GNSS Applications and QZSS High-Accuracy Services

UTOKYO_ICG GNSS TRAINING
2/12/2024
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Table of Contents

• Motivation
• QZSS high-accuracy service
  - Static and Kinematic test results in Japan
• MADOCA-PPP evaluations at 8 Countries
• GNSS applications
Motivation

• **PPP** has been developed by many researchers (many papers) for a long time and it’s time to put it to practical use.

• Currently, **PPP-RTK** is becoming popular in the word.

• Japanese **CLAS** is one of the good example of PPP-RTK.

• We would like to share some test results of these correction services compared to the **conventional RTK**.
## Correction service (current and future)

<table>
<thead>
<tr>
<th>Error Sources</th>
<th>SLAS</th>
<th>CLAS (PPP-RTK)</th>
<th>DFMC-SBAS</th>
<th>MADOOCA-PPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise orbit</td>
<td>Not separated</td>
<td>○</td>
<td>○</td>
<td>○</td>
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<tr>
<td>Precise clock</td>
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<td>○</td>
<td>○</td>
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<tr>
<td>Ionosphere</td>
<td></td>
<td>○</td>
<td></td>
<td>△</td>
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<tr>
<td>Troposphere</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Convergence</td>
<td>Instant</td>
<td>-1 min.</td>
<td>Instant ?</td>
<td>15-30 min.</td>
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<td>Measurement</td>
<td>Code phase</td>
<td>Carrier phase</td>
<td>Code phase</td>
<td>Carrier phase</td>
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<tr>
<td>GNSS</td>
<td>GPS/QZSS</td>
<td>GPS/QZSS/GALILEO</td>
<td>?</td>
<td>GPS/QZSS/GLONASS/GALILEO</td>
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<tr>
<td>Coverage</td>
<td>Japan</td>
<td>Japan</td>
<td>?</td>
<td>Asia, Oceania</td>
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</tbody>
</table>
All correction services through satellite!

• You don’t need to set up base station.
• You don’t need LTE/4G/5G.
• All you need is receiver and antenna.
• PPP is available within the coverage of QZSS
Elevation cutoff = 10 degree
How you can see elevations for each 4 QZSS (Kathmandu)

At least 3 satellites can be received all the time.

New QZSS will be launched. 7 QZSS constellations in 2024-2025 and 11 QZSS constellations in the future.
Static and Kinematic Test Results using PPP/CLAS/SLAS Correction Service through QZSS
Static test results of CLAS/PPP/SLAS at TUMSAT

- We started the real-time evaluation of CLAS/PPP/SLAS.
- Reference position is determined by some static PPP solutions in ITRF2014.

<table>
<thead>
<tr>
<th>No.</th>
<th>Label</th>
<th>Port</th>
<th>ID</th>
<th>Date (JST)</th>
<th>Latitude [deg]</th>
<th>Longitude [deg]</th>
<th>Height [m]</th>
<th>N Error [cm]</th>
<th>E Error [cm]</th>
<th>U Error [cm]</th>
<th>Fix type</th>
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<tbody>
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<td>CLAS</td>
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<td>35.66634190</td>
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<td>5</td>
</tr>
</tbody>
</table>

**CLAS**

- Core
  - AsteRx4

**PPP**

- Magellan Systems Japan
  - MJ-3008-GM4-QZS

**RTK**

- u-blox
  - F9P

**SLAS**

- Trimble
  - NetR9
  - u-blox

- 50km baseline
  - National defense academy and TUMSAT

- 4cm

- 1m
24h CLAS (static antenna)
June 13, 2021
Topcon Ant. + CORE AsteRx4
Fix rate : 99.6%
24h PPP (static antenna)
June 13, 2021

Trimble Ant. + MSJ receiver
24h SLAS (static antenna)
June 13, 2021

Trimble Ant. + u-blox F9P receiver
1. Kinematic test at farmer (Iwaki-san) CLAS/PPP/SLAS based on RTK

Base station for RTK was set up here.

Useful software! We can see where we plowed.

https://agri-info-design.com/
Ground Truck Comparisons

Test field
difficult to compare...
Position Errors for CLAS/PPP/SALS

CLAS
R=5cm

PPP
R=12cm

SLAS
R=50cm
3. CLAS/PPP demonstration at real construction site

- Sand/Soil delivery and fill using dump truck
- CLAS/PPP/RTK through same antenna
- Position comparisons for about 6 hours
Ground trucks of RTK as a reference

As for ground trucks, CLAS and PPP are same as RTK.

Truck height rises slightly due to delivery

Truck height descends slightly due to fill

Relatively open sky condition but some steep slope of soils
Temporal ENU positions of CLAS

Fix rate: 100%

Repetitive operations

Lunch break

Fix rate: 100%

9:00(JST) - 15:00(JST)
Comparisons between CLAS and RTK

Very stable positioning

Here is from RTK

NovAtel Ant. + CORE AsteRx4

Bias in height is due to our mistake (RTK base positions)

10:30(JST) 15:00(JST)
Comparisons between PPP and RTK

Several re-convergences were seen. But stable positioning during most of time.

NovAtel Ant. + u-blox F9P + Ntrip
4. Sendai Airport Test by ENRI

We have gathered GNSS data for 3 days with ENRI.

This is one of the test of 2 hours

RTK : 97.4% FIX except for airfield apron
These positions are used as reference.
Horizontal Errors of CLAS and SLAS

CLAS: 92.0% (RTK & CLAS)

SLAS: 96.5% (RTK & SLAS)

R = 10cm

R = 2m
MADOCA PPP Performance evaluation in Asia and Oceania
MADOCA PPP Performance evaluation in Asia and Oceania

• The first objective is to evaluate real MADOCA PPP performance in several countries in Asia and Oceania.

• The second objective is to find the potential users of PPP in these countries.

After 15 min., we can get 10 cm accuracy. With new method, we can shorten the time and PPP-AR is possible.

GPS • GLONASS • QZSS
Precise orbit and clock
+Galileo
Evaluation

• Receiver is multi-GNSS receiver manufactured by Magellan Systems Japan.
• Locations are 1 in Japan and 7 in foreign countries.
• Errors in each station are evaluated based on true position (ITRF2014) → suitable for moving platform in global.
• GNSS receiver for MADOCA-PPP is prepared as a chip (ASIC).
Outline of locations

Locations (Time)

TUMSAT JAPAN (August 2019)
Chula Thailand (August 2019)
UOP Philippine (August 2019)
MJIIT Malaysia (Nov. 2019)
Curtin Australia (Nov. 2019)
UOI Indonesia (Dec. 2019)
Singapore (Feb. 2021)
Vietnam (March 2023)
Horizontal 95% values at all countries in 2022
About this site

This site is mainly for students/beginners who learn basic of GNSS including precise positioning. We will update the experiments at least once a month in "Report". If it is difficult to modify RTKLIB by yourselves, please check "RTKcore". In addition, performance of MADOCA PPP in several countries are updated in "MADOCA PPP".

News

GNSS TUTOR is updated (1/14/2020).
Short Summary

• Performance evaluation of PPP/CLAS/SLAS for both static and kinematic were introduced.
• Static (95%): PPP 10cm (aft conv.), CLAS 3cm, SLAS 1m
• Kinematic (95%): PPP 15cm (aft conv.), CLAS 3-4cm, SLAS 1m
• CLAS can be used instead of RTK to some degree.
• PPP will be useful for monitoring stations because the base station of RTK moves due to the crustal movement.
• PPP is updated for PPP-AR and short convergence.
GNSS Applications
Robot-car demonstration

• We set up several waypoints at ground.
• Students developed the small semi-autonomous robot-car.
• Once started, the robot car will automatically pass through multiple waypoints and finally stop.
• It is not expensive ($500+MADOCA receiver) and good learning tool for students.
Automatic Waypoints Runs
Monitoring base station (station) using PPP

RTK has been used for these applications. As for buoy, PPP will be better selection. For monitoring the base station of RTK, **PPP can be used to monitor the base station itself.**
Monitoring base stations (GEONET: GNSS Earth Observation Network System)

About 1,300 stations
CLAS uses part of these stations.
This is a very sophisticated system.
PPP might be used for this purpose.
Results of MADOCA-PPP after big Noto Peninsula Earthquake

Movements MAP

Differences between GSI and student’s analysis using MADOCA-PPP

<table>
<thead>
<tr>
<th>電子基準点</th>
<th>MADOCA</th>
<th>国土地理院</th>
<th>差分</th>
</tr>
</thead>
<tbody>
<tr>
<td>輪島</td>
<td>123.2cm</td>
<td>123.8cm</td>
<td>-0.6cm</td>
</tr>
<tr>
<td>穴水</td>
<td>93.6cm</td>
<td>92.5cm</td>
<td>1.1cm</td>
</tr>
<tr>
<td>富来</td>
<td>87.0cm</td>
<td>86.9cm</td>
<td>0.1cm</td>
</tr>
<tr>
<td>珠洲</td>
<td>78.3cm</td>
<td>77.7cm</td>
<td>0.6cm</td>
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<tr>
<td>能登</td>
<td>69.2cm</td>
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</tr>
<tr>
<td>能登島</td>
<td>66.6cm</td>
<td>65.2cm</td>
<td>1.4cm</td>
</tr>
</tbody>
</table>

Geospatial information authority of Japan
Precise positioning anywhere in the world
Simple survey in campus
Install a cm-level receiver and antenna on the bicycle. Go around in a proper circle and generate a map of altitude.
You can clearly see that the area around the baseball mound is high.

Unit is m

-0.1m
0.4m

10cm

Longitude (m)

Latitude (m)
Precise 3D map generation by GNSS/IMU/Speed/Lidar
Depth Surveying by Small Boat
Depth Survey Results at Campus Pond
Questions and Comments
nkubo@kaiyodai.ac.jp
You can also see the exact slope of the road.
2. CLAS during 100km expressway

Approx. 100km

Core AsteRx4 CLAS 79.5%FIX
Mostly within 10cm

Softbank RTK 94.5%FIX
Mostly within 3cm

Gaps (sec) between CLAS FIX

Hakozaki interchange
5, Nov, 2023, real time

HUST, Vietnam

E-W (m):
- ORI = 21.004585400°N 105.843921510°E 34.7540m
- AVE = -0.0189m, STD = 0.0139m, RMS = 0.0235m

N-S (m):
- AVE = -0.0158m, STD = 0.0152m, RMS = 0.0219m

U-D (m):
- AVE = 0.1085m, STD = 0.0749m, RMS = 0.1319m
GNSS Meteorology

Near Real Time Processing with Forwarding Kalman Filter

- IGS ZTD (post-processing) tends to show offset at 00UTC because of window processing
- Seamless processing of batch data helps to avoid jumps of solutions at data boundary

Offset at 00UTC

IGS (Red) ZTD
Seamless PPP processing with batch data (Blue)