Improvement of RTK-GNSS using Multiple Antennas and Receivers

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Tokyo University of Marine science and Technology (TUMSAT)
Background (GNSS Usage)

ITS

Auto construction

UAV

Correction data Services (JAPAN)

Low cost receiver
GNSS Receiver output in challenging area

Orange plots: Float solutions
Green plots: Fix solutions
Yellow line: Actual tracks

Example: Car test result in Tokyo station
Actual test in Tokyo

Date (GPS Tow): 24/06/2022 451505~452810
Area: Near Tokyo station
GNSS receiver: Ublox F9P
Frequency: 5Hz
Valuation Target: Fix rate & Miss Fix rate

Green line: Actual tracks
Red frame: Deep urban area
### Actual test in Tokyo

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of Fix (Fix rate)</th>
<th>Number of Miss Fix (Miss Fix rate*)</th>
<th>Position error (3D)</th>
<th>Maximum Outage**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open sky (Fix solution)</td>
<td>6455 (100 %)</td>
<td>0 (0 %)</td>
<td>0.01m (Average)</td>
<td>0.2 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.01m (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.07m (Max)</td>
<td></td>
</tr>
<tr>
<td>Urban area (Fix solution)</td>
<td>5137 (89.37 %)</td>
<td>4 (0.0008 %)</td>
<td>0.03m (Average)</td>
<td>48.2 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.08m (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.86m (Max)</td>
<td></td>
</tr>
<tr>
<td>Dense urban area (Fix solution)</td>
<td>3500 (60.19 %)</td>
<td>1089 (31.14 %)</td>
<td>0.40m (Average)</td>
<td>166.4 sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.59m (STD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.18m (Max)</td>
<td></td>
</tr>
</tbody>
</table>

*Miss Fix rate = Number of miss Fix / Number of Fix

**Maximum outage for which no Fix solution was obtained

With the help of multi-GNSS and an excellent low-cost receiver, it is easier to obtain Fix solutions in urban areas. But, improving the reliability and availability of Fix solutions is essential if GNSS is to be adopted in areas such as ITS, especially dense urban area!!
Method For Robust GNSS Positioning

GOAL

- Improve reliability (reduce the miss Fix rate)
- Improve availability (Improve Fix rate)

- Precise 3D MAP
- Fish-eye view camera
- GNSS + IMU/Speed and other sensors
- Machine learning (LOS/NLOS classifier)
- **Multiple GNSS Antennas and Receivers**
Benefit of Multiple GNSS Antennas and Receiver

If using Multiple GNSS Antennas and Receiver, Heading and Attitude determined by moving base positioning. Also, each receiver is independently installed so that they can cross-check.
“AND selection” and “OR selection” method

Each GNSS receiver outputs the position, velocity, time (PVT), and observation data independently. By cross-checking the PVT and observation data from Multiple GNSS Antennas and Receiver, the robustness and availability of GNSS positioning can be improved.
“AND selection” is performed when all receivers output Fix solutions. The baseline length between fix solutions is also checked and detect miss Fix.

“AND selection” decreases availability, but increases robustness.
“OR selection” involves extracting an epoch when a Fix solution is outputted from one or more of the installed GNSS receivers.

“OR selection” increases availability but decreases robustness.
The data was obtained using car installed with Multiple Antennas and Receivers, and we drive along the route.

In Dense Urban area (Red frame), DGNSS positioning error easily reached several tens of meters or more.

Reference station is installed at TUMSAT (Our laboratory).

We've run the three times on March 2, 2021.
Lap1: 0:18:08 ~ 0:58:00 (UTC)
Lap2: 4:59:00 ~ 5:33:32 (UTC)
Lap3: 5:55:00 ~ 6:27:20 (UTC)

“AND selection” and “OR selection” were conducted using RTK-GNSS positioning solutions by Ublox F9P’s output and positioning software developed by our laboratory.
# Test (Equipment & Parameter)

## Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Model Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS receiver</td>
<td>u-blox F9P (base/rover)</td>
</tr>
<tr>
<td>GNSS antenna (rover)</td>
<td>Aero Antenna AT1675</td>
</tr>
<tr>
<td>GNSS antenna (Base)</td>
<td>Trimble Zephyr 2 Geodetic</td>
</tr>
<tr>
<td>Reference position</td>
<td>POSLV-520</td>
</tr>
</tbody>
</table>

## Parameter

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
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<tbody>
<tr>
<td>Mask angle</td>
<td>15 degrees</td>
</tr>
<tr>
<td>Maximum DOP</td>
<td>10.0(HDOP)/20(VDOP)</td>
</tr>
<tr>
<td>Minimum SNR</td>
<td>32 dB-Hz</td>
</tr>
<tr>
<td>Code phase measurements</td>
<td>Tracked</td>
</tr>
<tr>
<td>Carrier phase measurements</td>
<td>Tracked</td>
</tr>
<tr>
<td>LLI</td>
<td>Tracked and half-cycle resolved</td>
</tr>
<tr>
<td>Frequency</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Satellites</td>
<td>GPS/QZSS/GALILEO/BDS/GLONASS</td>
</tr>
<tr>
<td>Ambiguity Resolution method</td>
<td>1 epoch</td>
</tr>
</tbody>
</table>

![Diagram of Fore and Aft with 1.52m between them](image)
Result

**Fix rate (Number of Fix / Total epoch)**

- Single: Aft antenna’s result
- OR selection: OR selection’s result
- AND selection: AND selection’s result

**Miss Fix rate (Number of Miss Fix / Number of Fix)**

- Single: Aft antenna’s result
- OR selection: OR selection’s result
- AND selection: AND selection’s result

F9P output (Lap x): Ublox F9P’s output at lap x

Our laboratory (Lap x): Our laboratory positioning software’s output at lap x
Triple or more Antennas and Receivers

Baseline length \times

Fix

Baseline length \times

Fix

Baseline length \times

Fix

Fix

Green

Baseline length

Fix

GNSS antenna

Red
Triple or more Antennas and Receivers

Baseline length O ➔ Fix ➔ Baseline length × ➔ Fix ➔ Baseline length × ➔ Wrong Fix

GNSS antenna
Based on count the number of Fix solution, Robust and highly available GNSS solution can be output. → Majority vote
The data was obtained using a car installed with four Antennas and Receivers, and we drive along the route.

Reference station is installed at TUMSAT (Our laboratory).

We've run the three times on August 31, 2022.

Date: 0:48:00 ~ 01:17:02 (UTC)

Majority vote were conducted using RTK-GNSS positioning solutions output by Ublox F9P and positioning software developed by our laboratory.
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<td>Reference position</td>
<td>POSLVX-125</td>
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<tr>
<td>LLI (only RTK-GNSS)</td>
<td>Tracked and half-cycle resolved</td>
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</table>
### Result

<table>
<thead>
<tr>
<th></th>
<th>Aft antenna</th>
<th>Fore antenna</th>
<th>Right antenna</th>
<th>Left antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F9P</strong></td>
<td>Fix rate : 66.74 % Miss Fix rate : 1.67 %</td>
<td>Fix rate : 50.88 % Miss Fix rate : 13.15 %</td>
<td>Fix rate : 60.36 % Miss Fix rate : 5.81 %</td>
<td>Fix rate : 54.46 % Miss Fix rate : 0 %</td>
</tr>
<tr>
<td><strong>Our laboratory</strong></td>
<td>Fix rate : 54.80 % Miss Fix rate : 0.17 %</td>
<td>Fix rate : 49.66 % Miss Fix rate : 0.65 %</td>
<td>Fix rate : 38.04 % Miss Fix rate : 1.4%</td>
<td>Fix rate : 47.50 % Miss Fix rate : 0.2%</td>
</tr>
</tbody>
</table>

*Miss Fix rate = Number of miss Fix / Number of Fix

<table>
<thead>
<tr>
<th>Number of Fix=0</th>
<th>Fix rate /Miss Fix rate (F9P)</th>
<th>Fix rate /Miss Fix rate (Our laboratory)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.3%</td>
<td>35.0%</td>
</tr>
<tr>
<td>Number of Fix=1</td>
<td>12.9% / 64.9%</td>
<td>10.0% / 12.9%</td>
</tr>
<tr>
<td><strong>Number of Fix=2</strong></td>
<td>13.9% / 5.3%</td>
<td>11.38% / 0%</td>
</tr>
<tr>
<td>Number of Fix=3</td>
<td>11.25% / 0%</td>
<td>11.48 % / 0%</td>
</tr>
<tr>
<td>Number of Fix=4</td>
<td>40.1% / 0%</td>
<td>32.1 % / 0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>
# Result

<table>
<thead>
<tr>
<th>“Majority Vote”</th>
<th>Number of Fix / Miss Fix (F9P)</th>
<th>Number of Fix / Miss Fix (Our laboratory)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65.3% / 1.1%</td>
<td>55.0% / 0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Result (Dual)</th>
<th>“OR selection” result (Fore &amp; Aft)</th>
<th>“AND selection” result (Fore &amp; Aft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fore antenna (F9P)</td>
<td>Fix rate: 72.78%  Miss Fix rate: 8.3%</td>
<td>Fix rate: 43.81%  Miss Fix rate: 1.20%</td>
</tr>
<tr>
<td>Aft antenna (F9P)</td>
<td>Fix rate: 60.65%  Miss Fix rate: 0.61%</td>
<td>Fix rate: 43.44%  Miss Fix rate: 0.0%</td>
</tr>
<tr>
<td>Fore antenna (our laboratory)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aft antenna (our laboratory)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Idea of using Multiple Antennas and Receivers

- Common satellite
- Check Doppler Frequency by Multiple Antennas and Receivers
- Hold Ambiguity Method
- Modified “OR selection”
Exclusion of satellites strongly affected by multipath from positioning
Use a common satellite that can be tracked by both antennas.

<table>
<thead>
<tr>
<th></th>
<th>Before selecting common satellite</th>
<th>After selecting common satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fore (our laboratory)</td>
<td>Fix rate : 49.66 %  Miss Fix rate : 0.65 %</td>
<td>Fix rate : 50.77 %  Miss Fix rate : 0.11 %</td>
</tr>
<tr>
<td>Aft (our laboratory)</td>
<td>Fix rate : 54.80 %  Miss Fix rate : 0.17 %</td>
<td>Fix rate : 54.44 %  Miss Fix rate : 0.12 %</td>
</tr>
</tbody>
</table>
Check Doppler Frequency by Multiple Antennas and Receivers

When going straight ahead, Doppler frequency between the satellite and GNSS receiver is almost same at Fore and aft antennas. Frequency offset can be deleted by single difference.

\[ D_{p_{aft\_G24}} - D_{p_{aft\_G10}} \approx D_{p_{front\_G24}} - D_{p_{front\_G10}} \]  \hspace{1cm}  \cdots \hspace{0.5cm} (1)

If equation (1) does not satisfy, the satellite (G24) is affected by multipath error. We evaluate this method, but no effect on velocity estimation. → Due to the use of F9P?

How about use of Survey grade GNSS receiver?
Hold Ambiguity

- The biggest problem with Hold Ambiguity method is that it uses the wrong ambiguity to estimate position.

- Using “AND selection”, it can dramatically reduce miss Fix and find more reliable ambiguity.
Modified “OR selection”

If Fix solution is obtained at aft antenna’s position, the position of the fore antenna can also be determined from the Heading estimated by the IMU.

If the precise position of a few cm level is known, only ambiguity remains for the double difference at the fore antenna. → By checking for fractions of ambiguity, it is possible to determine if Fix solution is correct.

We evaluate this method, but it is difficult to detect the miss Fix.

※Wavelength
GPS(L1) : 19.03cm
GPS(L2) : 24.42cm
GPS(L1-L2) : 86.19cm
We introduced benefit of using Multiple Antennas and Receivers.

- “AND selection” significantly reduces miss Fix.
- “OR selection” significantly increases the number of Fix, but detection of miss Fix is issue.
- “Majority vote” is method that takes advantage of “AND selection” and “OR selection”.
- To verify Idea which did not fully confirm improvement.
  → This is the future work.