2000 NASA Software of the Year Award Nomination

GPS Enhanced Orbit Determination (GEODE) Software

Submitted by GSFC, Code 570

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Our Challenge: Move Satellite Navigation from Earth to Space

- Satellite navigation is now performed on the ground

- Our challenge is to build a navigation system for civilian satellites using GPS that
  - Computes satellite position and velocity onboard, instantaneously, with high accuracy
  - Operates reliably without human intervention
  - Fits within very limited computing resources
**Our Solution: GEODE**

State-of-the-art navigation algorithms and operating-environment-independent, object-oriented software implementation

- Unprecedented accuracy, reliability, and autonomy

- In use by NASA and commercial projects

- Open-architecture, licensed GSFC product

\[
\frac{d^2 X}{dt^2} = a_x
\]

\[
K = P(\cdot)H^T [HP(\cdot)H^T + R]^{-1}
\]

Enables advanced autonomous satellite operations
GPS Receiver Solution
Using Standard Method

- Designed primarily for near-Earth use
- Requires continuous visibility of at least four GPS satellites to compute position (receiver solution)
- Accurate use of GPS signals in civil domain is eight times harder than in the military domain
Unique Challenges of Using GPS for Satellite Navigation

- High accuracy velocity required for accurate position prediction
- GPS receiver outages due to hostile space environment (solar particle radiation or high velocities)
- GPS visibility limited by antenna placement and changing satellite orientation
- Many potential science missions are above the GPS constellation
- Limited computer processing power in space
Key Accomplishments vs Evaluation Criteria

Innovation

Science and Technology Significance and Impact

Extent of Current and Potential Use

Usability of Software

Quality Factors
## Innovation: State-of-the-Art Algorithms for the Space Environment

<table>
<thead>
<tr>
<th>Innovative Algorithms</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Accurate model for satellite motion (gravity, Earth’s atmosphere, etc.)</td>
<td>Can coast through receiver outages for more than 24 hours</td>
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<td>Kalman filter for computation of corrected position and velocity</td>
<td>Computes real-time corrections</td>
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<td>Computes high-accuracy velocity solutions</td>
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<td>Requires measurements from only 1 visible GPS satellite</td>
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<td>Combination of accurate model and Kalman filter</td>
<td>Eliminates impact of GPS signal corruption</td>
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Innovation: A Better Way to Fly

GEODE’s Predicted Solution

Receiver’s Solution

GEODE’s Filtered Solution

Receiver’s Solution, if Predicted

True Satellite Position

4 or more GPS Satellites Acquired by Receiver

1-3 GPS Satellites Acquired by Receiver

No GPS Satellites Acquired by Receiver
Innovation: Demonstrated Performance Improvements

![Graph showing position error over time for TOPEX Satellite with Commercial Receiver’s Solution and GEODE’s Solution compared.](image-url)
Significance: Unprecedented Accuracy and Reliability

- **Unprecedented Accuracy**
  - Drives down navigation errors by a factor of 15 in position, a factor of 50 in velocity versus receiver solution

- **Unprecedented Reliability**
  - Maintains performance using measurements from only 1 GPS satellite
  - Predicts position for 24 hours without GPS measurements

GEODE is the only licensed, open-architecture product available that provides this level of performance!
Significance: Supports Advanced Earth and Space Science Mission Concepts

- Critical technology for meeting NASA’s strategic needs for increased satellite autonomy
- Essential technology for collaborative science missions
- Opens up GPS navigation to satellites with severely limited GPS visibility, e.g. high-Earth and geosynchronous missions
- Enabling technology for many proposed formation-flying/constellation missions, e.g. Orion/Emerald
Impact: Better, Faster, Cheaper Satellite Operations

- High accuracy navigation products
  - Increase accuracy of satellite orientation control
  - Provide more precise scientific measurements
  - Enable autonomous maneuver planning and control

- High reliability reduces risk

- Streamlined operations provide satellite position instantaneously in science data stream

- Autonomous operation drives down ground operations costs

BEFORE Ground-Based Navigation Scenario

AFTER GEODE Navigation Scenario

2-30 Day Delay

Instantaneous
Impact: Other Science and Technology Applications

- Enroute aircraft navigation to eliminate or augment FAA’s GPS/WAAS
- Improved navigation accuracy using GPS receivers for Search and Rescue
- Other commercial GPS-related applications
Extent of Use

Current Uses

◆ Autonomous navigation capability for the New Millennium EO-1/ Landsat 7 formation-flying experiment
◆ Critical element in GSFC’s development of low-cost GPS receivers for high-Earth and formation flying missions
◆ License agreements in place/under negotiation:
  – OSC
  – ITT
  – United Space Alliance
  – MIT Lincoln Laboratory
  – LaRC
  – Ball Aerospace
  – UCLA
  – University of Colorado
  – Aerospace Corp.

Potential Uses

◆ Advanced Earth Science formation-flying missions such as MMS and Auroral lites
◆ Provided to LaRc for potential use by Picasso/CENA
◆ OSC may integrate GEODE into a space-qualified version of their Astech GPS receiver
◆ Development of advanced autonomous satellite systems by universities and industry
Usability: Highly Reusable System

- Portable: ANSI standard C, environment-independent implementation
- Modular: Object-based architecture, with encapsulated interfaces
- Reuse of GEODE by GSFC for EO-1 and SPARTAN and OSC for ORBVIEW has saved more than $1 million per project

Encapsulated interfaces maximize reuse
Quality Factors

- Object-oriented architecture selected to build in flexibility to support a wide range of mission types
- ANSI C language selected to reduce code size and for ease of portability
- Designed to be operating-environment independent
- Successfully executed in the following environments:
  - PC/Windows
  - Sun/HP/ Unix
  - Dec Alpha/Linux
- TRL 8, flight-qualified against operational standards
- Recently adapted for high-Earth missions and formation-flying applications with relative ease
Quality Factors: Engineered to Satisfy Cost and Resource Constraints

- Reused GSFC-developed TONS components to save more than $1,400,000 in initial development
- Engineered to fit within the constraints of an onboard processor without compromising accuracy
Bottom Line

◆ **Significance and Impact**
  GEODE is more accurate and more reliable than any commercial GPS navigation system. GEODE is enabling technology for NASA’s future formation-flying missions.

◆ **Extent of Use**
  Licensed GSFC product. Currently active in NASA and commercial sectors.

◆ **Usability**
  Used successfully on several projects to support wide-range of missions.

◆ **Quality Factors**
  Meets or exceeds all original performance objectives.

◆ **Innovation**
  GEODE is the only licensed, open-architecture product suitable for satellites with limited, intermittent GPS visibility.
Autonomous satellite navigation using GPS is still a developing technology.

Our team is a pioneer and leader in this technology.