A Unique Approach to Strong Multipath Mitigation in Dense Urban Areas

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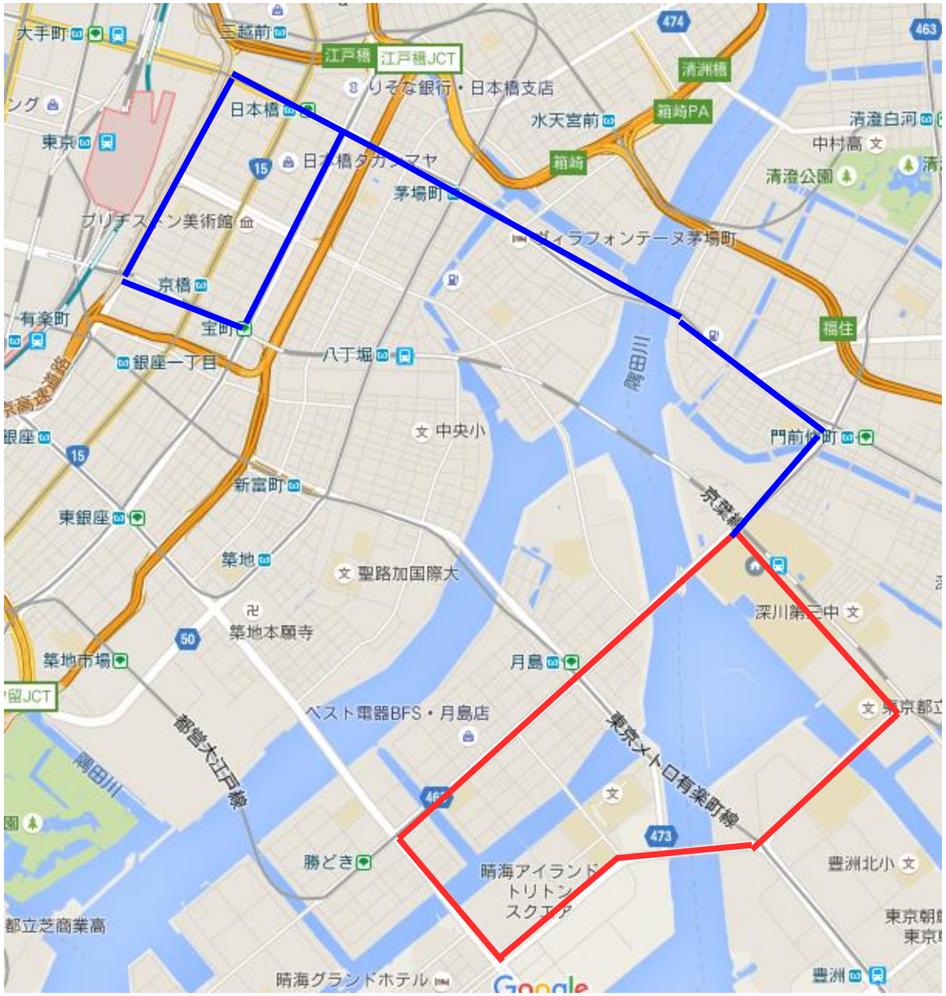
Outline

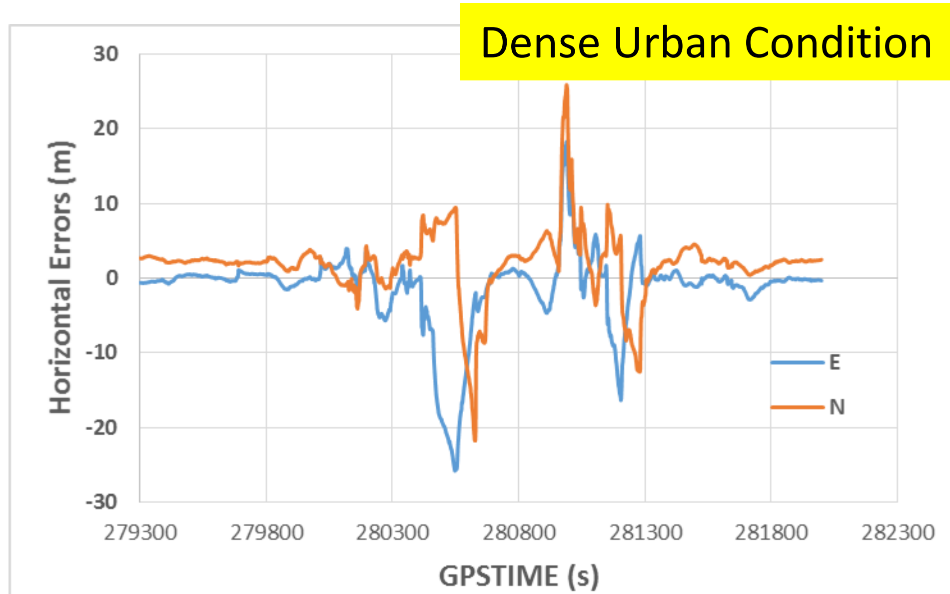
- Background and Objective
- Multipath Errors and Speed
- Antenna Motion test
- Proposed Multipath Mitigation Test
- Summary

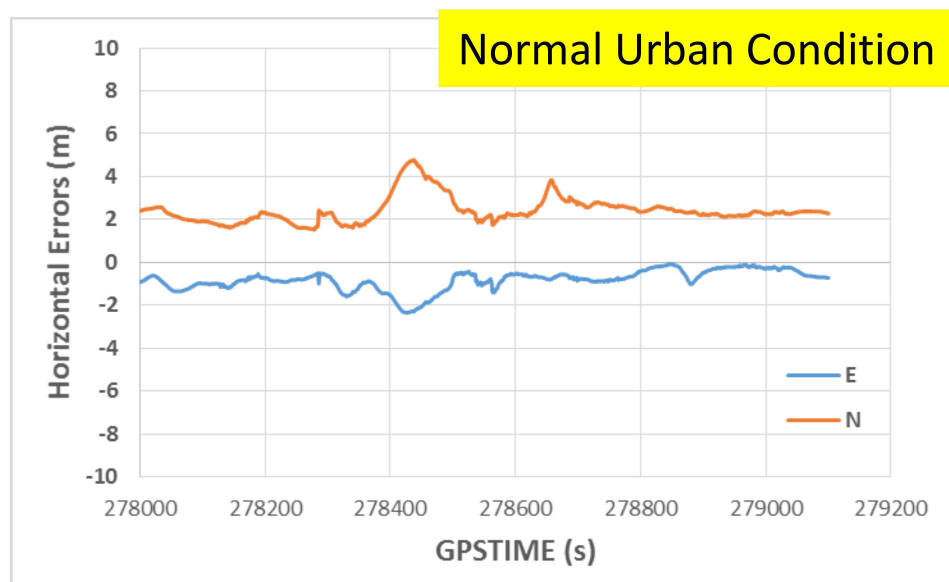
Background

- Future ITS services will focus on technologies for vehicles safety driving. The number of death while walking is significantly high in Japan (1444/4013 , 35%).
- GNSS is one of the candidates for these ITS services.
- Except for tunnel and long underpass, multipath is a major source of error in high precision GNSS.
- There are many important works related to multipath mitigation techniques.
- Even using these techniques, we still need to reduce multipath errors more.

Present performance of low-cost commercial receiver in urban areas (car)







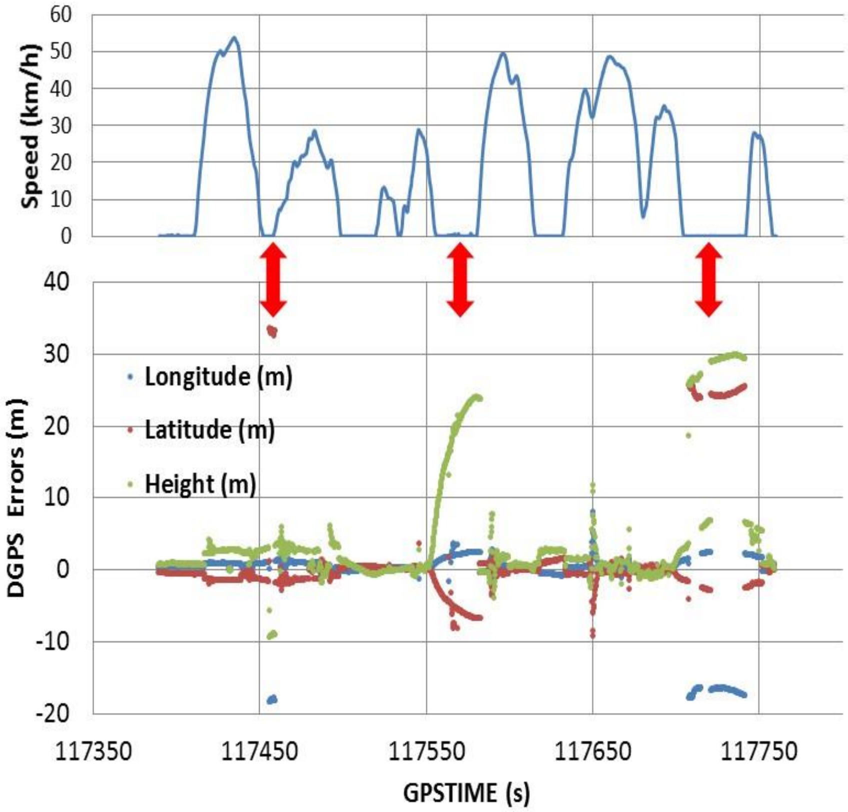
Single frequency multi-GNSS
Reference positions : POS/LV

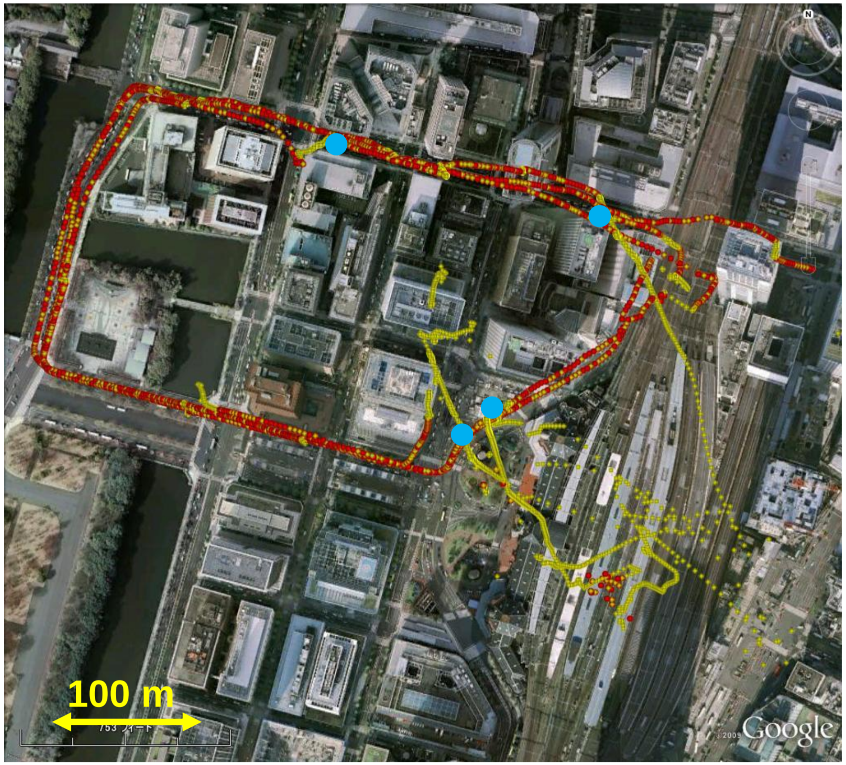
Objective

Our target : Maximum horizontal error within 1.5m of the car using only low-cost single frequency GNSS receiver under normal urban areas

- Consumer GNSS receiver
  - ✓ Can provide several meters level horizontal positions with high availability
  - ✓ Can provide raw measurements (Pr, Dp, Cp)
  - × Affected by strong multipath including NLOS
  - × Accurate pedestrian navigation is not so popular
- Approach
  - ✓ Mitigating strong multipath using a unique method
  - ✓ Optimizing the use of Doppler frequency based velocity

Multipath and Speed (only GPS)



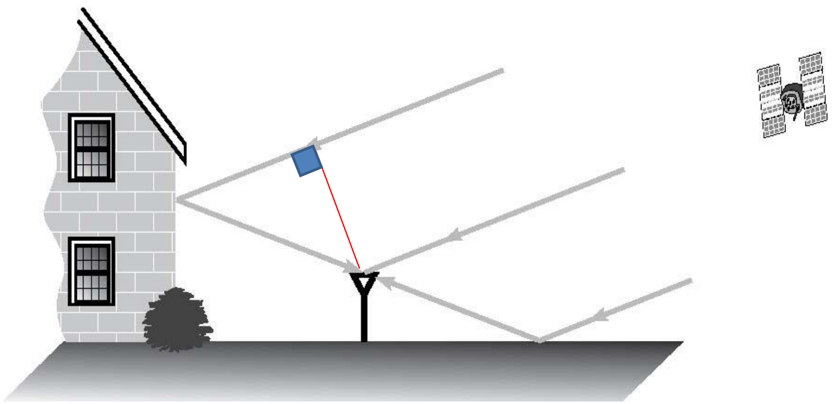


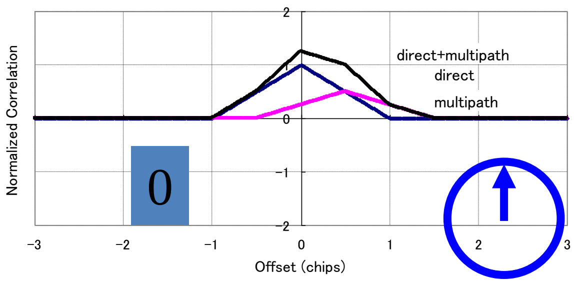
DGPS of Survey grade receiver in normal urban areas

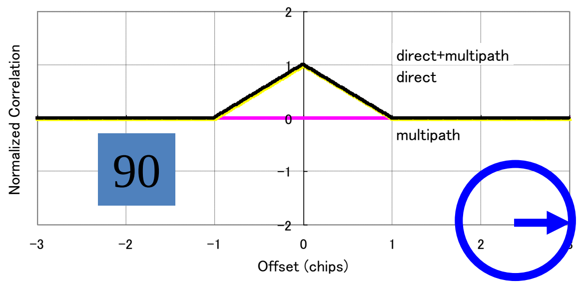
Standalone positioning of low-cost receiver in dense urban areas

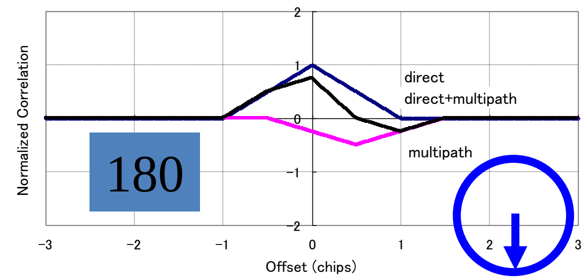
Why do we receive strong multipath ?

- The range measurement error due to multipath depends on the strength of the reflected signal and the delay (relevant to phase) between direct and reflected signals.

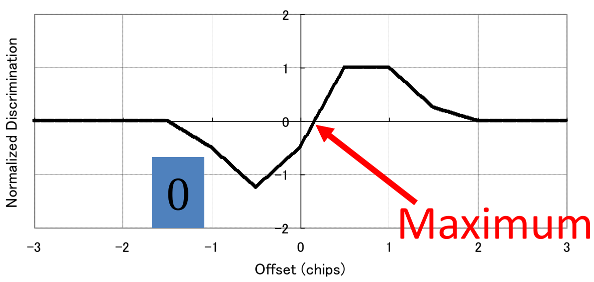


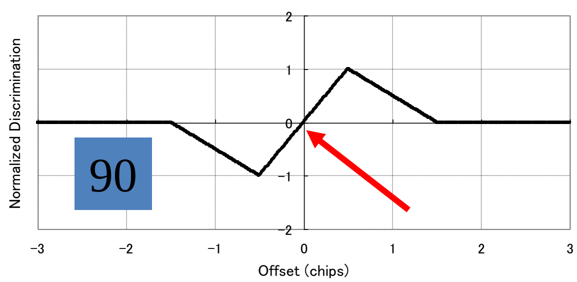


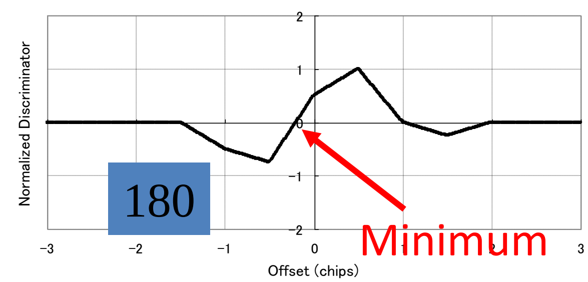




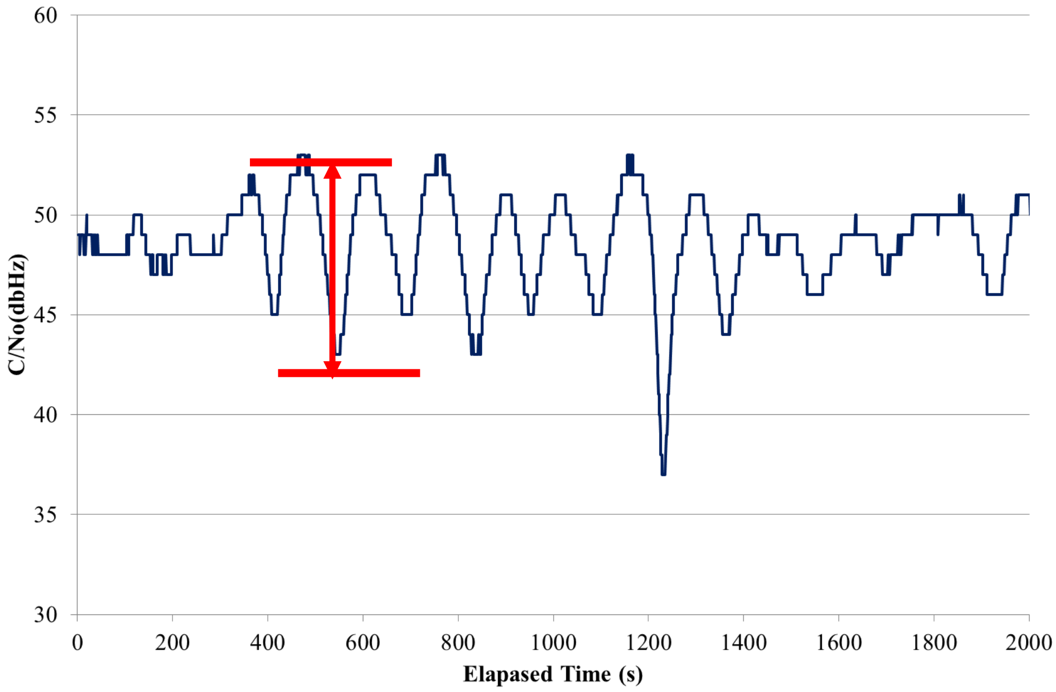
Delay = N*wavelength

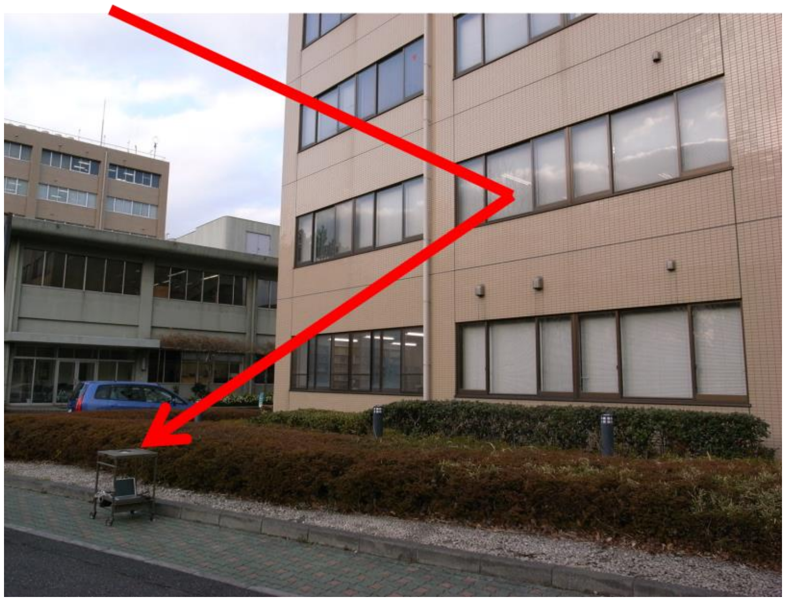






Multipath errors at Zero Speed near building



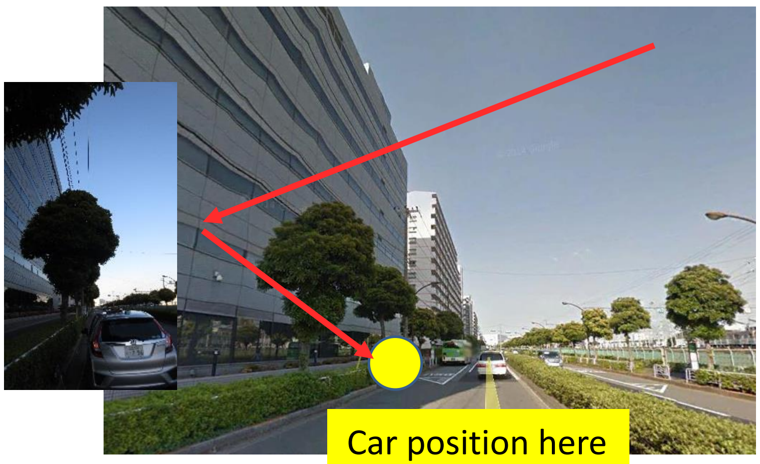


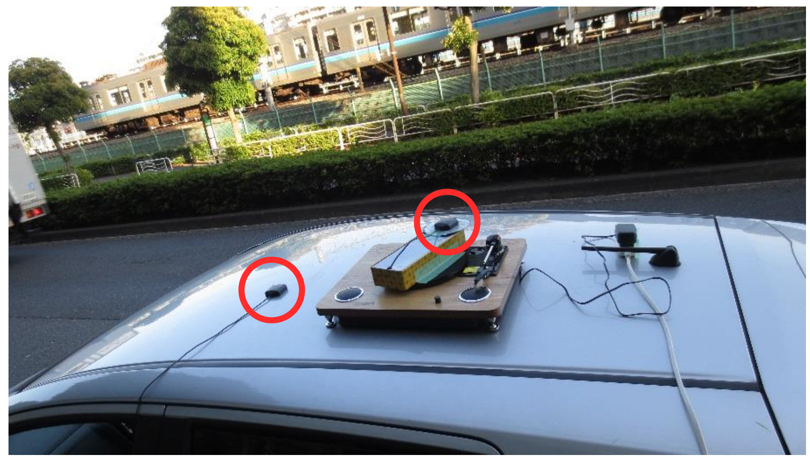
The satellite elevation and azimuth changes little by little.
→ the delay of the multipath changes **slowly**.
→ the phase of the multipath changes **slowly.**
→ we have the maximum errors due to multipath

It is easy for us to imagine that this kind of strong multipath can't be received often when the car is moving (→ the phase of the multipath changes **quickly**).

Antenna motion test

- We demonstrated the characteristic that standard GNSS receivers are vulnerable to multipath interference when the rover antenna is static. Then, **we attempt to use this characteristic to mitigate strong multipath errors**.



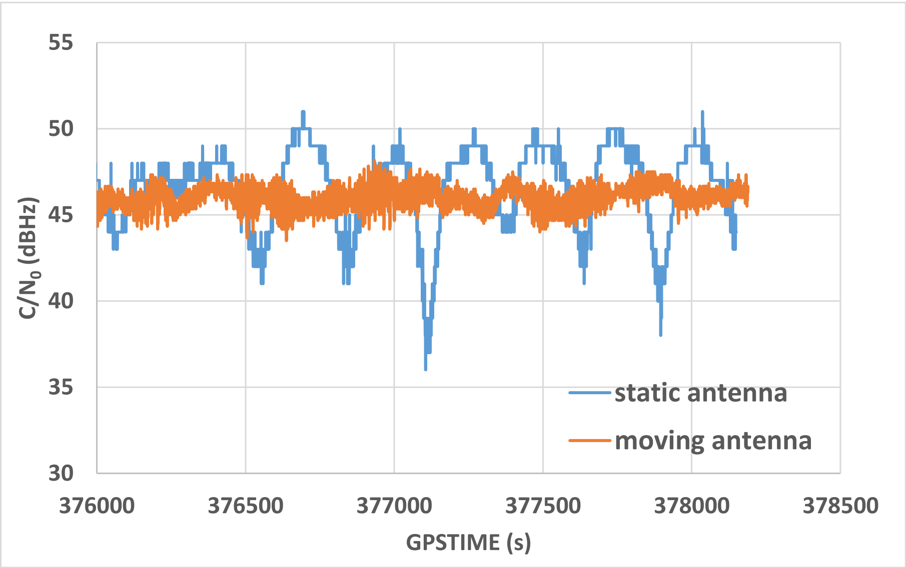


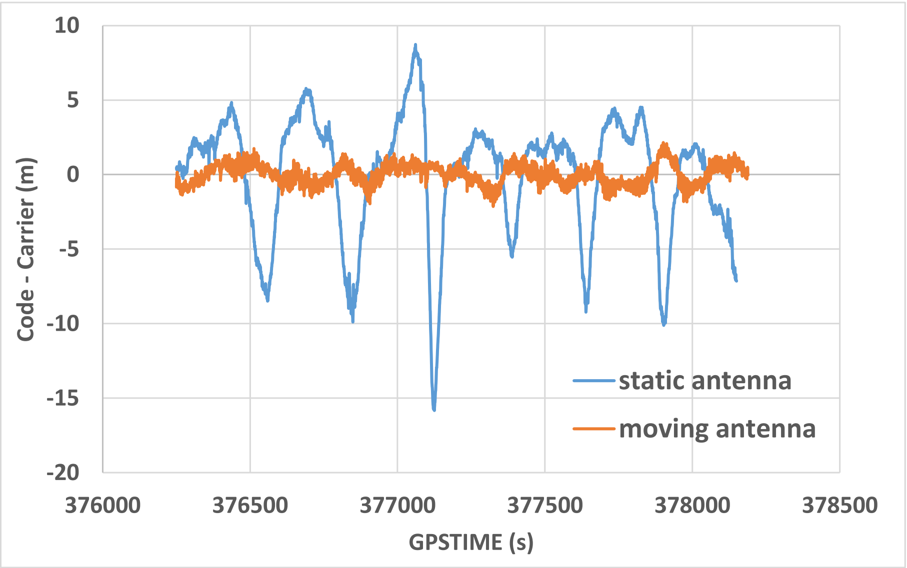
Record player 33.3/min.

Clear strong reflected signal (QZS) was received in this environment.

We investigated the difference between static antenna and turning antenna in terms of C/N_0 and code multipath.

C/N_0 and Code multipath using low-cost receiver

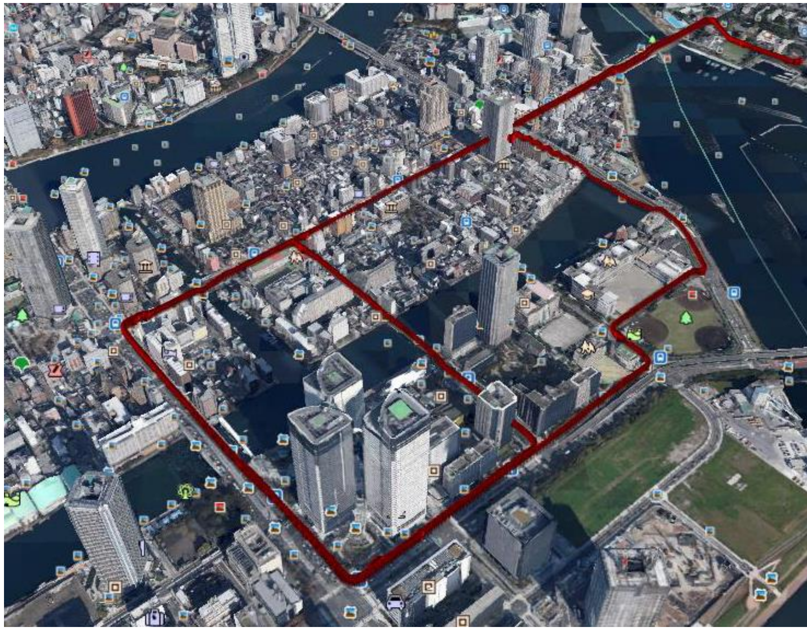




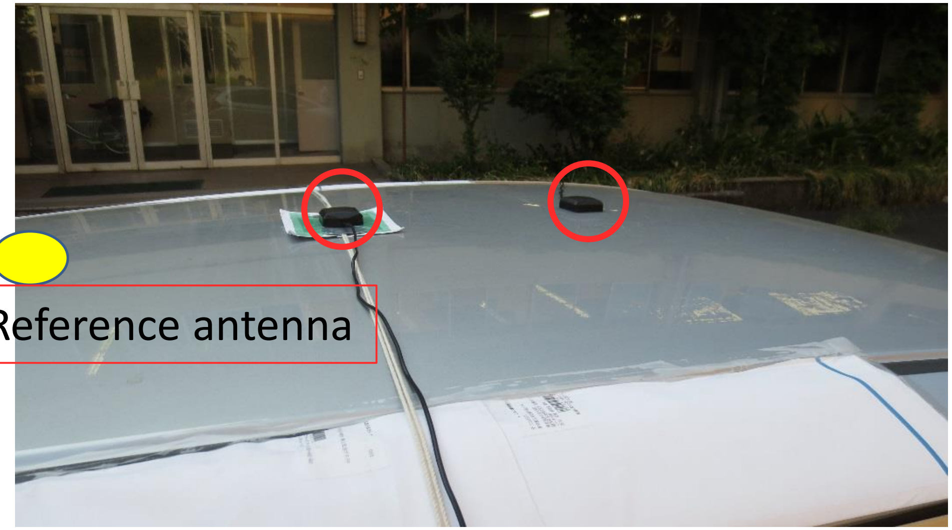
Both results show the distinct difference between static antenna and moving antenna.
The multipath error was mitigated heavily owing to the antenna motion.

The results will depend on the parameters of the receiver tracking loop.
It means the integration time or loop filter design is related to these results.
For example, with more than 1 second filter, the multipath effect in the moving antenna will be averaged. Phase wind up effect has to be considered in this case.

Kinematic test
(antenna motion test on the rooftop of the car)



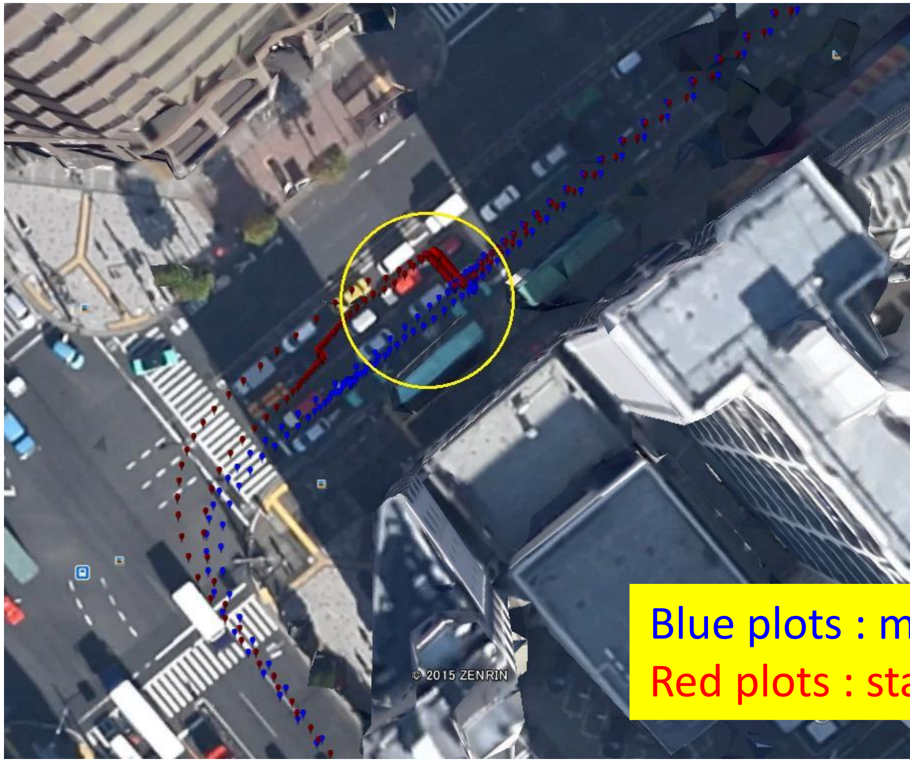
Test route (normal urban area)

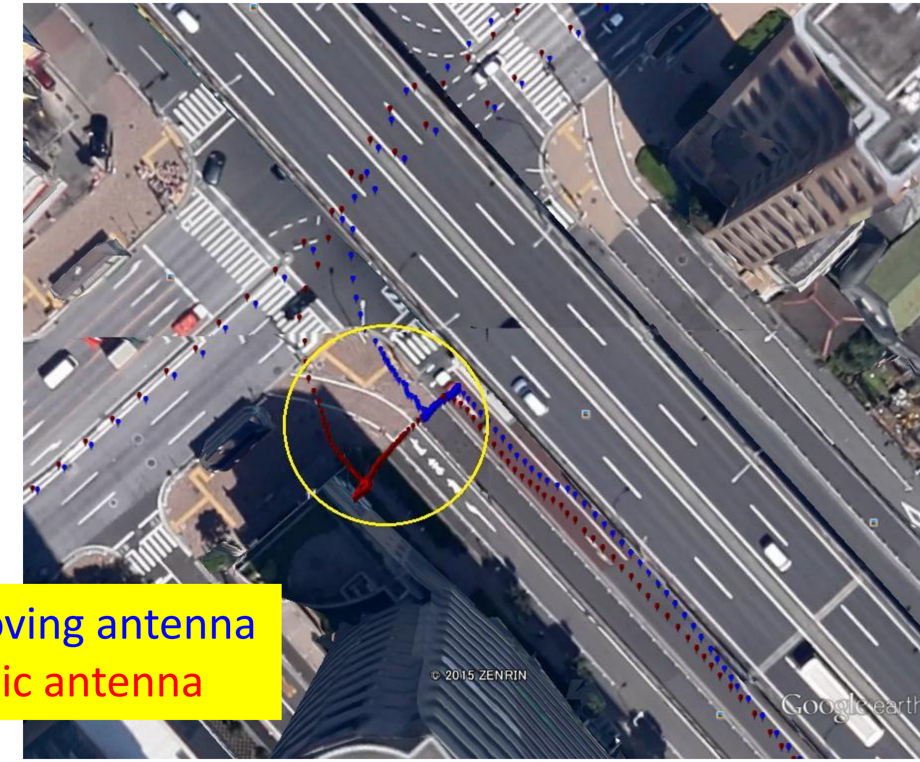


While I was driving the car, my student shook the second antenna manually when the vehicle speed was less than approximately 5 km/h.

- Two low-cost same receivers (same configurations)
- GPS/BEIDOU/QZS
- 20 minutes test with 5Hz raw-data
- Reference positions : RTK-GNSS (Correct Fix rate over 90%) + FOG + Speed

Comparison of horizontal plots between moving antenna and static antenna (the car stooped at an intersection)





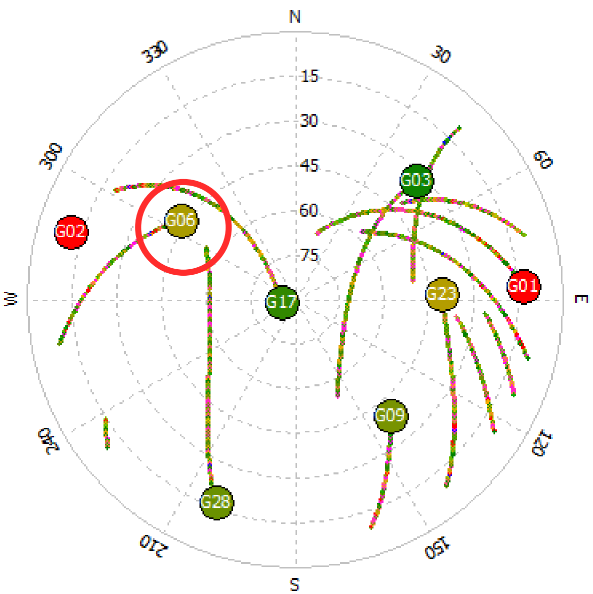
Blue plots : moving antenna
Red plots : static antenna

* Maximum deviation was approx. 6 m in red.
* The horizontal results of the moving antenna did not deviate in blue.

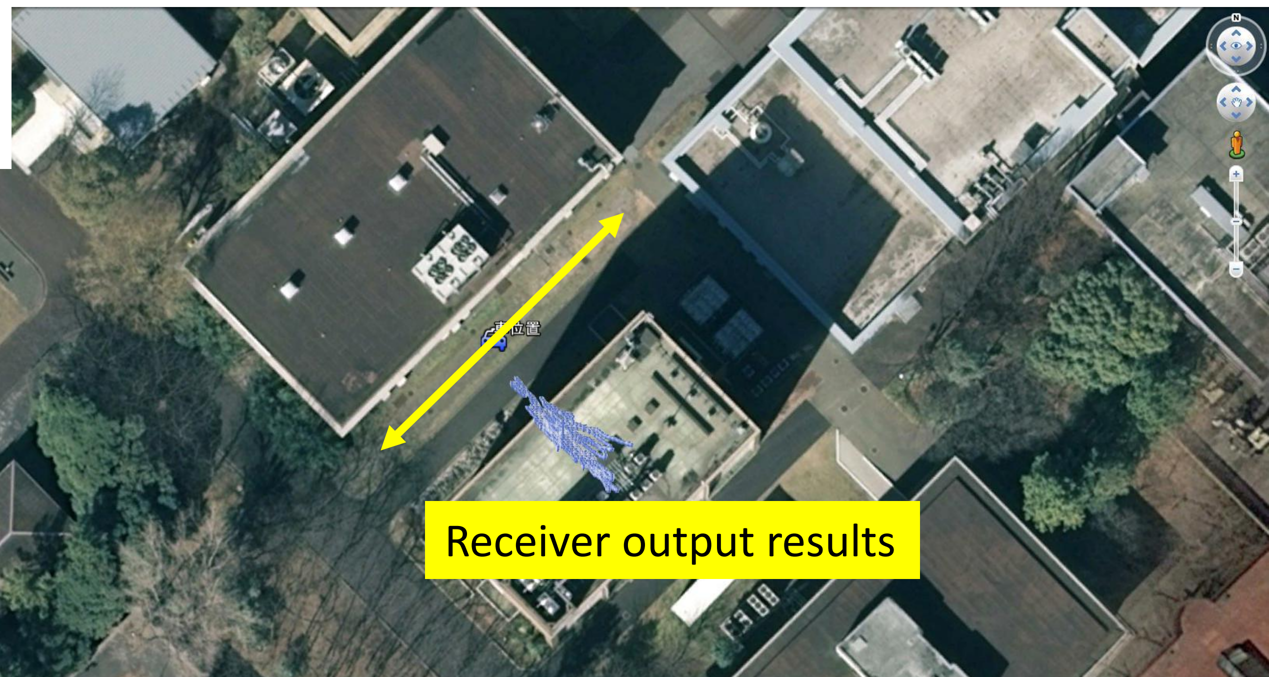
* Maximum deviation was approx. 15 m in red.
* Maximum deviation was approx. 5 m in blue.

Maintaining antenna motion can attenuate the effect of a strong multipath signal.
Velocity accumulation in the static antenna during this stop was approx. within 50 cm.

How about NLOS ?

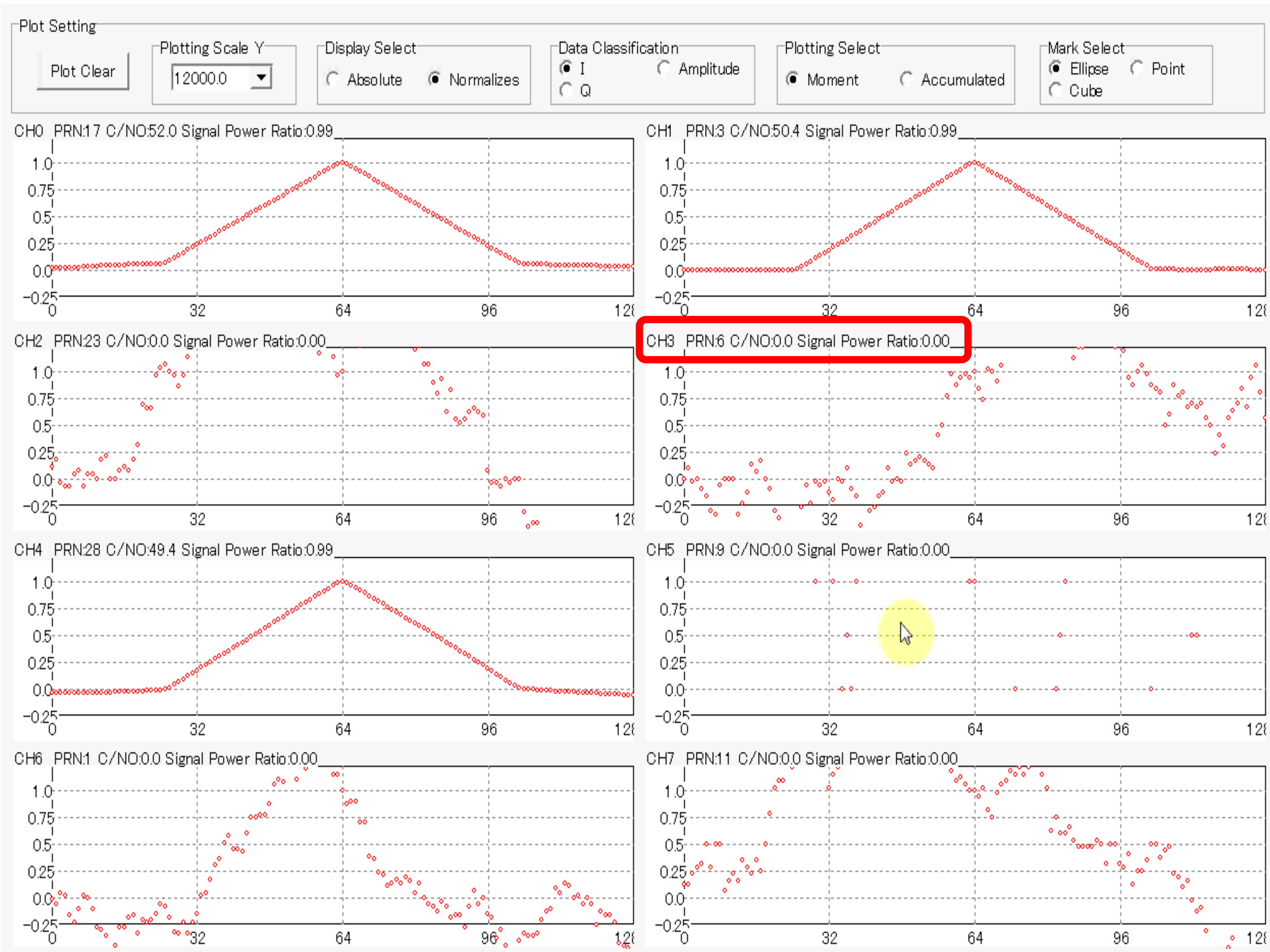


* Clear NLOS reception from GPS PRN6 (ele=45)
* The car was moving slowly (forward and backward).
* Receiver output positions were deviated due to NLOS.
* There was not big improvement using record player.



Velocity accumulation was quite accurate even in this case

Correlation values while the car was moving slowly



The proposed method is effective for
Direct + Multipath.

Not effective for NLOS.

For the receiver, NLOS is just like direct signal

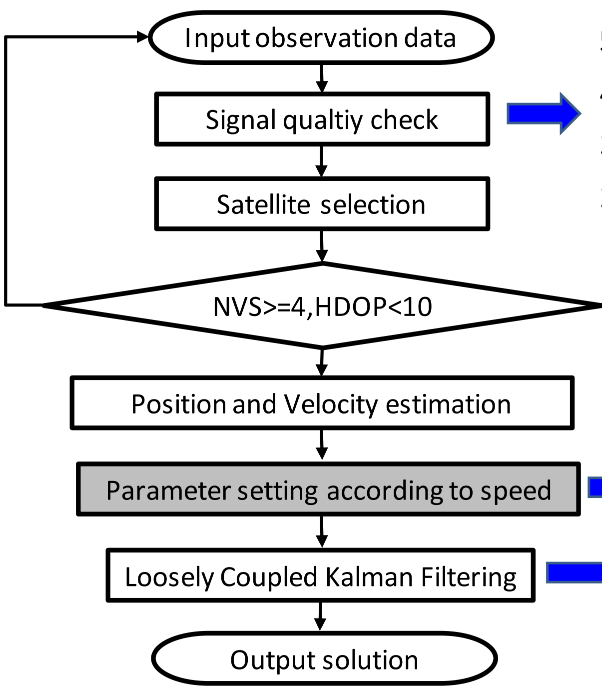
ENRI's SQM receiver developed by Furuno

Proposed Multipath Mitigation Method Corresponding to Speed

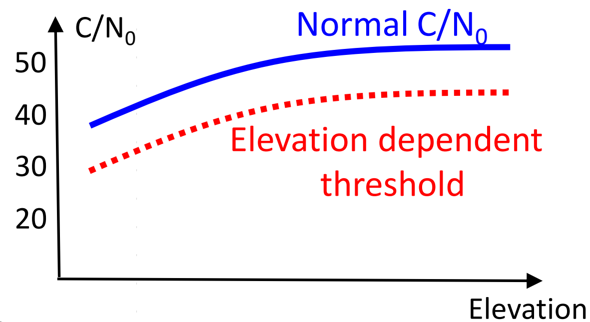
Proposed antenna motion method may not be practical...

Based on the amount of our test data,

* Doppler frequency derived **"velocity"** is quite tolerant to strong multipath condition.
* Pseudo-range based **"position"** is not tolerant to strong multipath condition.
* We need to put them together efficiently **according to speed**.
* **NLOS** satellite has to be removed as much as possible.



Flowchart



Speed	Weighting
Slow or zero	**Position <<< Velocity**
Normal	**Position < Velocity**

$$x_{k+1} = Fx_k + Gw_k$$

$$y_k = Hx_k + v_k$$

$$\boldsymbol{x_k} = [x(k), y(k), v_x(k), v_y(k), a_x(k), a_y(k)]^{\mathrm{T}}$$

$$x(k+1) = x(k) + v_x(k)\Delta T + a_x(k)\Delta T^2/2.0$$

$$y(k+1) = y(k) + v_y(k)\Delta T + a_y(k)\Delta T^2/2.0$$

$$v_x(k+1) = v_x(k) + a_x(k)\Delta T$$

$$v_y(k+1) = v_y(k) + a_y(k)\Delta T$$

$$\boldsymbol{F} = \begin{bmatrix} 1 & 0 & \Delta T & 0 & \Delta T^2/2 & 0 \\ 0 & 1 & 0 & \Delta T & 0 & \Delta T^2/2 \\ 0 & 0 & 1 & 0 & \Delta T & 0 \\ 0 & 0 & 0 & 1 & 0 & \Delta T \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{y_k} = [x(k), y(k), v_x(k), v_y(k)]^{\mathrm{T}}$$

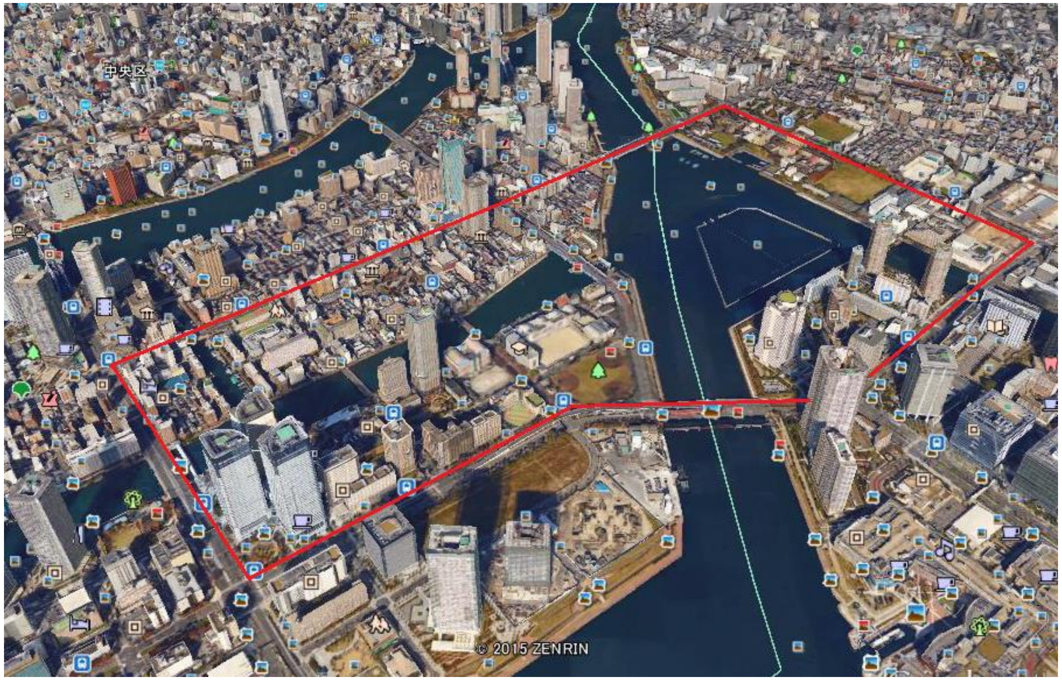
$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

x_k : *state vector*
w_k : *system noise*
y_k : *measurement vector*
v_k : *measurement noise*

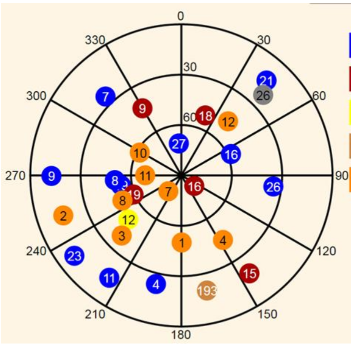
F : *state transition matrix*
G : *noise distribution matrix*
H : *observation matrix*

Loosely coupled KF

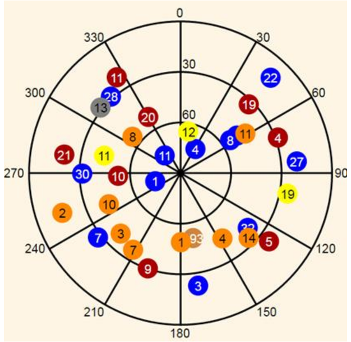
Kinematic Car Test



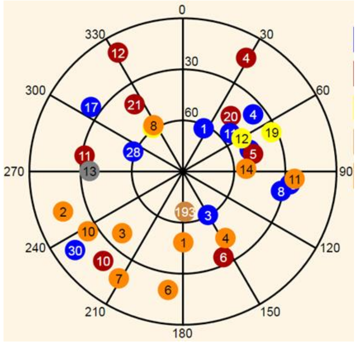
Test route



1st



2nd

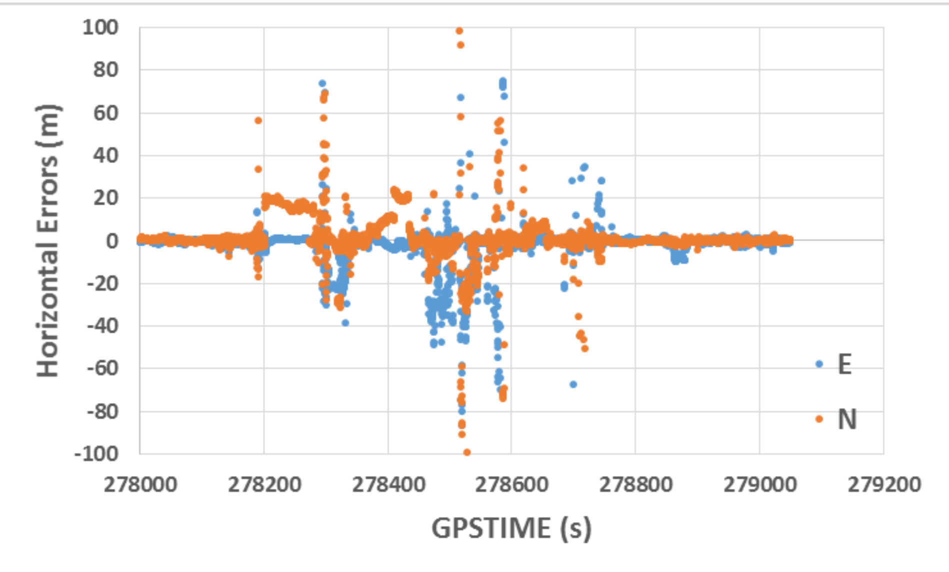


3rd

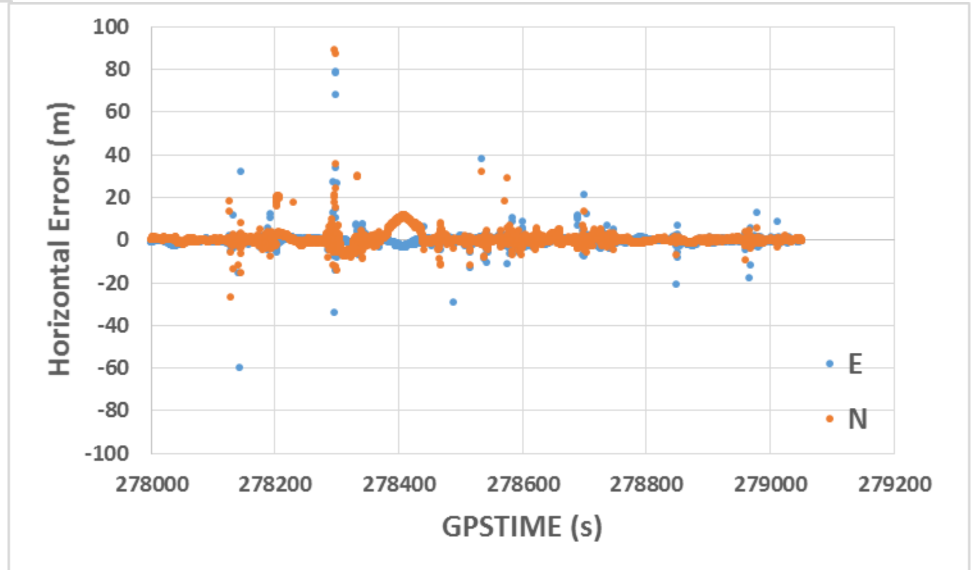
- August 2015
- Tsukishima, Tokyo
- Popular low-cost single frequency GNSS receiver
- GPS/BEI/QZS (DGNSS)
- 3 times for same route
- 20 minutes with 5Hz
- References : POS/LV
- Normal urban areas except for several high-rise buildings

Detailed results are introduced using 3rd period raw-data (normal constellation) GLO/GAL were not used.

Code Based Positions with or without C/N_0 check



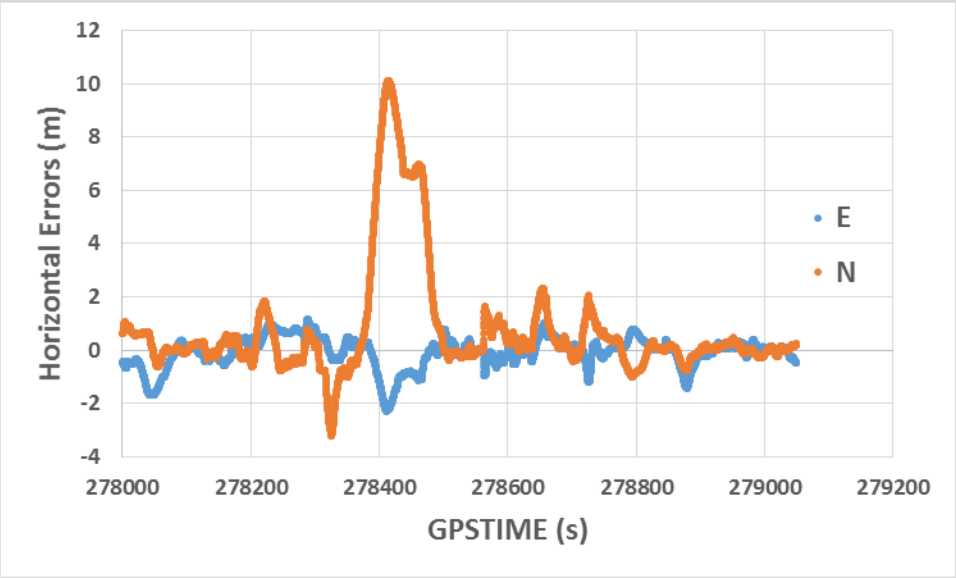
Without C/N_0 check



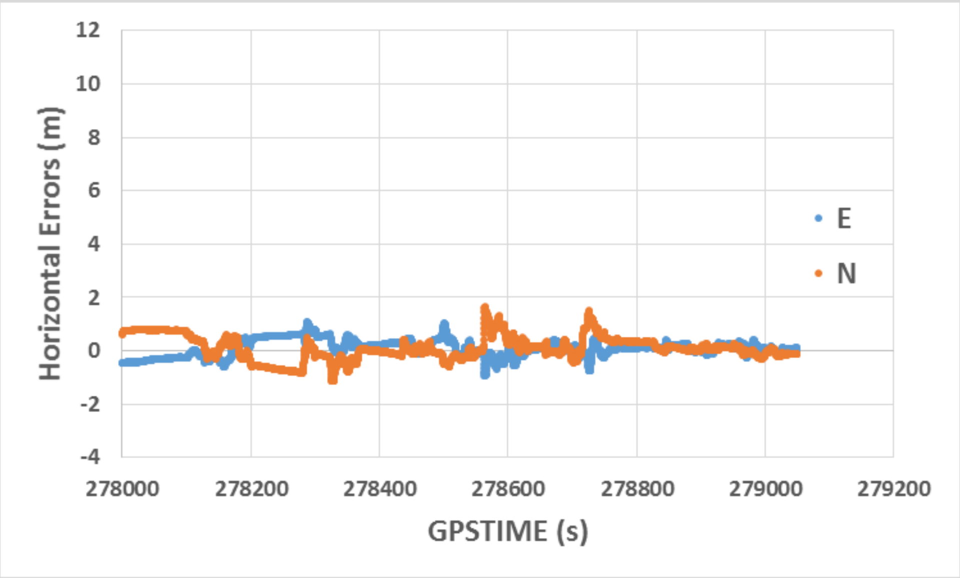
With C/N_0 check

- We need to reduce the large jumps probably due to NLOS satellite as much as possible before coupling.
- C/N_0 based satellite selection is effective to some degree.
- Usually, “7-8 dB” is set as a gap between normal and threshold.

Final Loosely Coupled Positions with or without Speed Consideration



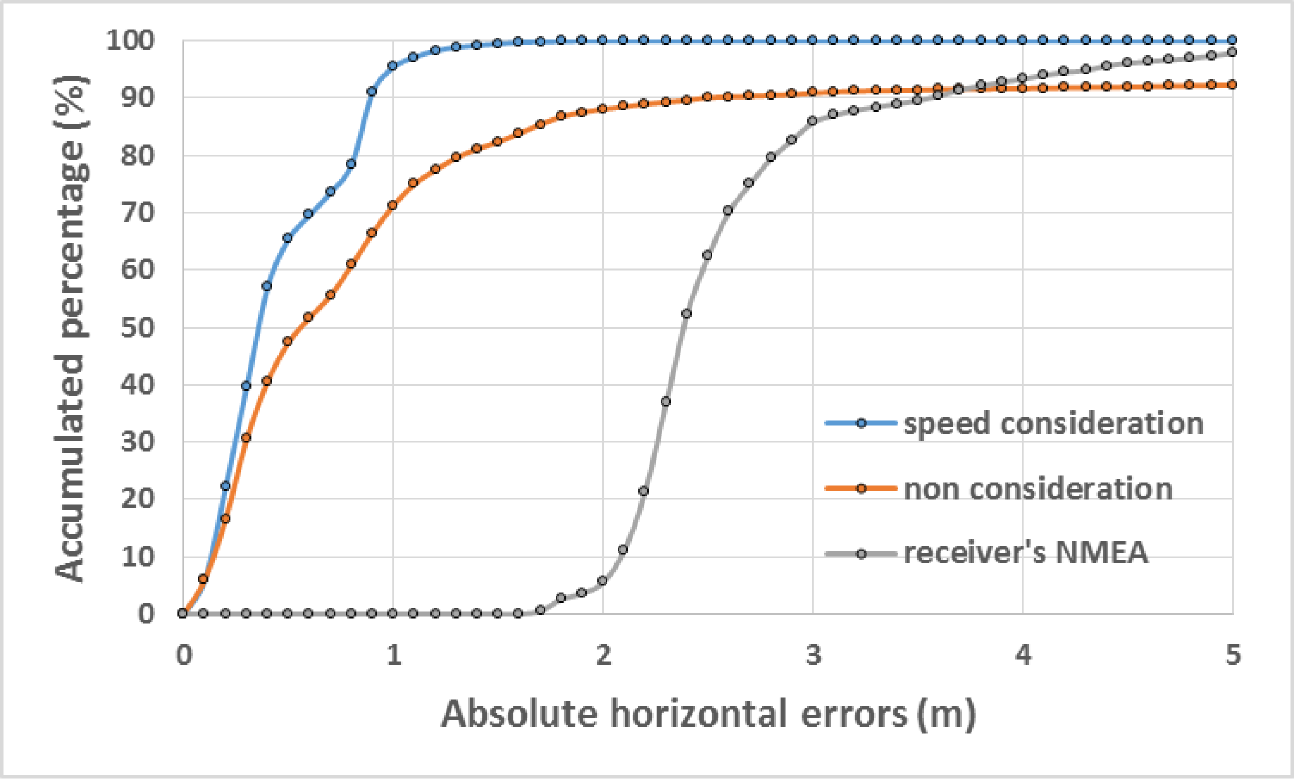
Without speed consideration



With speed consideration

- The normal weighting for “positioning / velocity” is “5m / 0.05m/s”.
- “Speed consideration” means we heavily rely on velocity when the car speed is very slow or zero.

Relationship between Accumulated Percentage and Absolute Horizontal Errors



	Maximum error	% within 1.5 m
Speed consideration	1.86 m	99.5 %
Non consideration	10.36 m	82.4 %
Receiver's NMEA	5.31 m	0 %

(No correction)

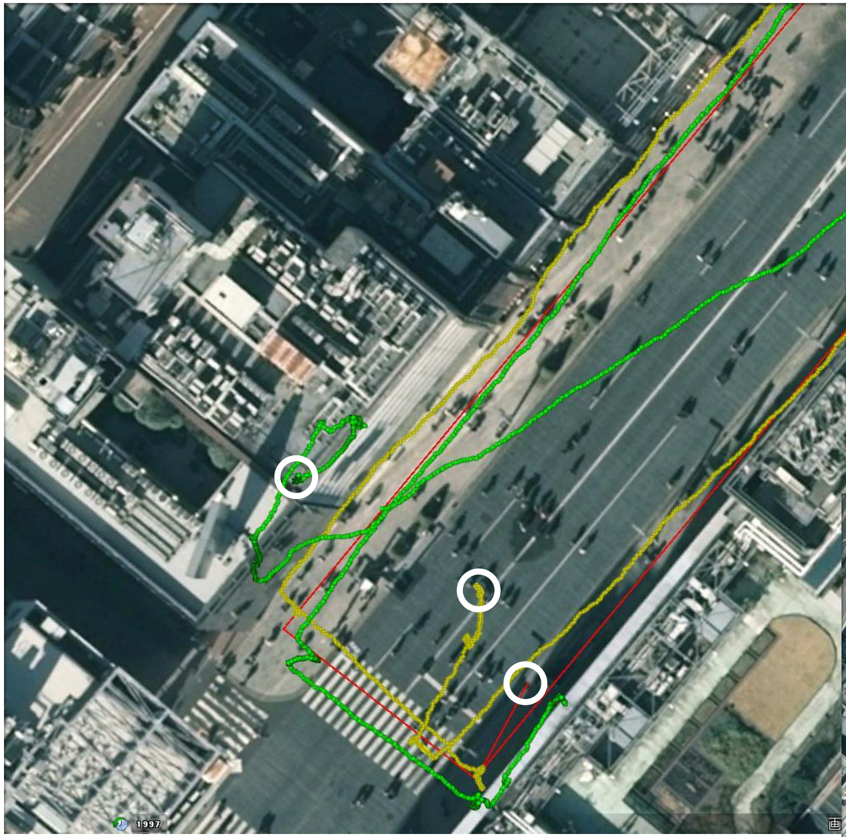
Results of other 2 tests were almost same tendency.

Pedestrian test in urban street using same method

- August 2015
- Ginza, Tokyo
- Popular low-cost single frequency GNSS receiver
- GPS/BEI/QZS (DGNSS)
- Good constellation during this test
- 9 minutes with 5Hz
- Walking along many buildings
- No reference positions

…NMEA …Proposed Method __Actual route

Accuracy of initial position…



…NMEA
…Proposed Method
__Actual route

Code based positions with C/N_0 check

Conclusion

- A different approach to mitigate multipath errors considering the speed was introduced and evaluated.
- Even using popular low-cost receiver, our proposed method was effective to reduce large multipath errors.
- To make use of the above technique, loosely coupled KF was introduced to combine pseudo-range based positions with velocity information effectively.
- In the normal urban areas, horizontal accuracy of DGNSS was improved using the car. Over 99 % within 1.5 m.
- Can be applied to pedestrian data.

- The raw data in the dense urban areas are checked. The performance strongly depends on the constellation.

Accumulated Percentage and Absolute Horizontal Errors + low-cost single frequency RTK