Improvement of RTK-GNSS using Multiple Antennas and Receivers

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Background(GNSS Usage)

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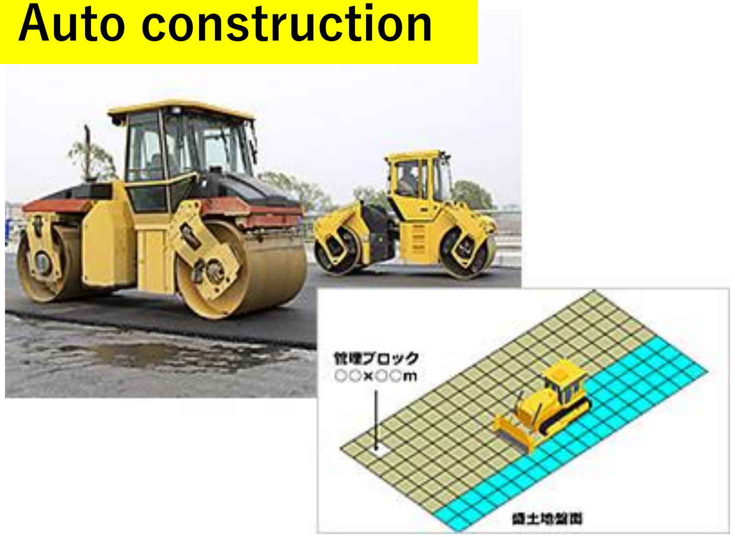
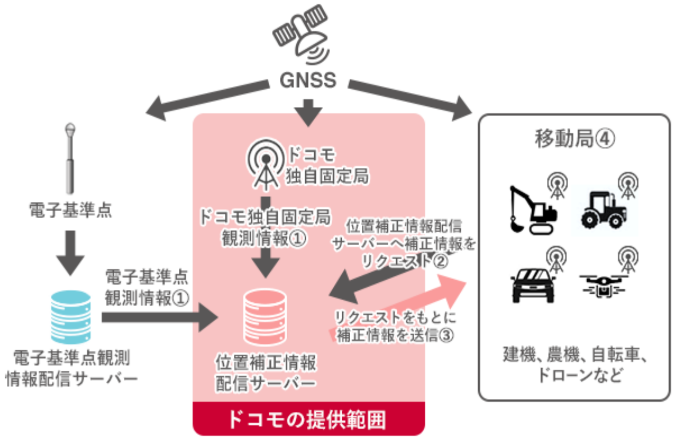
ITS

Auto construction

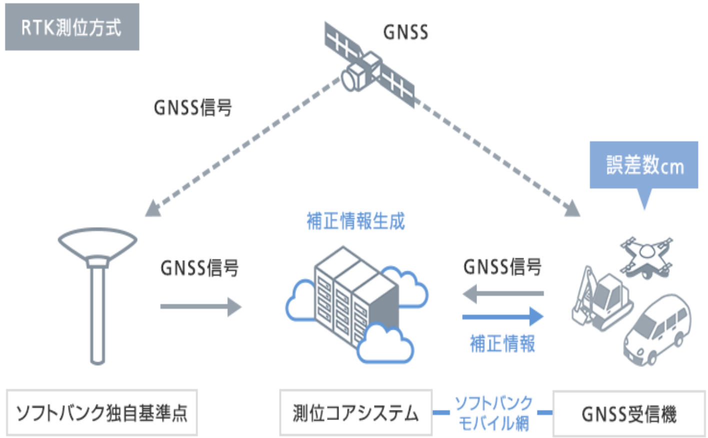


UAV

Correction data Services(JAPAN)

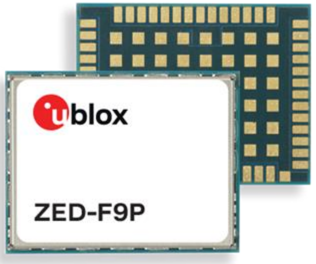


docomo

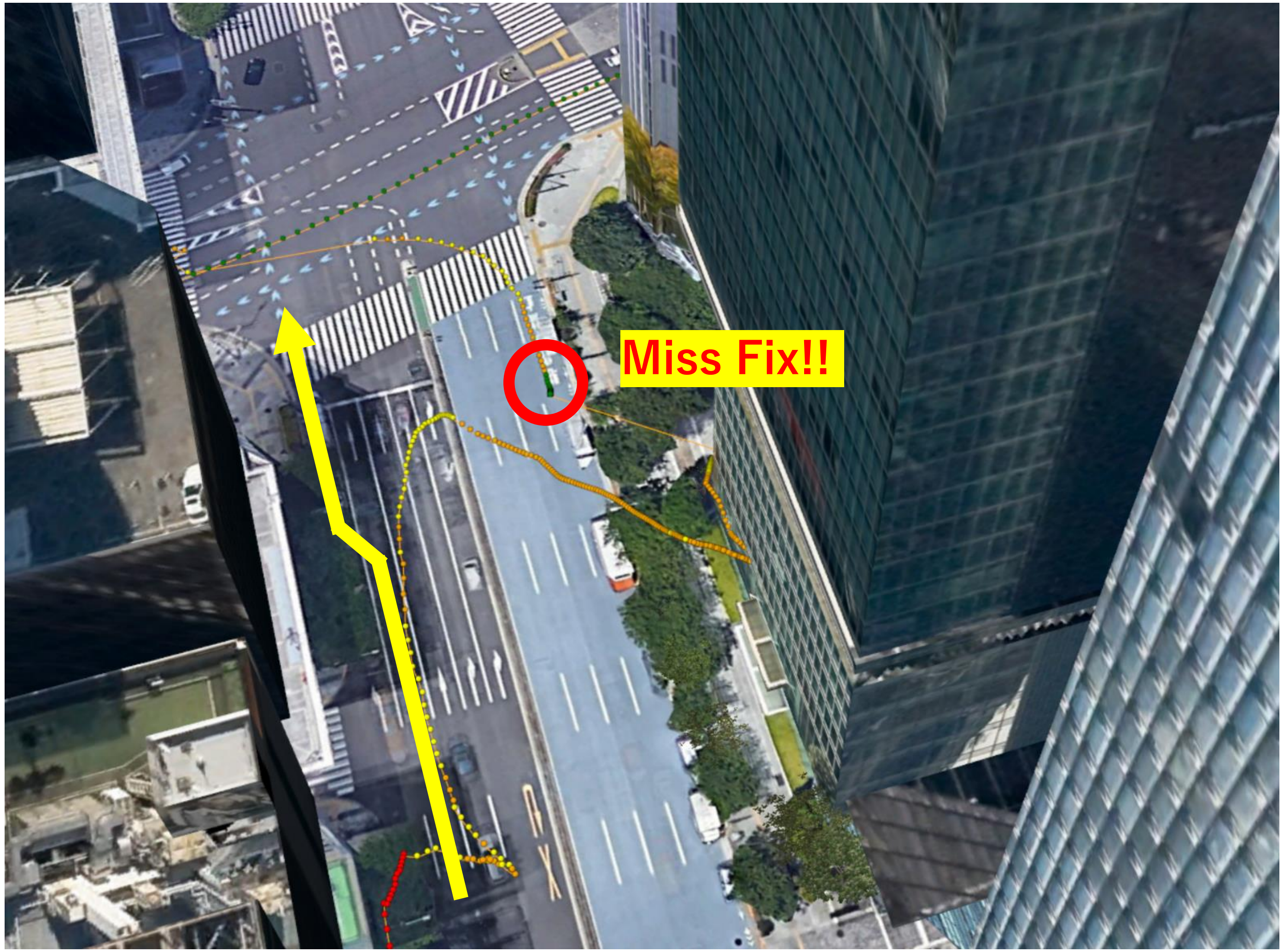


Softbank

Low cost receiver



GNSS Receiver output in challenging area



Example : Car test result in Tokyo station

Orange plots :Float solutions
Green plots :Fix solutions

Yellow line : Actual tracks

Actual test in Tokyo

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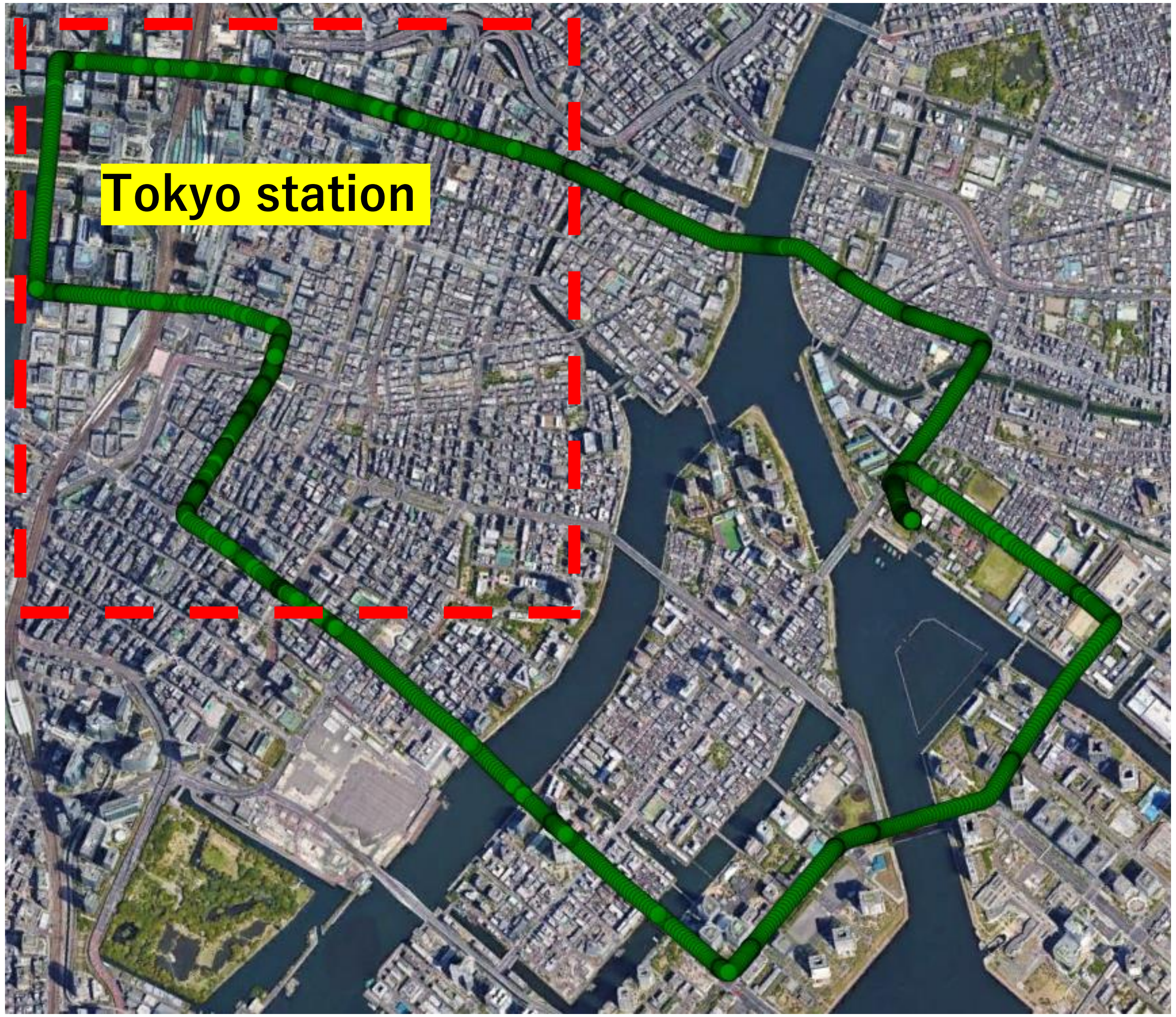

Green line : Actual tracks
Red frame : Deep urban area

Content	Setting
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

Actual test in Tokyo

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

*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

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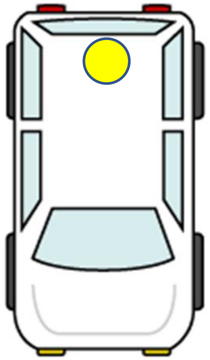
GOAL

- **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

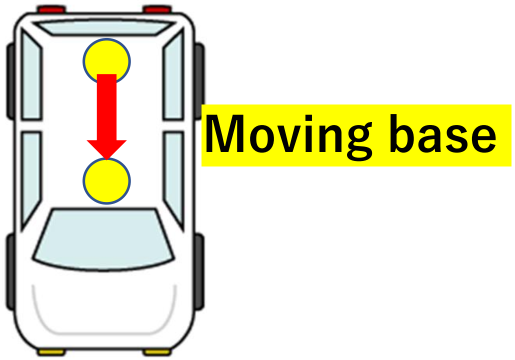
Single GNSS Antenna and Receiver



Value	○/△/×
Position	○
Speed	○
Heading	△
Attitude	×

● GNSS antenna

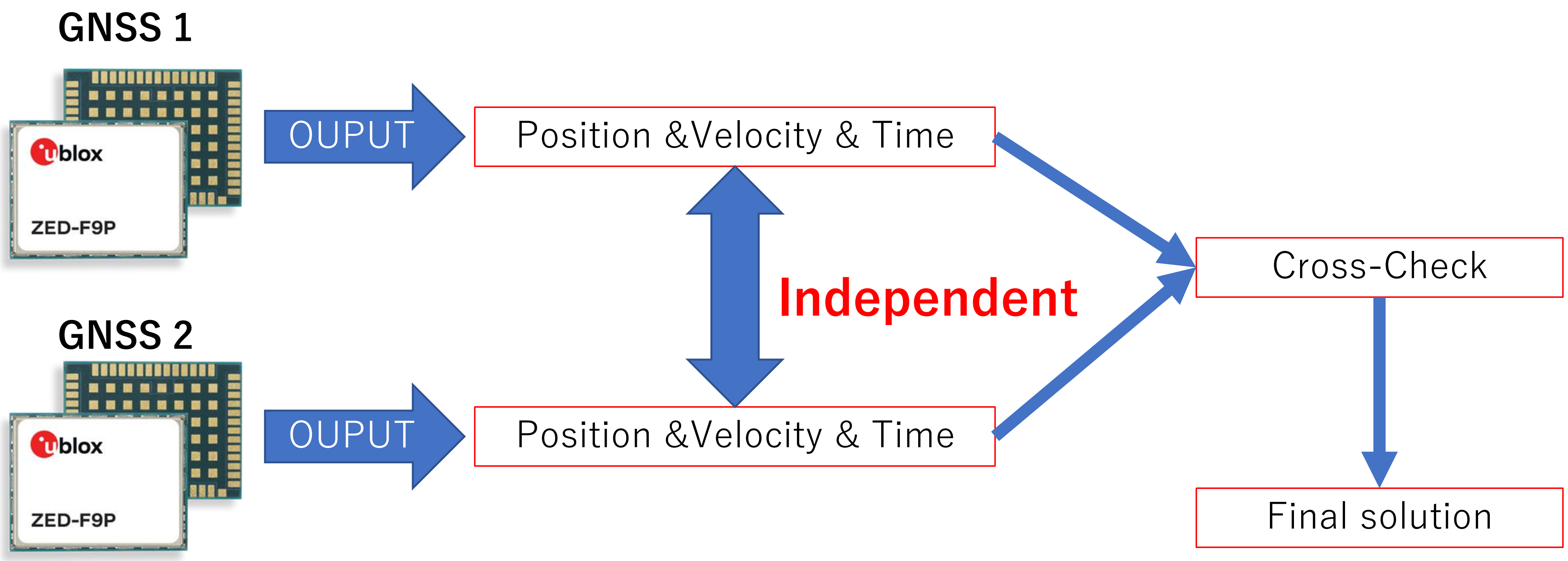
Multiple GNSS Antenna and Receiver



Value	○/△/×
Position	○
Speed	○
Heading	○
Attitude	○

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.

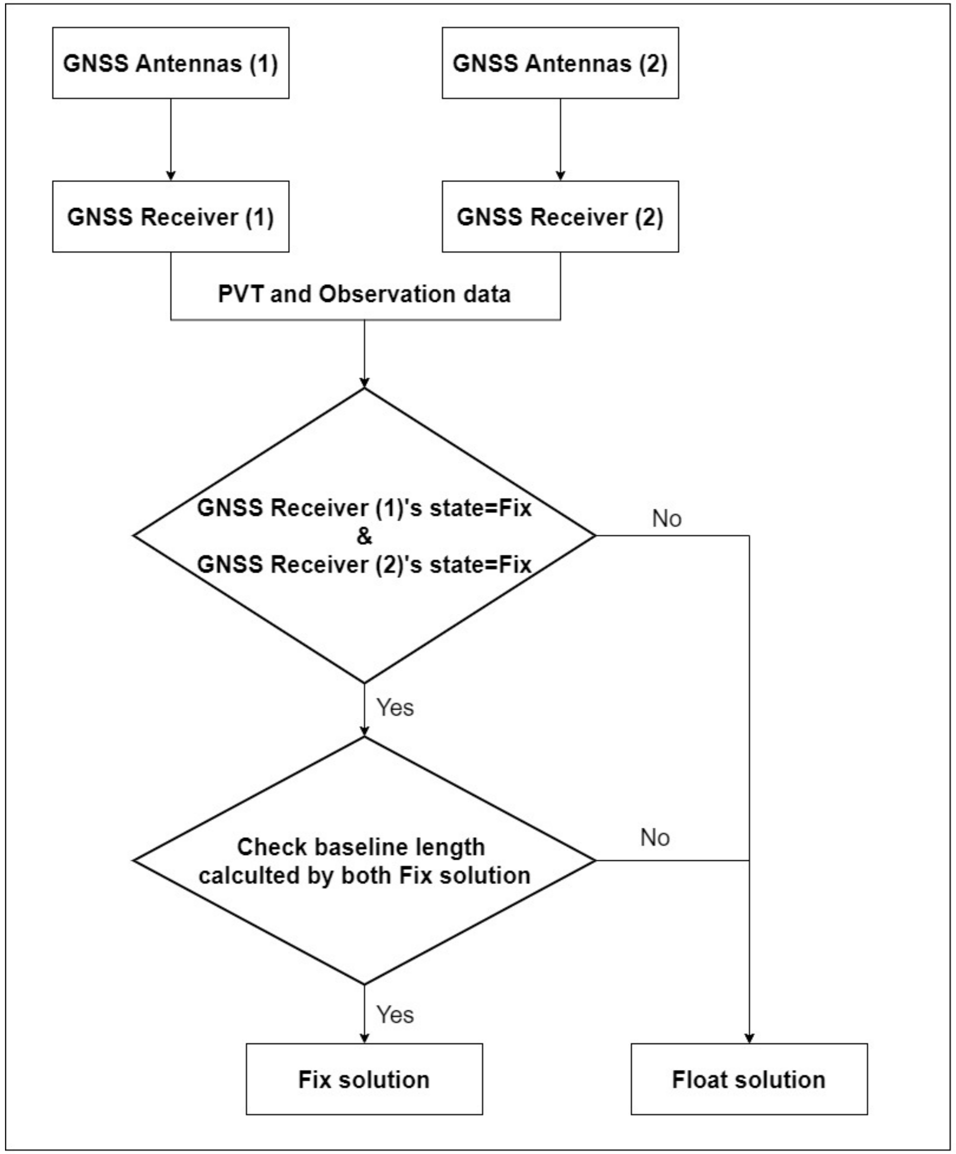
“AND selection” and “OR selection” method



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.

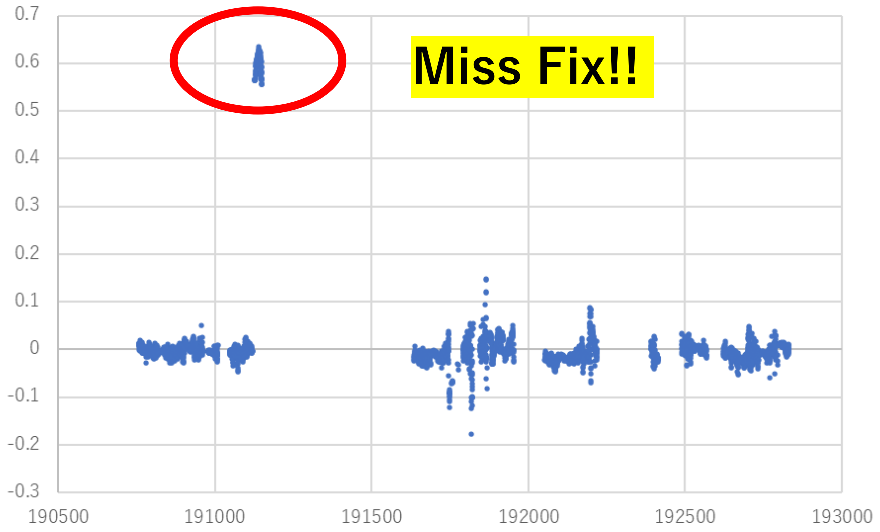
“AND selection” method

"AND selection"

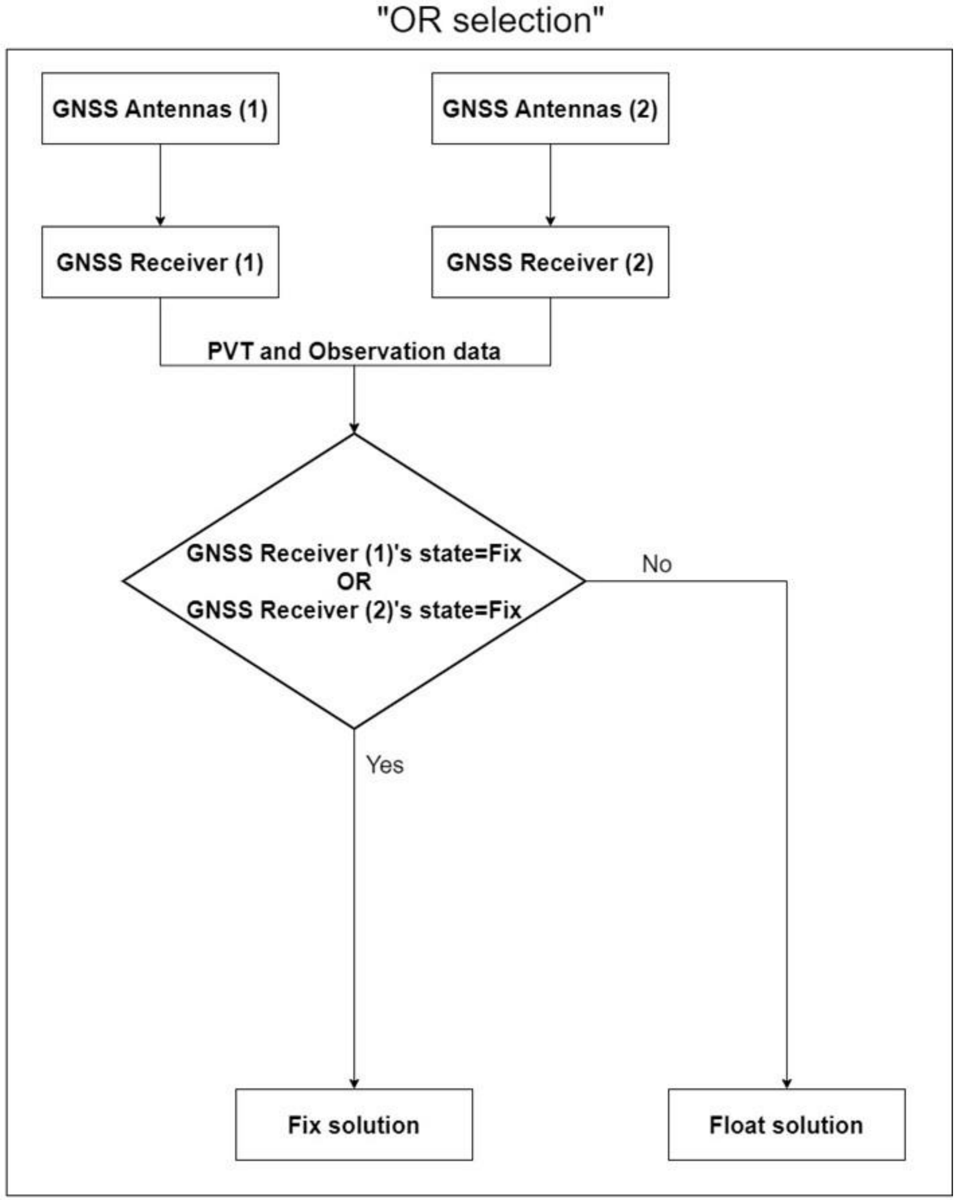


“AND selection” is performed when all receivers output Fix solutions.
The baseline length between fix solutions is also checked and detect miss Fix.

“AND selection” decreases availability, but increases robustness.

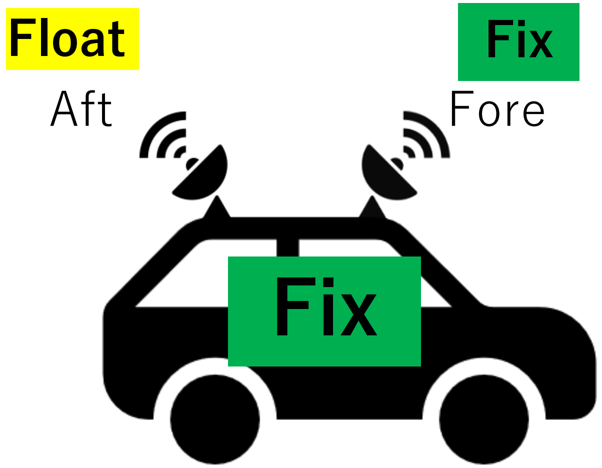


“OR selection” method



“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.



Test (route)

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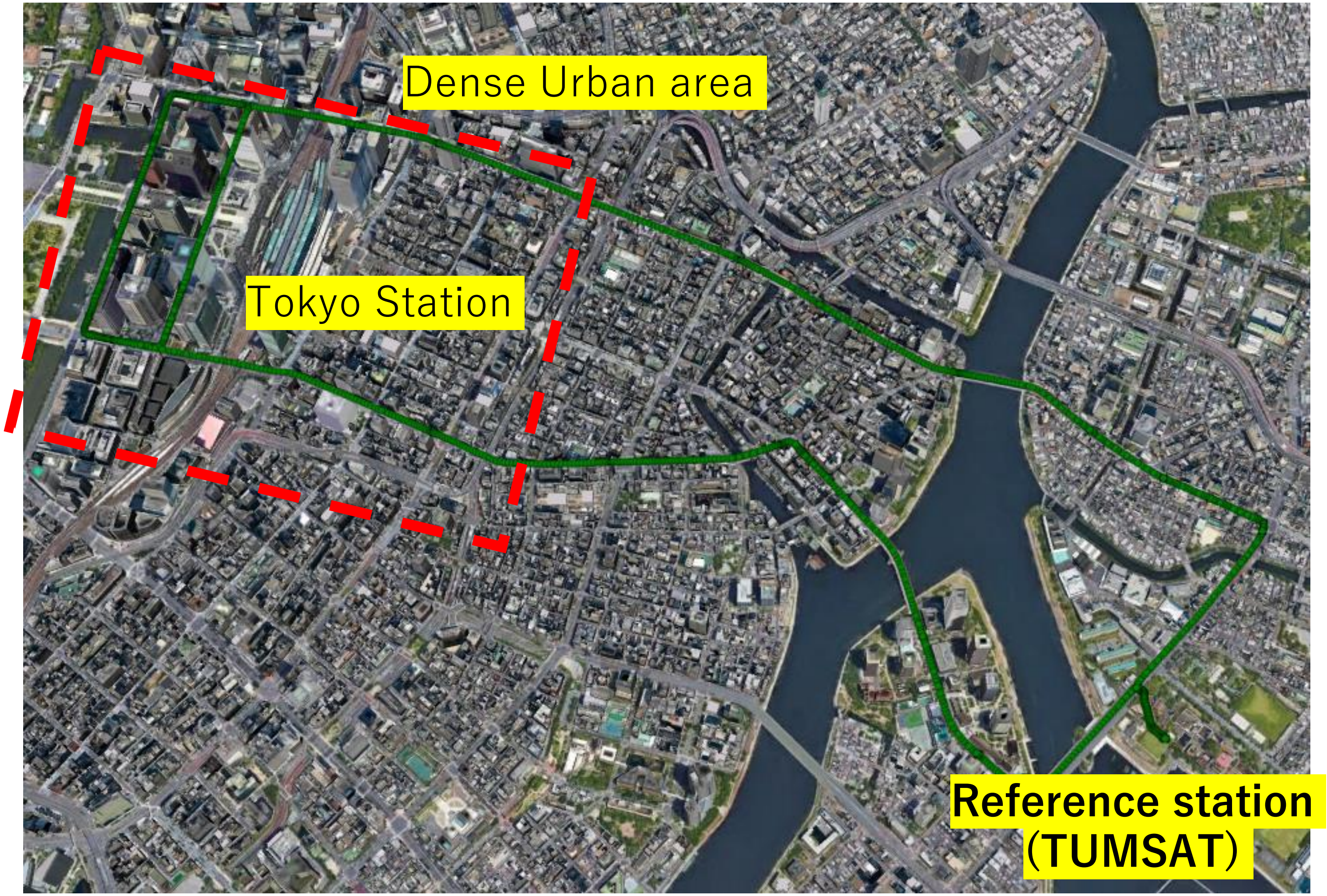


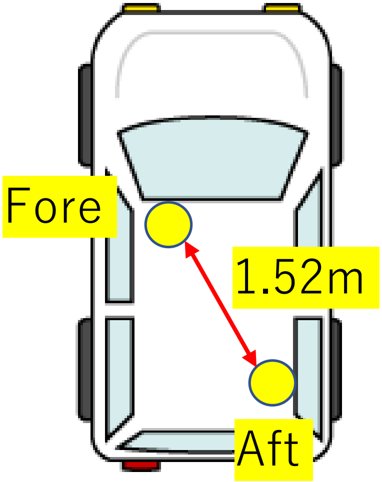
- The data was obtained using car installed with Multiple Antennas and Receivers, and we drive along the route.
- In Dense Urban area (Red frame), DGNSS positioning error easily reached several tens of meters or more.
- Reference station is installed at TUMSAT(Our laboratory)
- We've run the three times 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	Model Name
GNSS receiver	u-blox F9P (base/rover)
GNSS antenna (rover)	Aero Antenna AT1675
GNSS antenna (Base)	Trimble Zephyr 2 Geodetic
Reference position	POSLV-520

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



Result

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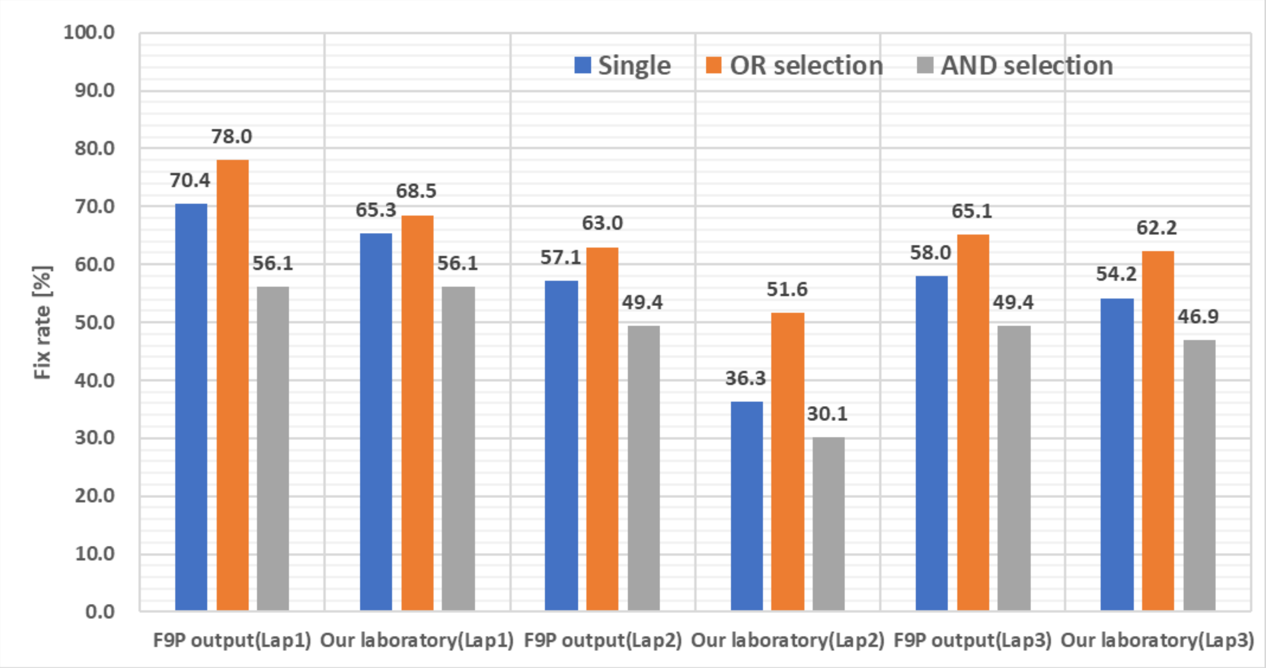
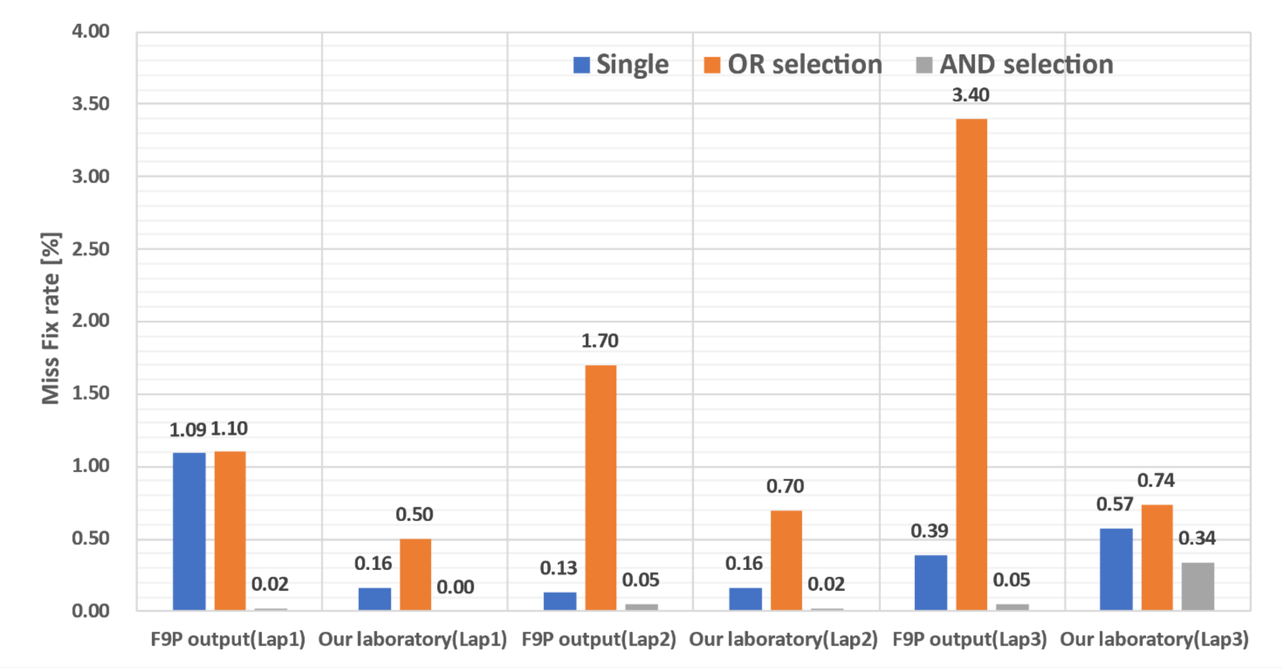
Fix rate(Number of Fix / Total epoch)

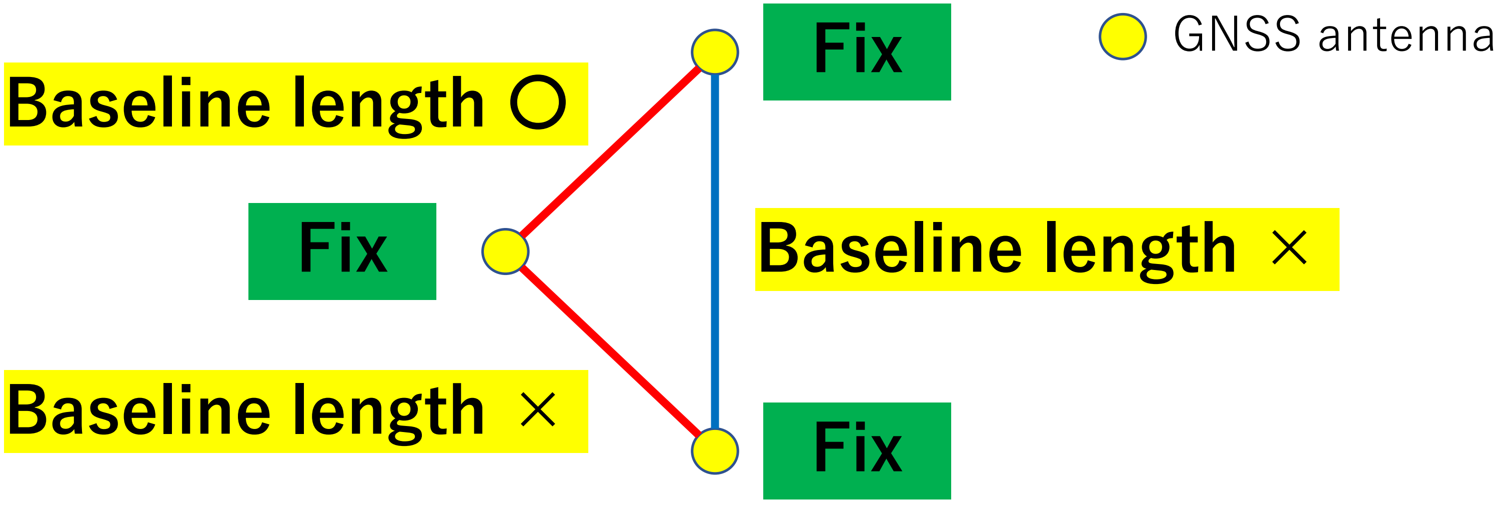


Miss Fix rate(Number of Miss Fix / Number of Fix)

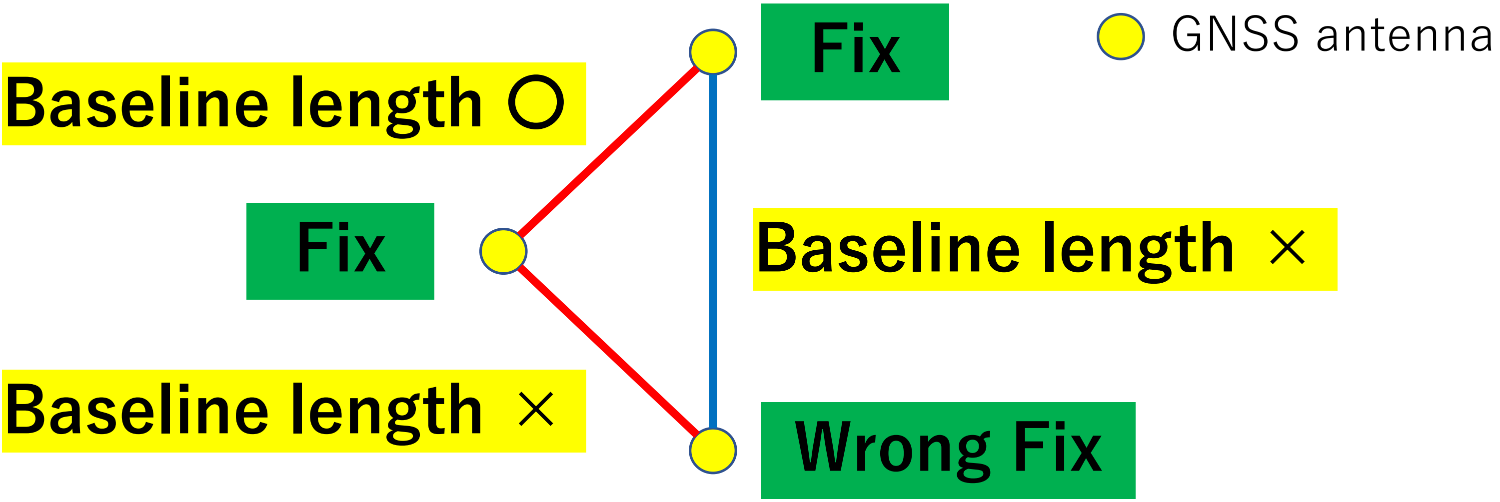


Single : Aft antenna's result
OR selection : OR selection's result
AND selection : AND selection's result
F9P output(Lap x) : Ublox F9P' s output at lap x
Our laboratory (Lap x) : Our laboratory positioning software' s output at lap x

Triple or more Antennas and Receivers

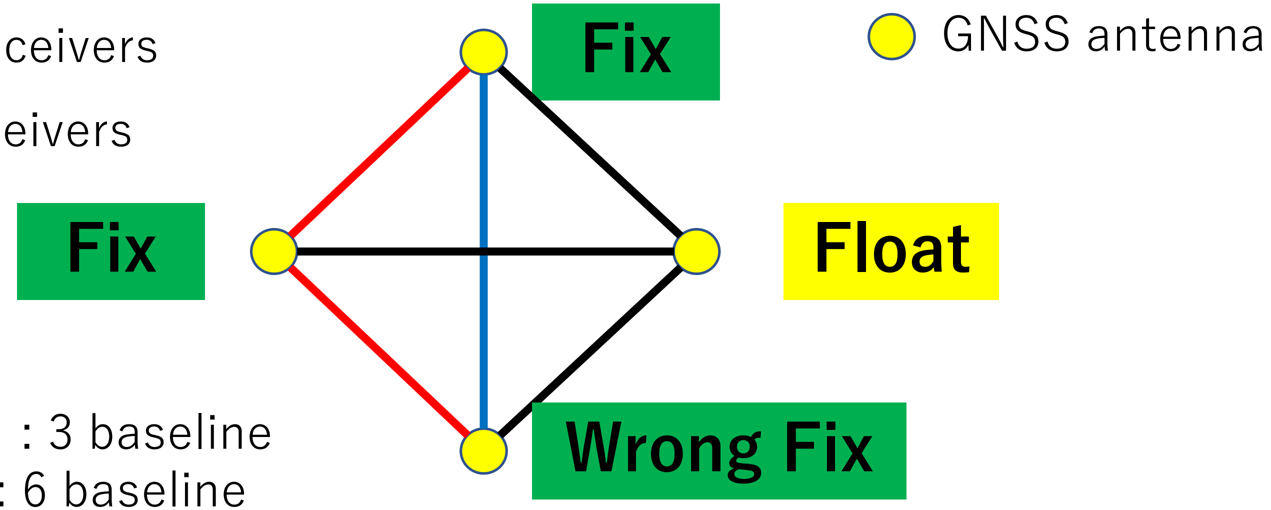


Triple or more Antennas and Receivers



Triple or more Antennas and Receivers

- Dual Antennas and Receivers
- Triple Antennas and Receivers
- Four Antennas and Receivers



Triple Antennas and Receivers ：3 baseline
Four Antennas and Receivers ：6 baseline

Based on count the number of Fix solution,
Robust and highly available GNSS solution can be output.
→ Majority vote

Test (route)

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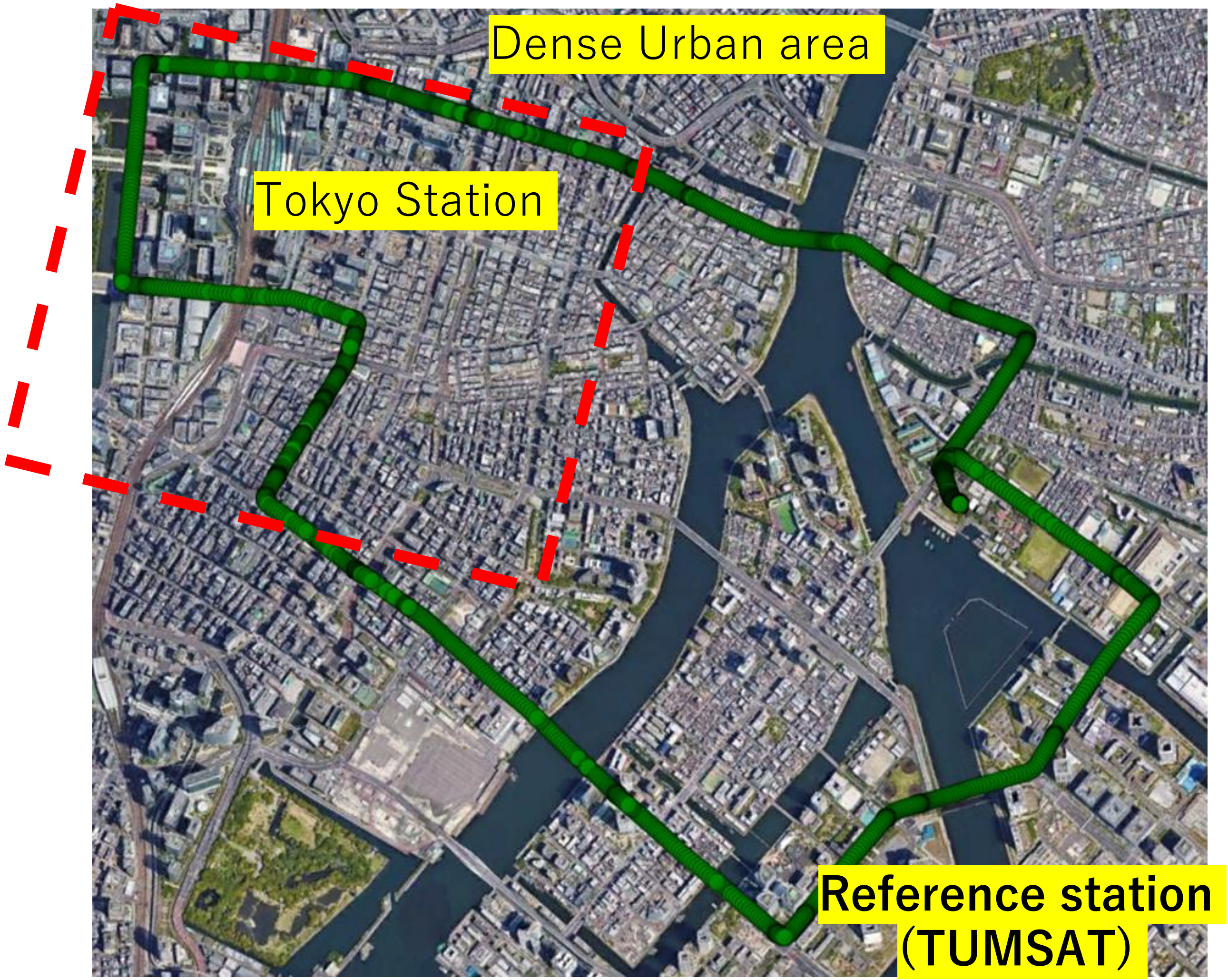

- The data was obtained using car installed with **four** Antennas and Receivers, and We drive along the route.
- Reference station is installed at TUMSAT(Our laboratory)
- We've run the three times on August 31, 2022.
  Date : 0:48:00 ～ 01:17:02 (UTC)

Majority vote were conducted using RTK-GNSS positioning solutions output by Ublox F9P and positioning software developed by our laboratory.

Test (Equipment & Parameter)

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Equipment	Model Name
GNSS receiver	u-blox F9P (base/rover)
GNSS antenna (rover)	Aero Antenna AT1675 ANN-MB-0000
GNSS antenna (Base)	Trimble Zephyr 2 Geodetic
Reference position	POSLVX-125

Item	Parameter
Mask angle	15 degrees
Maximum DOP	10.0(HDOP)/20(VDOP)
Minimum SNR	32 dB-Hz
Code phase measurements	Tracked
Carrier phase measurements	Tracked
LLI(only RTK-GNSS)	Tracked and half-cycle resolved
GNSS	5 Hz
Satellites	GPS/QZSS/GALILEO/BDS/GLONASS

Result

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	Aft antenna	Fore antenna	Right antenna	Left antenna
F9P	Fix rate : 66.74 % Miss Fix rate : 1.67 %	Fix rate : 50.88 % Miss Fix rate : **13.15** %	Fix rate : 60.36 % Miss Fix rate : 5.81 %	Fix rate : 54.46 % Miss Fix rate : 0 %
Our laboratory	Fix rate : 54.80 % Miss Fix rate : 0.17 %	Fix rate : 49.66 % Miss Fix rate : 0.65 %	Fix rate : 38.04 % Miss Fix rate :1.4%	Fix rate : 47.50 % Miss Fix rate : 0.2%

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

	Fix rate /Miss Fix rate (F9P)	Fix rate /Miss Fix rate (Our laboratory)
Number of Fix=0	21.3%	35.0%
Number of Fix=1	12.9% / 64.9%	10.0% / 12.9 %
Number of Fix=2	13.9% / 5.3%	11.38%/ 0%
Number of Fix=3	11.25% / 0%	11.48 % / 0 %
Number of Fix=4	40.1% / 0%	32.1 %/ 0 %
Total	100 %	100 %

Result

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	Number of Fix /Miss Fix (F9P)	Number of Fix /Miss Fix (Our laboratory)
“Majority Vote”	65.3% / 1.1%	55.0 %/ 0%

Result (Dual)	“OR selection” result (Fore & Aft)	“AND selection” result (Fore & Aft)
Fore antenna (F9P)	Fix rate: 72.78% Miss Fix rate: 8.3%	Fix rate: 43.81% Miss Fix rate: 1.20%
Aft antenna (F9P)		
Fore antenna (our laboratory)	Fix rate: 60.65% Miss Fix rate: 0.61%	Fix rate: 43.44% Miss Fix rate: 0.0%
Aft antenna (our laboratory)		

Idea of using Multiple Antennas and Receivers

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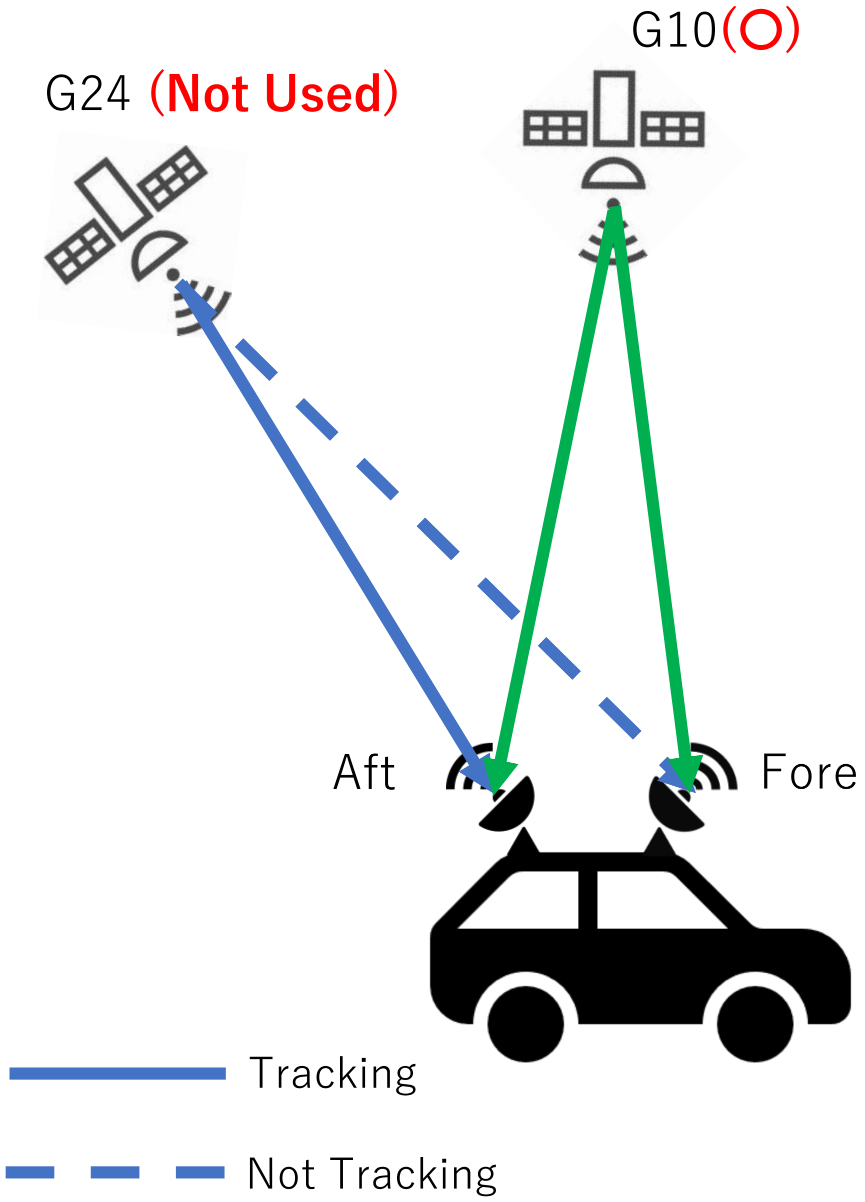
- Common satellite
- Check Doppler Frequency by Multiple Antennas and Receivers
- Hold Ambiguity Method
- Modified “OR selection”

Common satellite



- ✓ Exclusion of satellites strongly affected by multipath from positioning
- ✓ Use a common satellite that can be tracked by both antennas.

	Before selecting common satellite	After selecting common satellite
Fore(our laboratory)	Fix rate : 49.66 % Miss Fix rate : 0.65 %	Fix rate : 50.77 % Miss Fix rate : 0.11 %
Aft(our laboratory)	Fix rate : 54.80 % Miss Fix rate : 0.17 %	Fix rate : 54.44 % Miss Fix rate : 0.12 %

Check Doppler Frequency by Multiple Antennas and Receivers

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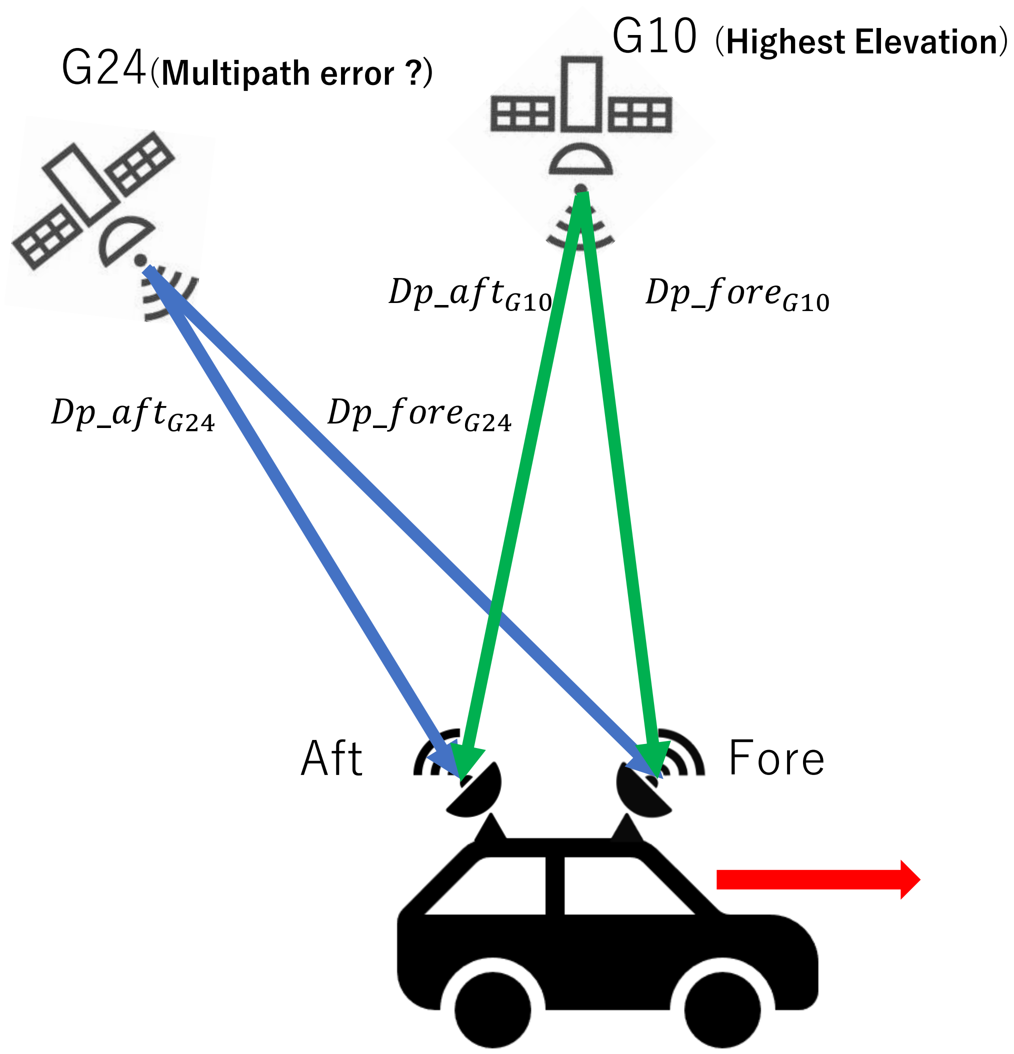

When going straight ahead,
Doppler frequency between the satellite and GNSS receiver is almost same at Fore and aft antennas.
Frequency offset can be deleted by single difference.

$$Dp_{aft_{G24}} - Dp_{aft_{G10}} \approx Dp_{front_{G24}} - Dp_{front_{G10}} \quad \cdots (1)$$

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

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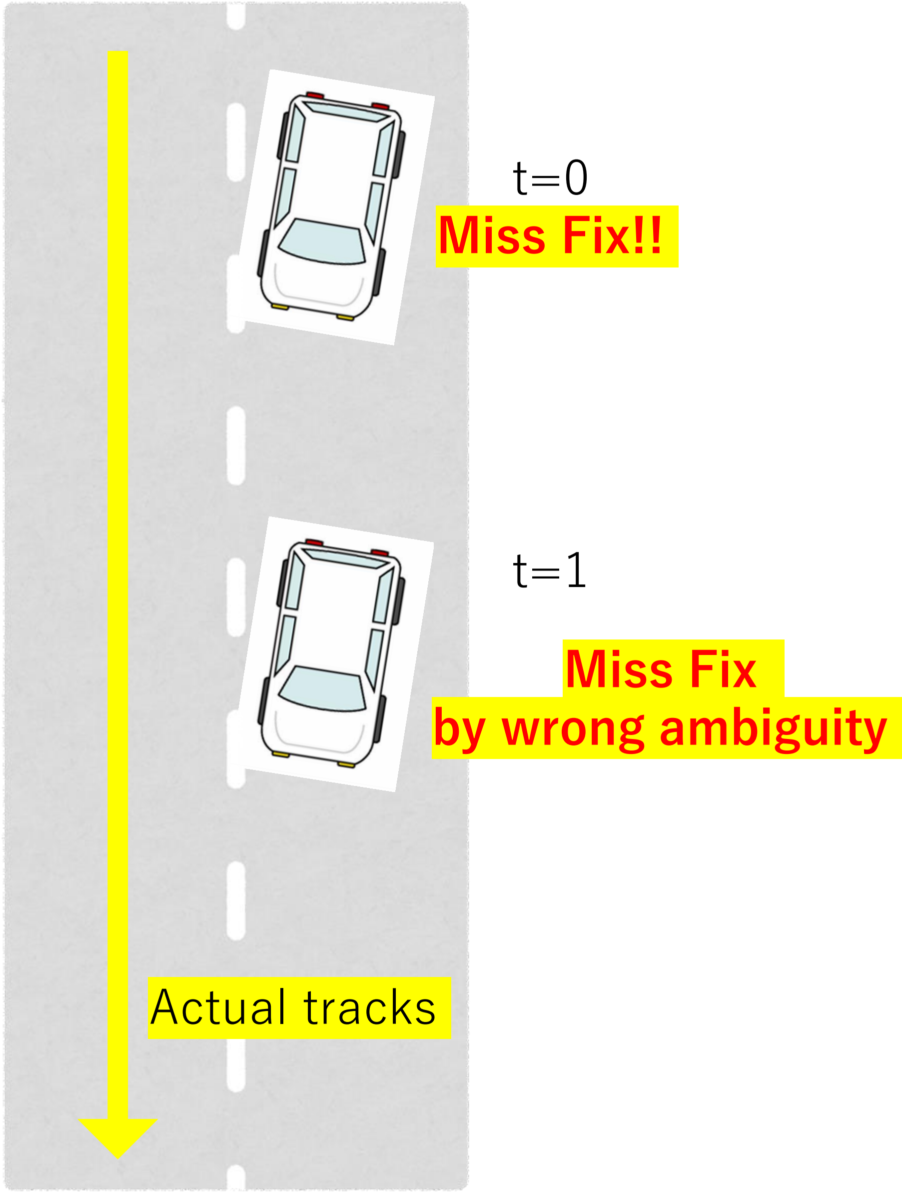
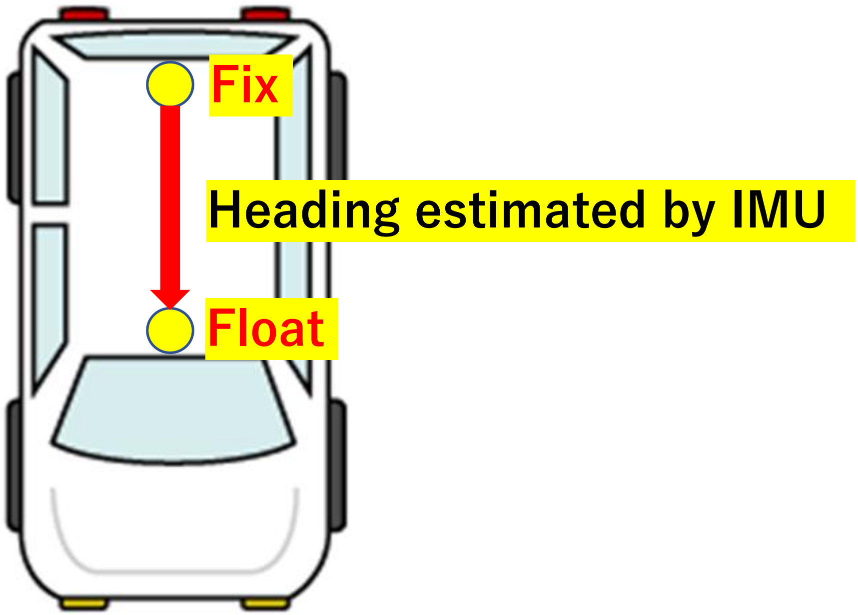
- The biggest problem with Hold Ambiguity method is that it uses the wrong ambiguity to estimate position.
- Using "AND selection", it can dramatically reduce miss Fix and find more reliable ambiguity.



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

Conclusions

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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.