

1997
- Automobile positioning
  Demonstrated 80-cm (98)

1998
- 2nd RTG license to Raytheon (MSAS-Japan)

1999
- Internet-based Global Differential GPS (IGDG)

2000
- Global Differential GPS with IGDG operational
- IGDG wins NASA Software of the Year Award
- Initial ground positioning
  Demonstrated 50-cm (97)

- Internet-based Global Differential (IGDG) (00)
  Real time ground positioning
  Demonstrated 10 cm horizontal, 20 cm vertical accuracy

- Aircraft real-time Wide Area Differential navigation:
  NASA SAR plane (98)
  and FAA/WAAS (99)
  Demonstrated 40-cm vertical 30-cm horizontal (98)

- X-33/RLV IGDG real-time positioning demo (01)
  Goal: sub-meter accuracy

- Real-time autonomous positioning and navigation for Earth orbiters (00-01)
  Goal: sub-10-cm accuracy
JPL has established a global, real-time, GPS ground network

- **Real-time user accuracies:** 8 cms RMS horizontal, 20 cms RMS
  - ~10 times better than best available commercial and military systems
- 30-40 cms 3D (RSS) global GPS orbits, in real-time
- *Winner of the 2000 NASA Software of the Year Award!*
- NASA, DoD and commercial applications being studied, including:
  - X33/RLV navigation (X33 flight demo planned)
  - Automated LEO navigation and onboard science data product generation

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[Image of world map with markers labeled AOA Benchmarks, Turbo-Rogues, and Ashtech Z-12s]
JPL’s New Global Global Capability Supports 10-20 cm User Accuracy, Anywhere, Real-Time

Revolutionary new capability: 
*decimeter real time positioning, anywhere, anytime*

<table>
<thead>
<tr>
<th>Capability</th>
<th>JPL’s IGDG</th>
<th>Un-augmented GPS</th>
<th>Others (WADGPS services)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Seamless</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Usable in space</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accuracy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic applications</td>
<td>0.1 m horizontal</td>
<td>5 m</td>
<td>&gt; 1 m</td>
</tr>
<tr>
<td></td>
<td>0.2 m vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbit determination</td>
<td>0.01 – 0.05 m (goal)</td>
<td>1 m</td>
<td>N/A</td>
</tr>
<tr>
<td>Dissemination method</td>
<td>Internet/broadcast</td>
<td>Broadcast</td>
<td>Broadcast</td>
</tr>
<tr>
<td>Targeted users</td>
<td>Dual-frequency</td>
<td>Dual-frequency</td>
<td>Single-freq.</td>
</tr>
</tbody>
</table>

Remote user running IGDG

For more info: http://gipsy.jpl.nasa.gov/igdg

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Summary

- A significant advance in real-time GPS technology has been achieved
  - Decimeter real-time global navigation accuracy
  - Few-cm real-time low-Earth orbit determination may be realized within a year or so
  - Enable new Earth science capabilities
  - Real-time operations enable sensor-web type architectures for extended ground+space platform networks with extensive connectivity
  - Anticipate lower operations costs in connection with remote sensing on space platforms, and new operations paradigm incorporating near-real time delivery of science data to PIs