Satellite Laser Ranging Evaluation to Quasi-Zenith Satellite System

November 6, 2018
NEC Corporation
Ryoma Ishibashi
Outline

1. Overview of the Quasi-Zenith Satellite System (QZSS)
2. Improve orbit determination accuracy by SLR data
3. Future plans of the QZSS & Summary
1. Overview of the Quasi-Zenith Satellite System (QZSS)
MICHIBIKI No.1 was launched on Sep. 11, 2010. Afterwards, Government of Japan decided to make QZSS into a 4-satellite. 4-satellite constellation was established in 2017, and the operational service was started in Nov. 1st, 2018.
QZSS Satellite(s) Overview

Block I-Q: MICHIBIKI No.1
- Lifetime: 10 years
- Orbit (QZO: Quasi-Zenith Orbit)
  - Semi-major Axis (a): 42164[km]
  - Eccentricity (e): 0.075
  - Inclination (i): 41 deg

Block II-Q: MICHIBIKI No.2, 4
- Lifetime: 15 years+
- Orbit (QZO: Quasi-Zenith Orbit)
  - a, e, i: same as Block I-Q

Block II-G: MICHIBIKI No.3
- Lifetime: 15 years+
- Orbit (GEO: GeoStationary Orbit)
  - Longitude: E 127/ Latitude: 0
QZSS Orbit

Japan Region
- Over 20 degrees elevation (More than 2 QZS are available)
- Over 60 degrees elevation (1 QZS is available)

QZSS Coverage Area at least one QZS is visible

QZO: “8 Letter” Orbit

GEO: on the Equator

1 Geostationary satellite
**QZSS Satellite(s) Launch**

**MICHIBIKI** Launched from Tanegashima space center.

<table>
<thead>
<tr>
<th></th>
<th>No.1*</th>
<th>No.2</th>
<th>No.3</th>
<th>No.4</th>
</tr>
</thead>
</table>

* MICHIBIKI No.1 was transferred from JAXA to Cabinet Office on Mar. 2017.
Typical Mission of QZSS

QZSS provides positioning-related service and messaging service.

Positioning-related service

- **Satellite Positioning, Navigation & Timing Service (PNT)**
  The service to provide satellite positioning as same as US-GPS.
- **Sub-meter Level Augmentation Service (SLAS)**
  The service to provide accurate positioning around 1-2 meters*.
- **Centimeter Level Augmentation Service (CLAS)**
  The service to provide highly accurate positioning around 10 centimeters*.
  
  * Ionosphere disturbance (fluctuations), multipath and others will affect the accuracy.

Messaging Service

- **Satellite Report for Disaster and Crisis Management (DC Report)**

Positioning-related service supported by JCAB

- **SBAS Service**

To evaluate and improve the positioning accuracy by SLR data.
PNT Service (GPS Complementary)

QZSS can be seen at high elevation angle and reduces the multipath effect.

QZSS transmits two types of the regional ionospheric parameters, i.e. parameters for the Southeast Asia and Oceania regions, and parameters for the area near Japan.
2. Improve orbit determination accuracy by SLR data
Tuning routine on QZSS operation

Accuracy evaluation using SLR data has helped modeling and parameter tuning of orbit determination.

- [Broadcast data]
  - Almanac products
  - Ephemeris products etc...

- [QZSS web site]
  - http://qzss.go.jp/en

- [QZSS archive data]
  - Final products etc...

- [Generation products]
  - Almanac products
  - Ephemeris products
  - Final products etc...

- [Parameter Tuning]
  Orbit estimation (SRP* parameter) tuning by SLR data.

* SRP = Solar radiation pressure
SLR visible stations for MICHIBIKI

SLR visible station for QZO (over 20 degrees elevation)

<table>
<thead>
<tr>
<th>Name</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>YARL</td>
<td>667</td>
</tr>
<tr>
<td>SHA2</td>
<td>246</td>
</tr>
<tr>
<td>CHAL</td>
<td>106</td>
</tr>
<tr>
<td>BEIL</td>
<td>49</td>
</tr>
<tr>
<td>STL3</td>
<td>7</td>
</tr>
<tr>
<td>GMSL*</td>
<td>341</td>
</tr>
</tbody>
</table>

Number of ranging data per SLR station

* GMSL is quarantine station (reference value). Data provided by JAXA.
SLR visible stations for MICHIBIKI

Time series graph of Number of SLR NPT data

We could obtain so many SLR data
- We thanks to the SRP parameter tunings by using these data, improve orbit estimation accuracy!! (detail is next slides)

Thank you for your cooperation!!
Solar radiation pressure (SRP)
• SRP, which is a kind of force models for satellites, is key factor for precise orbit determination and estimation.

Force models for satellite.

<table>
<thead>
<tr>
<th>Gravity</th>
<th>Geopotential, Third-Body potentials, etc...</th>
<th>It is not necessary to estimate the models. Can be applied the same models for satellites. (For example, DE430).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-gravity</td>
<td>SRP, Atmospheric Drag, etc...</td>
<td>It is necessary to estimate the model for each satellite (especially SRP).</td>
</tr>
</tbody>
</table>

SRP models for orbit determination
• Analysis models
• Empirical models ✓: Adopted in MICHIBIKI

Depends on orbit position and β-angle. long-term fittings (parameter tuning) is required.
SRP parameter tunings for MICHIBIKI by SLR(2/4)

CODE model (A kind of SRP empirical models)
- Define of the DBY coordinate system

Coordinate System

Acceleration

\[ a_{srp} = S \times \left( D(u)e_D + Y(u)e_Y + B(u)e_B \right) \times 10^{-9} \]

\[ D(u) = D_0 + D_c \cos(u) + D_s \sin(u) \]
\[ Y(u) = Y_0 + Y_c \cos(u) + Y_s \sin(u) \]
\[ B(u) = B_0 + B_c \cos(u) + B_s \sin(u) \]

\[ S = F_{\text{shadow}} \times AU^2 / |r - r_s|^2 \]
\[ F_{\text{shadow}} = \text{Penumbra/umbra of earth/moon} \]
\[ AU = \text{Astronomical unit} \]

⇒ We should optimize these 9 parameters (Dx, Bx, Yx) for each satellites.
SRP parameter tunings for MICHIBIKI by SLR(3/4)

Determination flow of SRP coefficients (Dx, Bx, Yx).

Find the SRP parameter which minimize the residual error:
① The difference between the SP3-orbit and SLR.
② The SP3-orbit overlap of successive generation.
Parameter tuning for MICHIBIKI by SLR(4/4)

Result of SRP parameter fitting for MICHIBIKI No.2 (Offline).

Before SRP fitting (old SRP coef.)

Residuals (SP3-overlap and SLR): 0.46m (rms)

SP3 Orbit-overlap: 0.30m (rms)

After SRP fitting (new SRP coef.)

Residuals (SP3-overlap and SLR): 0.37m (rms)

SP3 Orbit-overlap: 0.17m (rms)
Evaluation for MICHIBIKI

Accuracy evaluation of all QZS products by SLR data.

SLR residuals of No.2 and No.4 was improved by thanks to SRP fitting. We will carry out continuous tuning for Other QZS.

We appreciate ILRS’ laser ranging activities, and need continuous support by ILRS for QZS’ accuracy improvement.
3. Future plans of the QZSS & Summary
Future plans of QZSS

4-satellite constellation of QZSS has just started on this November. It will be established 7-satellite constellation in 2023.

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>QZSS 4-satellite constellation</td>
<td>Trial Service</td>
<td>From Nov.1</td>
<td></td>
<td></td>
<td></td>
<td>No.1 replacement</td>
</tr>
<tr>
<td>QZSS 7-satellite constellation</td>
<td></td>
<td></td>
<td>Development/Launch Additional 3 satellites</td>
<td></td>
<td></td>
<td>Service</td>
</tr>
</tbody>
</table>
Summary

The 4-satellites constellation was established by the end of 2017 and the full operational service has started on this Nov. 1st.

QZSS achieved high-performance positioning results as GPS complemental system.

The evaluated results of SRP fittings by SLR data is quite a good result. QZSS wants continuous cooperation by ILRS.

We will start the development of 7-satellite constellation, and it will be established within 2023.

Acknowledgements

We would like to express the special thanks to ILRS’ cooperation.
Thank you for your attention.

For more information, please visit our web site

http://qzss.go.jp/en
Laser ranging for QZS

All QZS equipped the LRA for laser-ranging. Property information is below.

Location of LRA optical center

<table>
<thead>
<tr>
<th>Coordinates (w.r.t origin of satellite reference frame) [mm]</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block I·Q</td>
<td>-1150.0</td>
<td>-550.0</td>
<td>+4505.3</td>
</tr>
<tr>
<td>Block II·Q</td>
<td>-988.2</td>
<td>-860.8</td>
<td>+4373.3</td>
</tr>
<tr>
<td>Block II·G</td>
<td>+1081.8</td>
<td>-460.8</td>
<td>+4373.3</td>
</tr>
</tbody>
</table>

Envelope (same as all QZS)

- 400[mm] x 400[mm] x 100[mm]

Number of corner cube reflector

- 56 (7 rows x 8 lines)
## Signal of QZSS

In addition to the positioning signals (GPS complementation), QZSS transmits the augmentation signals and the message/experimental signals.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Frequency</th>
<th>Purpose</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Satellite</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;-4&lt;sup&gt;th&lt;/sup&gt; Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1C/A</td>
<td>1575.42MHz</td>
<td>Positioning (PNT)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L1C</td>
<td></td>
<td>Positioning (PNT)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L1S</td>
<td></td>
<td>Augmentation (SLAS)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Message Service</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L2C</td>
<td>1227.60MHz</td>
<td>Positioning (PNT)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L5</td>
<td>1176.45MHz</td>
<td>Positioning (PNT)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L5S</td>
<td>1176.45MHz</td>
<td>Augmentation (Experimental)</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>L6D</td>
<td>1278.75MHz</td>
<td>Augmentation (CLAS)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>L6E</td>
<td></td>
<td>Experimental</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>L1Sb</td>
<td>1575.42MHz</td>
<td>Augmentation</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>S-band</td>
<td>2GHz band</td>
<td>Message Service</td>
<td>N/A</td>
<td>✓</td>
</tr>
</tbody>
</table>
Thanks to the QZS added navigation, the residual error for user positioning accuracy was improved rather than the GPS only.

**GPS+QZS**

3D RMS: 1.63m

**GPS Only**

3D RMS: 2.49m

2018/5/15 at Kobe, Hyogo Prefecture, Japan