RECENT TIMING ACTIVITIES AT THE U.S. NAVAL RESEARCH LABORATORY

Ronald Beard, O. Jay Oaks, Kenneth Senior, and Joseph White
U.S. Naval Research Laboratory
E-mail: Joe.white@nrl.navy.mil

Abstract

The U.S. Naval Research Laboratory has a number of ongoing time and frequency programs. This paper provides an overview of work currently being done. The programs include GPS clock life testing and on-orbit analysis, Distributed Time and Frequency Systems, and iGPS. An update on UTC (NRL) is also presented.

Timing Related Projects

IGS Related Activities
GPS On-Orbit Analysis
Next Generation GPS Timescale Support (OCX)
Distributed Time & Frequency Simulation Environment
GPS Timing Receiver Calibration
Precise Clock Evaluation Facility (PCEF)
   GPS Space Clock Life Testing
High Integrity GPS
**Recent Timing Activities at the U.S. Naval Research Laboratory**

**41st Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 16-19 Nov 2009, Santa Ana Pueblo, NM**

**Abstract**

see report

**Security Classification of:**

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<th>1. REPORT</th>
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**Limitation of Abstract:** Same as Report (SAR)

**Number of Pages:** 10

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NRL IGS Activities

The International GNSS Service (IGS) is a federation of over 200 agencies. Produces standards and products for application in the geosciences.

NRL chairs the IGS Clock Products Working Group (CPWG)

Primary responsibility of the CPWG is the production of the IGS timescales

- Rapid IGS clock products are aligned to IGRF daily
- Final IGS clock products are aligned to IGSST weekly
- Allows dissemination of IGS time ($1 \times 10^{-10}$ @ 1 d)

Dissemination of UTC < 50 ns

IGS timescales are generated from a distributed network of clocks

- Kalman filter implementation
- dynamically weighted clocks
- driven mostly by H-Masers
- IIR Rb clocks – 1% each

Tracking Station Clocks:
- H-masers (57)
- cesiums (12)
- rubidiums (30)
- time lab stations (26)

Satellite Clocks:
- cesiums (7)
- rubidiums (24)

UT1/LOD Analysis

New Kalman filter for optimally combining VLBI UT1 & GPS LOD

- New filter produces best UT1/LOD as compared to all other similar products by multiple measures including comparison with independent Atmospheric and Oceanic Angular Momentum Data
- Used to support recent U.S. NRC Study
- Code made available

IERS combinations do not use VLBI UT1 & GPS LOD inputs optimally!
- Fidelity of high-frequency geodetic measurements is degraded

Main Issues: VLBI UT1 & GPS LOD combinations must recognize & mitigate systematic errors

- UT1 from VLBI Intensives has serious baseline- & time-dependent errors
- UT1 from weak VLBI sessions should be rejected
- GPS LODs have bias & harmonic errors that should be modeled

Motivation: IGS real-time orbit predictions require better EOP predictions

- UT1 prediction errors (= R2 rotation errors) dominate real-time performance
- Polar motion prediction errors are also significant
New Time Scale – Tie to UTC

Current Version relies on GPS Time for Reference to UTC

Multiple Stations collocated at Timing Centers will provide a better quality and robust link to UTC, relatively calibrated to UTC through Circular \( T \)

Stability of the average of these clocks suggest a steering time constant of about 70 days

GPS On-Orbit Analysis

- On Line Databases of all SV and MS tracking data
- Precise measurement data in system and external
- Characterization of SV and MS clocks
- Anomaly investigation
- Tuning of Filter Q's

<table>
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<tr>
<th>Data Source</th>
<th>Data Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>NGA</td>
<td>15-minute phase</td>
<td>SV clock offsets relative to IOD Master Clock</td>
</tr>
<tr>
<td>NGA</td>
<td>5-minute phase</td>
<td>GPS MS clock offsets relative to IOD Master Clock</td>
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<td>IGS</td>
<td>5-minute phase</td>
<td>SV clock offsets relative to IGS time scale</td>
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<tr>
<td>IGS</td>
<td>5-minute phase</td>
<td>IGS GPS ground clock offsets relative to IGS time scale</td>
</tr>
<tr>
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<td>5-minute phase</td>
<td>IGS timescale reference data</td>
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<tr>
<td>NRL analytical results</td>
<td>SV clock discontinuity</td>
<td>SV clock phase, frequency, and drift discontinuities of magnitude and epoch</td>
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<td>MS clock discontinuity</td>
<td>MS clock phase, and frequency discontinuities of magnitude and epoch</td>
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<tr>
<td>GPS MTS</td>
<td>Time period</td>
<td>SV clock operating periods</td>
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<tr>
<td>GPS MTS</td>
<td>Time period</td>
<td>SV position in the GPS constellation</td>
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<tr>
<td>NRL computed</td>
<td>SV eclipse periods</td>
<td>SV periods of time when the earth shadows a portion of the orbit from the sun</td>
</tr>
<tr>
<td>NGA</td>
<td>SV x.s trajectories</td>
<td>Precise post-fit SV ephemerides</td>
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<tr>
<td>IGS</td>
<td>GPS broadcast data</td>
<td>Predicted orbit and clock transmitted in the GPS signal</td>
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On-Orbit Performance

GPS Clock Instabilities
15 June – 5 July 2007

- IIA cesiums
  - poorest overall stability
  - behave mostly as random walk phase noise
  - MDEV power-law slope: -1/2
  - excess deviations near 13,600 s

- IIA rubidiums
  - similar to Cs clocks but much more stable
  - flicker phase component for intervals < 100 s
  - also with excess near 13,600 s

- IIR & IIR-M rubidiums
  - newer generation clocks less stable than IIA Rb up to 1000 s
  - complex high-frequency behavior due to onboard Time Keeping System (TKS)
  - some excess near 13,600 s

Next Generation GPS Timescale

CONTEXT/PROBLEM:
- GPS system functionality relies on stable satellite clocks & the ability to predict them well; individual clock prediction in turn requires a stable reference timescale
- Next Generation GPS operational ground control segment (OCX) now being designed
  - NRL support requested by JPL

Goal / NRL Approach:
- Develop a more stable ensemble timescale
- Leverage existing Kalman filter approaches but with improved clock modeling
- Algorithm developed under ONR funded project
- NRL providing algorithm/code development/testing/consultation

Challenges:
- Intended for operational use
- Must be highly robust against individual clock failures
- Must be adaptive in its determination of model parameters
Distributed Timekeeping

- Current proliferation of single-source (GPS-centric) timekeeping
- A new approach that inter-compares & combines existing embedded timing signals:
  - would enable in-situ determination of performance,
  - improve & make more robust the timekeeping (holdover) capability,
  - provide synchronization,
  - provide integrity feedback to individual systems/sensors,
  - limit single-source failures & vulnerabilities

Requires new theory & algorithms for combining timing signals of very different type & quality through widely varying links

- Clocks perform very differently:
  - in same & different environments
  - over different periods of time (scales)

DTFS Simulation Environment

Distributed Time and Frequency Simulink
simulation environment

Used to model distributed common
time/frequency architectures

Includes ensemble clock models, timescale
calgorithms, control loops, and multiple external links
GPS Timing Receiver Calibration

Simulator Calibration

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Simulator L1 Bias</th>
<th>Simulator L2 Bias</th>
<th>Corrected L1 Receiver Offset</th>
<th>Comments</th>
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<tr>
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<td>4</td>
<td>22.3 ns</td>
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<td>5/23 7:00</td>
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Space Applications Branch
U.S. Naval Research Laboratory

GPS Timing Receiver Calibration

Space Applications Branch
U.S. Naval Research Laboratory
Precise Clock Evaluation Facility (PCEF)

- Precise and Accurate Time and Frequency References
- Maintain realization of Universal Coordinated Time, UTC(NRL)
- Multiple precise dual mixer phase comparison systems
- Automated data collection and archival systems
- Precise time/frequency transfer and dissemination systems
- Multichannel 1PPS evaluation system

UTC (NRL)

Purpose is to support Navy/NRL time & frequency research activities

Unique tool for investigation of time scale algorithms and techniques

Began submitting clock data to BIPM in September '07 under test/evaluation

Official submissions began in January 2008
Space Clock Extended Life Tests

1. Space-Like Environment (vacuum & temperature)
2. Installation in test chambers duplicates mounting in SV
3. Continuous Operation for a minimum of three years

- Validates SV Telemetry and Control Interface
- Validates operation prior to actual flight in operational SV
- High precision performance evaluation

GPS Block IIF DCBFS Life Test

Began in August 2004

Interrupted in 2006
GPS Block IIF RFS Life Test

Two GPS IIF production clocks, No 5 and 25 are under test.

Test configuration improved over that used in prior tests.

High Integrity GPS (iGPS)
Operational Concept

Iridium Satellite
- Low Orbit
- High Power
- Fast Moving

GPS Satellite
- High Orbit
- Slow Moving

Operating Principle
- Iridium provides high power signal and rapidly changing ground track to accelerate initial position fix
- Enables GPS receiver to quickly lock on to GPS signal and to maintain GPS lock in presence of strong jamming

c

Jammer

Cold Start Sequence Timeline under Jamming 
- Acquire at 70 dB J/S
- Geolocate with Iridium in 4-8 min
- GPS Lock in 2-4 min

Iridium Reference Ground Station

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