Performance Evaluation and Future Application of Real-Time PPP Product in Japan

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Motivation

- Quasi-Zenith Satellite System (QZSS)

Previous research:

QZSS enhances GNSS services from both availability and reliability perspective.
QZSS transmits augmentation signals.
→ L-band experimental (LEX) signal
Real-time GNSS satellite ephemeris and clock correction for
Precise Point Positioning (PPP) (2011/06~)
Centimeter Level Augmentation Service (CLAS) (2018/01~)

**Issues of CLAS:**
The coverage area of CLAS is restricted to the territorial land and the Sea of Japan
→ Coverage of all QZSS orbit areas are impossible

**Improvements in this research:**
Transmitting precise orbit and clock correction from QZSS
→ It can be used in entire Asia-Oceania regions
MADOCA : Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis

Previous researches on verifications of MADOCA :


**Issues of Previous researches :**
Verifications using ships at sea do not exist.

**What’s new in the present work :**
Performance evaluation of long-term voyage at sea
About MADOCA and International GNSS Service (IGS)

Users can download precise orbit and clock correction for free from them.

Previous researches about IGS products:


Issues of IGS products:

Only GPS → It is impossible to carry out the analysis by Multi-GNSS.

15 minutes data interval → Users have to interpolate orbit and clock.

What’s new in the present work:

Analysis of benefits using precise orbit and clock by MADOCA products
Objective

We considered the utilization of MADOCA products.

1. Performance evaluation of long-term voyage at sea

2. Analysis of benefits using precise orbit and clock
Theory : QZSS overview

• QZSS Orbit

First QZSS named “MICHIBIKI” was launched in September, 2010.

QZSS orbit is elliptical and known as “high-inclined elliptical orbit (HEO)".

When QZSS orbit is viewed from Japan, it draws an asymmetric figure-of-eight trajectory that comes back to the same position in about one day.

QZSS always enables users to receive signals from a high elevation angle.
# QZSS Program Schedule

<table>
<thead>
<tr>
<th>year</th>
<th>2015</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>~2022</th>
<th>2023~</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Michibiki</td>
<td>Post-Michibiki</td>
<td>In-Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QZSS 4-Sat.</td>
<td>Launch No.2,3,4</td>
<td></td>
<td>Service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QZSS 7-Sat.</td>
<td>Development/Design (Additional 3 Sats.)</td>
<td></td>
<td></td>
<td></td>
<td>SBAS Service</td>
<td>Service</td>
</tr>
</tbody>
</table>
Two Augmentation Signals

1. Sub-meter Augmentation with Integrity Function (L1-SAIF)
   Providing wide-area differential corrections
   Allowing sub-meter level positioning accuracy

2. LEX signal
   Achieving positioning accuracy for both sub-meter and centimeter level augmentation service

These signals are under investigation for overseas users!
Theory : Status of MADOCA

- Developed by JAXA (2011/06~)
- Test transmission of MADOCA-LEX signal (2013/04/09~)
- Internet broadcasting of real-time products (2014/09/11~)
- Both of off-line and real-time processing
- Satellite orbit and clock determination for multi-GNSS constellation

GPS, GLONASS, QZSS, Galileo and Beidou

<table>
<thead>
<tr>
<th>Processing Pattern</th>
<th>System</th>
<th>RMS error</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-line</td>
<td>GPS</td>
<td>1.81cm</td>
<td>wrt by IGS Final</td>
</tr>
<tr>
<td></td>
<td>clock</td>
<td>0.131ns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GLONASS</td>
<td>4.92cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>QZSS</td>
<td>5.99cm</td>
<td>24H overlap</td>
</tr>
<tr>
<td>Real-time</td>
<td>GPS</td>
<td>3.44cm</td>
<td>wrt by IGS Final</td>
</tr>
<tr>
<td></td>
<td>clock</td>
<td>0.184ns</td>
<td>by Simulation</td>
</tr>
</tbody>
</table>
Experiments and results

- Both of off-line and real-time processing
  - Access real-time PPP products freely

Two experiments and results

1. Use of real-time PPP product by MADOCA at sea
2. Use of precise orbit and clock for code-based positioning
Use of real-time PPP product by MADOCA at sea

- Experiment Setup: 40 days (Tokyo~Cairns~Singapore~Kobe)

<table>
<thead>
<tr>
<th>Receiver</th>
<th>JAVAD DELTA-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>Trimble Zephyr Geodetic 2</td>
</tr>
<tr>
<td>Satellites</td>
<td>GPS, GLONASS and QZSS</td>
</tr>
<tr>
<td>Mode</td>
<td>Kinematic</td>
</tr>
<tr>
<td>Elevation Mask</td>
<td>15°</td>
</tr>
</tbody>
</table>
Results and Discussion

• Performance evaluation of PPP at sea

  Positioning rate

  Comparison of relative positioning solution

• It is impossible to process an ambiguity resolution for real-time PPP product by MADOCA. → PPP float solution

• We analyzed results of positioning accuracy after convergence.
Changes in Positioning Rate

Tokyo ~ Cairns

Cairns ~ Singapore

Singapore ~ Kobe
The Track in Horizontal Direction

Anchored State

Navigational State
The Track in Vertical Direction

Anchored State

Navigational State
Experimental Environment and Change in the Number of Satellites

Experiment Environment

Change in the Number of Satellites

Antenna

Radar Mast

Chimney

Graph showing the number of satellites over time.
Comparison of Relative Positioning Solution at Tokyo Bay

Positioning Rate of PPP was more than 97%.

### Anchored State

<table>
<thead>
<tr>
<th></th>
<th>Latitude (m)</th>
<th>Longitude (m)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>0.043</td>
<td>0.077</td>
<td>0.186</td>
</tr>
<tr>
<td>Average</td>
<td>0.102</td>
<td>-0.100</td>
<td>0.056</td>
</tr>
<tr>
<td>RMS</td>
<td>0.111</td>
<td>0.125</td>
<td>0.194</td>
</tr>
</tbody>
</table>

### Navigational State

<table>
<thead>
<tr>
<th></th>
<th>Latitude (m)</th>
<th>Longitude (m)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>0.022</td>
<td>0.046</td>
<td>0.098</td>
</tr>
<tr>
<td>Average</td>
<td>-0.025</td>
<td>0.023</td>
<td>0.178</td>
</tr>
<tr>
<td>RMS</td>
<td>0.033</td>
<td>0.052</td>
<td>0.203</td>
</tr>
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</table>
Use of Precise Orbit and Clock for Code-based Positioning

• Code-based positioning with **precise orbit, clock and dual-frequency observation** has a potential to provide decimeter level navigation.

• DGNSS is regional service but this is world-wide.

<table>
<thead>
<tr>
<th></th>
<th>Carrier-phased PPP</th>
<th>Code-based PPP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positioning Accuracy</strong></td>
<td>1-10 cm</td>
<td>50-100 cm</td>
</tr>
<tr>
<td><strong>Convergence</strong></td>
<td>0.5-1 hour</td>
<td><strong>Instant Robustness</strong></td>
</tr>
</tbody>
</table>
Test Results in Horizontal Direction on Land Fixed Point
24 hours of January 3\textsuperscript{rd}, 2016
Test Results using Car in Urban Environment

- August 2015
- Tsukishima, Tokyo (near university)
- Semi-urban with high-rise buildings
- 20 minutes with 5Hz
- References: POS/LV

<table>
<thead>
<tr>
<th></th>
<th>Maximum error</th>
<th>% within 1.5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code-base PPP</td>
<td>1.86 m</td>
<td>99.5 %</td>
</tr>
<tr>
<td>Receiver’s NMEA</td>
<td>5.31 m</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Receiver’s NMEA is not able to use corrections (only stand-alone)
Big difference in terms of precise orbit, clock and ionosphere errors
Conclusion

• Positioning rate of PPP was very high 97%-100%. Positioning accuracy on board was approximately 10cm. It is possible to use all over the world.

• We achieved a decimeter level accuracy only code-based positioning by use of precise orbit and clock correction. We can widely extend service areas of a decimeter level accuracy without installing reference stations.

• MADOCA product is capable of a wide range of utilization in both land and sea applications. It will bring several benefits to users.