GNSS Innovative Technology - Introduction of Precise Point Positioning Using QZSS

Proposal Summary of QZSS Measurement

- Proposing configuration of equipment for QZSS measurement

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) GNSS Antenna</td>
<td></td>
</tr>
<tr>
<td>(2) GNSS (QZSS) Receiver</td>
<td></td>
</tr>
<tr>
<td>Positioning Augmentation Message (Downlink)</td>
<td></td>
</tr>
<tr>
<td>(Real-Time) GNSS Positioning in ~ 5cm accuracy</td>
<td></td>
</tr>
</tbody>
</table>

QZSS Overview

QZSS is a satellite positioning system operated by Japanese government as complementary and augmentation satellites of GPS.

Four satellites of the first constellation has already been launched, and now the final confirmation for official service is ongoing under the staring program administrated by Cabinet Office.

Concept
- Regional Navigation Satellite System
- Compatible with GPS satellites
- Provision of extra service signals

Transmission Signals

In principle signals are designed as compatible with GPS to complement it. Additionally L6 and S-band frequency bands and several services are provided as listed in orange description in the below table.

QZSS signal frequencies and services

<table>
<thead>
<tr>
<th>Name</th>
<th>Frequency</th>
<th>Transmission Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1C/A</td>
<td>1575.42MHz</td>
<td>Satellite positioning</td>
</tr>
<tr>
<td>L1C</td>
<td></td>
<td>Satellite positioning</td>
</tr>
<tr>
<td>L1B</td>
<td></td>
<td>Sub-meter Level Augmentation</td>
</tr>
<tr>
<td>L1B+</td>
<td></td>
<td>Satellite Signal for CNav[+1]</td>
</tr>
<tr>
<td>L1B+-</td>
<td></td>
<td>SBAS Transmission [(2020-)]</td>
</tr>
<tr>
<td>L2C</td>
<td>1176.45MHz</td>
<td>Satellite positioning</td>
</tr>
<tr>
<td>L3</td>
<td></td>
<td>Satellite positioning</td>
</tr>
<tr>
<td>L5</td>
<td></td>
<td>Centimeter Level Augmentation</td>
</tr>
<tr>
<td>L5B</td>
<td></td>
<td>Positioning Technology Verification</td>
</tr>
<tr>
<td>L5B+</td>
<td></td>
<td>Positioning Technology Verification</td>
</tr>
<tr>
<td>S-band</td>
<td>1176.45MHz</td>
<td>QZSS Safety Confirmation [+3]</td>
</tr>
</tbody>
</table>

Frequency Compatibility between GNSS systems

[Image and table]
Positioning Augmentation Service on L6

There are two channels to broadcast centimeter-level augmentation message on L6 of QZS-2/3/4 (excluding QZS-1).

Currently, “Positioning Technology Verification” message on channel-2 can be used for global users, providing Precise Point Positioning (PPP) augmentation message.

<table>
<thead>
<tr>
<th>Name</th>
<th>Freq.</th>
<th>Transmission service</th>
<th>Broadcasted from</th>
</tr>
</thead>
<tbody>
<tr>
<td>L6</td>
<td>12276.75 MHz</td>
<td>Centimeter Level Augmentation</td>
<td>QZS-1, QZS-2, QZS-3, QZS-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positioning Technology Verification</td>
<td>Currently available, Preparing, Planning</td>
</tr>
</tbody>
</table>

**Positioning Example**

- General GNSS accuracy is about a few meters in case of standalone positioning, and it can be improved up to centimeter-level by various methods (e.g., Kinematic-GNSS, Static).
- The augmentation service from QZSS also provides centimeter-level accuracy. According to evaluation results by some users, less than 5cm horizontal and less than 10cm vertical accuracy could be achieved.

**System Configuration**

- QZSS Augmentation message to improve the accuracy of positioning is generated using the processing software (so called “MADOCA”[5]) with global observation data from the world-wide monitoring network. The error values in the satellite-side environment, such as orbit error, satellite’s clock error, and clock bias, are estimated by MADOCA, and those are transmitted to users so that the positioning error can be corrected.

- “MADOCA” is developed by JAXA based on the technology for estimating satellite orbit and clock corrections.

**Demonstration CORS Network for QZSS Augmentation**

Global monitoring network of MADOCA is being operated as an experiment under the international collaboration between JAXA and cooperation organizations. Currently about 90 monitoring stations are under operation including Nagarkot station provided by BS of Nepal.

**Principle of Positioning**

In case of PPP method, the augmentation message provides only satellite-side error corrections, such as orbit, clock, and signal biases on satellite-side.

Other errors, such as ionosphere and troposphere should be corrected at user-side. In principle, double-frequency (L1/L2) GNSS receiver is required to estimate ionosphere error. To estimate troposphere error, a certain volume of time-series data observed by user’s receiver is used.

**Positioning Calculation**

Error sources 1-3 (satellite-side environment) can be corrected by simultaneous observation with more than 4 monitoring network.

Error sources 4-5 (caused by signal delay) is corrected using user’s observation data. For estimating ionosphere delay, dual-frequency observation is mandatory.

**Visibility / Availability**

Four satellites constellation is consisted of three QZO (inclined geosynchronous orbit) satellites and one GEO satellite. Nepal is located within the coverage area of QZSS service. QZS-2 has started to provide experimental service of “positioning technology verification”.

The contour shows the predicted rate of visibility for one QZ0 satellite over 15 degrees.
Performance of PPP Augmentation

Satisfactory performance has been confirmed for centimeter-level positioning to estimate multi-GNSS orbit / clock.

<table>
<thead>
<tr>
<th>GLONASS (ref-SF)</th>
<th>GPS (ref-SF)</th>
<th>QZSS (ref-SF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm</td>
<td>5 cm</td>
<td>10 cm</td>
</tr>
</tbody>
</table>

Real-Time

Ref | GPS | IAC | JAXA
---|-----|-----|-----
100 | 5.0 | 1.0 | 0.5
140 | 8.0 | 1.0 | 0.5
240 | 7.0 | 1.0 | 0.5


d = RMS(cm) 2 = STD(%)


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Positioning Performance of PPP

Less than 5cm RMS of horizontal accuracy, and less than 10cm RMS of vertical accuracy can be achieved by JAXA’s evaluation.

<table>
<thead>
<tr>
<th>0.5 cm</th>
<th>1.0 cm</th>
<th>1.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 cm</td>
<td>1.0 cm</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>0.5 cm</td>
<td>1.0 cm</td>
<td>2.5 cm</td>
</tr>
</tbody>
</table>

Convergence Time

Due to tropospheric delay, about 30 minutes of data is required to estimate the tropospheric error by Kalman filter with time-series observations.

For this reason, the accuracy immediately after starting the positioning process is not stable, then it will converge to cm-class in about 30 minutes.

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Estimated Position (Reference Coordinate System)

Satellite coordinates in QZSS augmentation are provided based on ITRF2008. User’s GNSS receiver should output coordinates based on WGS84 as is the case with other GNSS positioning.

In case of QZSS-PPP positioning, about 90 of world-wide monitoring stations are used for producing augmentation message (satellite orbits etc.), and the coordinates of stations are estimated with satellite’s coordinates at all times, therefore, the estimated user’s position does not affected by determination of monitoring site’s location. This means that PPP positioning provides “absolute” coordinates.

Satellite and monitoring station coordinates at the same time

First: coordinates of satellites and monitoring stations. Second: Augmentation message (ITRF2008)

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Demonstration Projects using QZSS-PPP

Some demonstration projects using QZSS-PPP are ongoing. PPP solution can be utilized without the need for relative reference GNSS station around user’s position. This means that PPP is available “anywhere” in the world.

The following video is past demonstration projects using PPP technology.

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Visibility from Mt. Everest (Sagarmatha)

- Peak position: 27.987 deg Lat, 86.925 deg Lng, 8848m Hgt
- OZSS-2 visible from 09:45 to 17:45 UTC, 11/30/2017
- OZSS-2 can be tracked about 54% of time above 30 degrees elevation with visible time changing to about 4 minutes earlier per day as the sidereal period of the satellite is about 23 hours 56 minutes.

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Advantages and Issues to be considered in case of QZSS-PPP

Advantages:
- Centimeter-level positioning is available in real-time
- No changes for receiving augmentation message as “Positioning Technology Verification” Service
- No communication link is required except GNSS
- Absolute coordinates are measured
- No effect by deformation of reference GNSS monitoring station

Issues to be considered:
- QZSS-PPP compatible receiver is currently limited
  - cold weather prevention is mandatory
- Visible time of QZSS may be limited on Mt. Everest
- At least 30 minutes observation is required for convergence

Summary
- Four QZSS satellites have been launched and some experimental service is being provided.
- “Positioning Technology Verification” service (PPP augmentation service) has started experimentally by Global Positioning Augmentation Service Corporation from QZS-2.
- Some demonstration projects using QZSS-PPP service are ongoing.
- Absolute 10cm accuracy is available in vertical axis by applying augmentation from QZSS service, after 30 minutes convergence time.
- 54% visibility of QZS-2 above 30 degrees elevation is expected at the peak of Mt. Everest. Soon visibility will become 100% above 35.4 degrees elevation after checking out of QZS-3/4.
- One type of QZSS-PPP compatible receiver is available as an evaluation kit.