Availability Improvement of RTK-GPS with IMU and Vehicle Sensors in Urban Environment

ION GPS/GNSS 2012

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Background

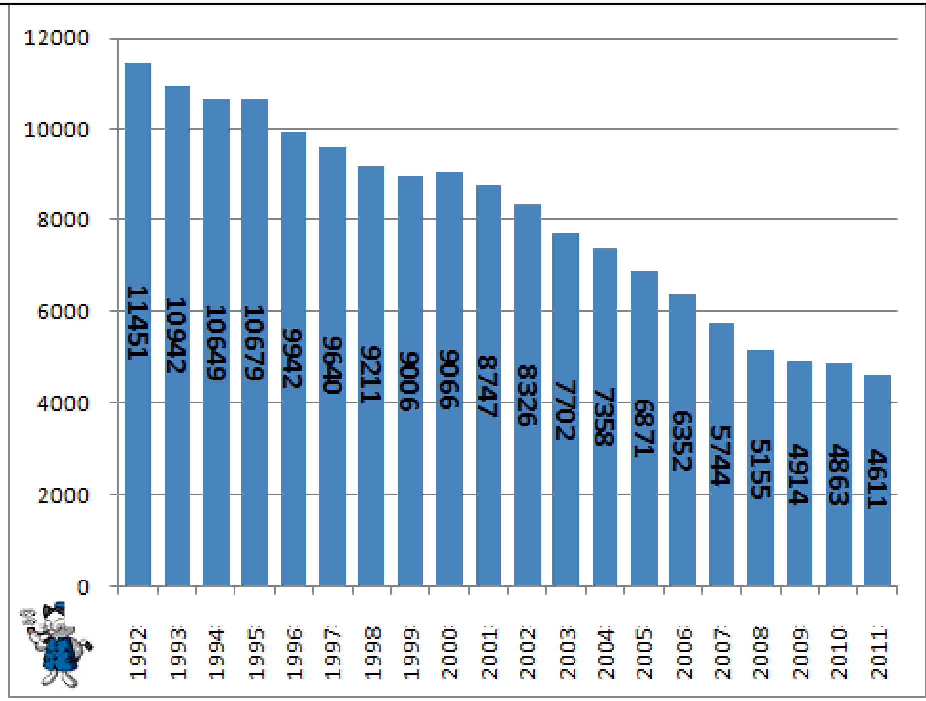
- The number of traffic accident deaths is decreasing in Japan for two decades.
- Future ITS still requires more efficient transport system.

  -Safety

  -Energy saving

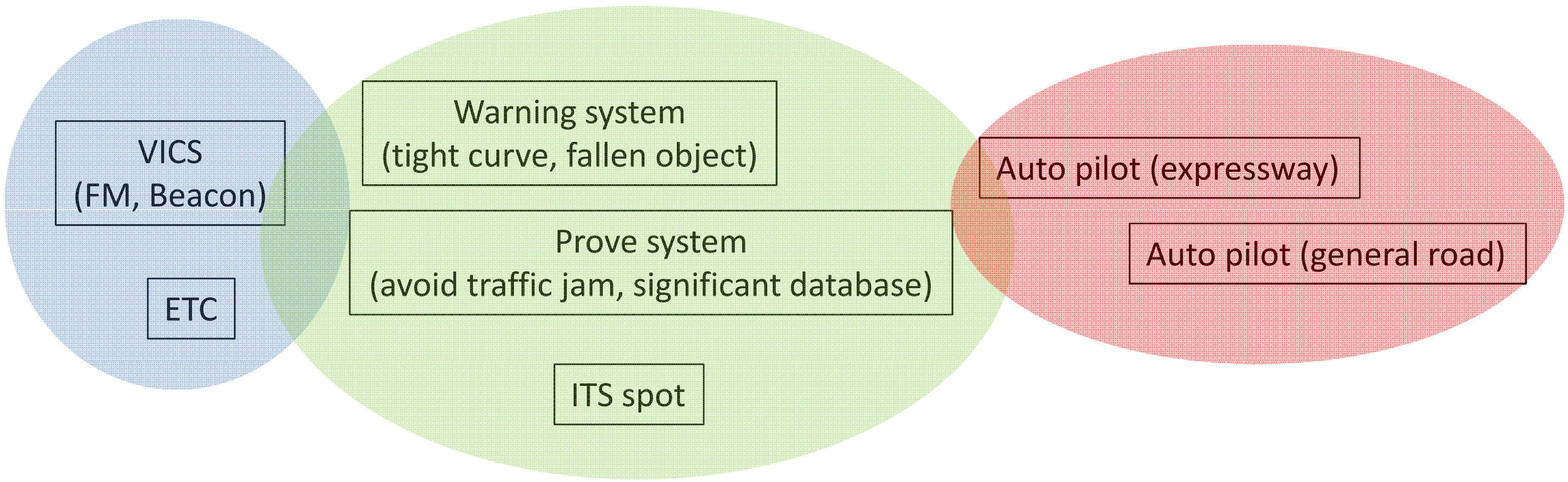
  -Standardization
- What is a roll of GNSS ?

Transition of the number of deaths for 20 years in Japan (within 24 hours)



ITS and GNSS

- Automatic collision avoidance system have been installed recently. They are not related to GNSS.
- However, most of present and future services for ITS will still rely on GNSS to some extent.



Where is your position ? (10m or 1m or 10cm)

Two Commercial Products

#1 Survey-grade GNSS + DMI + military-grade IMU

-Expensive but fully-integrated turnkey position

-10 cm accuracy even with one minute outage

-it is often used as a reference system for automobile

#2 Car-navigation-grade GNSS + Speed sensor + IMU

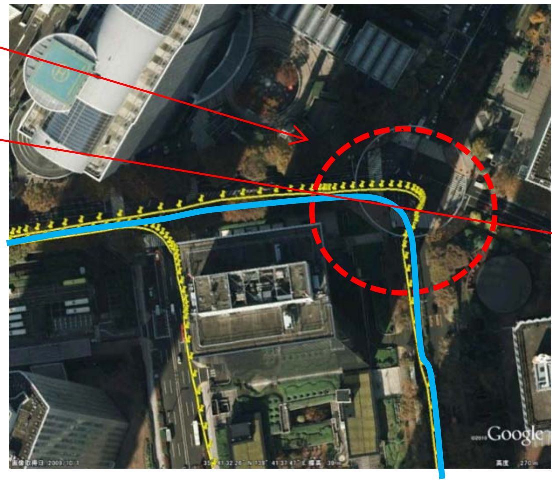
-A few hundred dollars but several meters accuracy

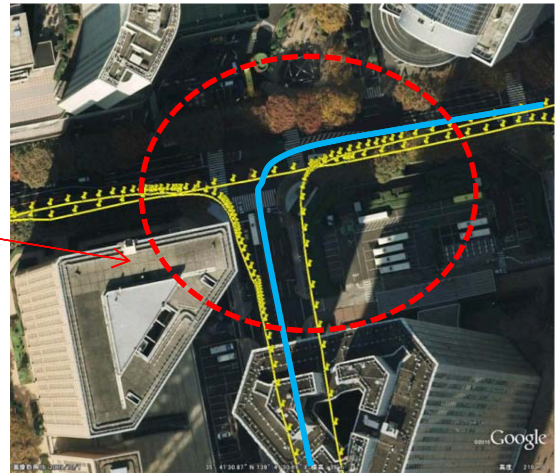
-100% coverage, continuous positioning

Performance of #2 Product

- Open-sky: Horizontal Errors were within 3m
- Urban: Horizontal Errors were within 5m
- Dense-urban: following figures
- Underground: 10m- / minute

West Shinjuku in Tokyo
(many skyscrapers)





Maximum deviation: about 10m

Provided by HONDA R&D

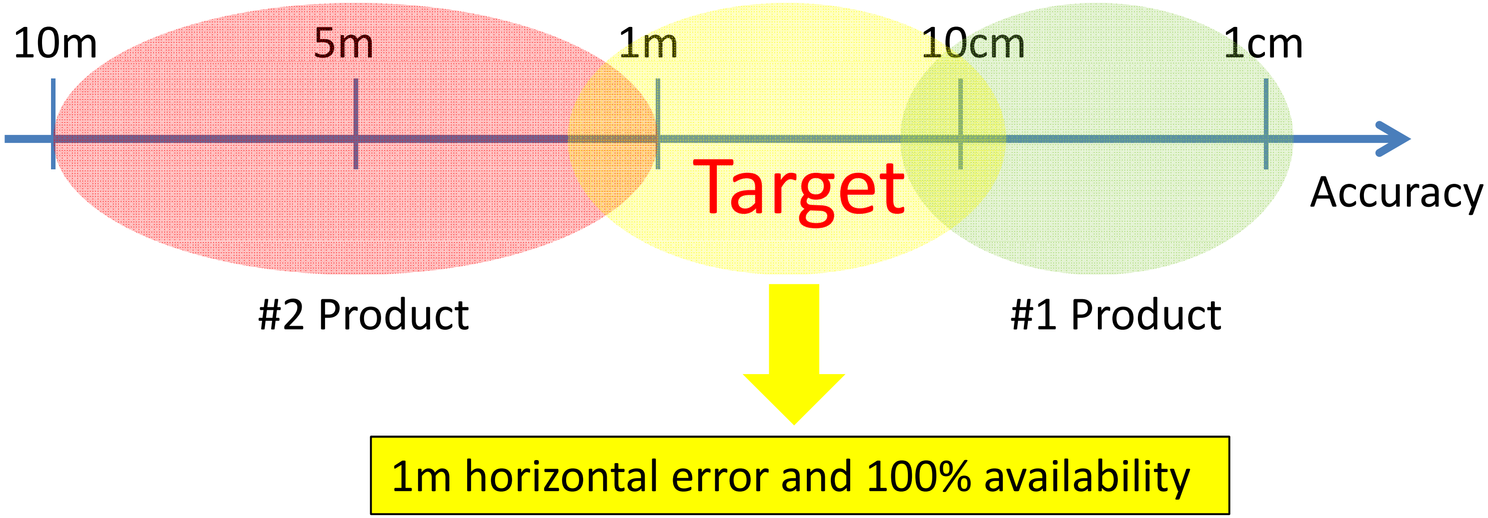
Our Objective

- Survey-grade GNSS + Speed sensor + IMU

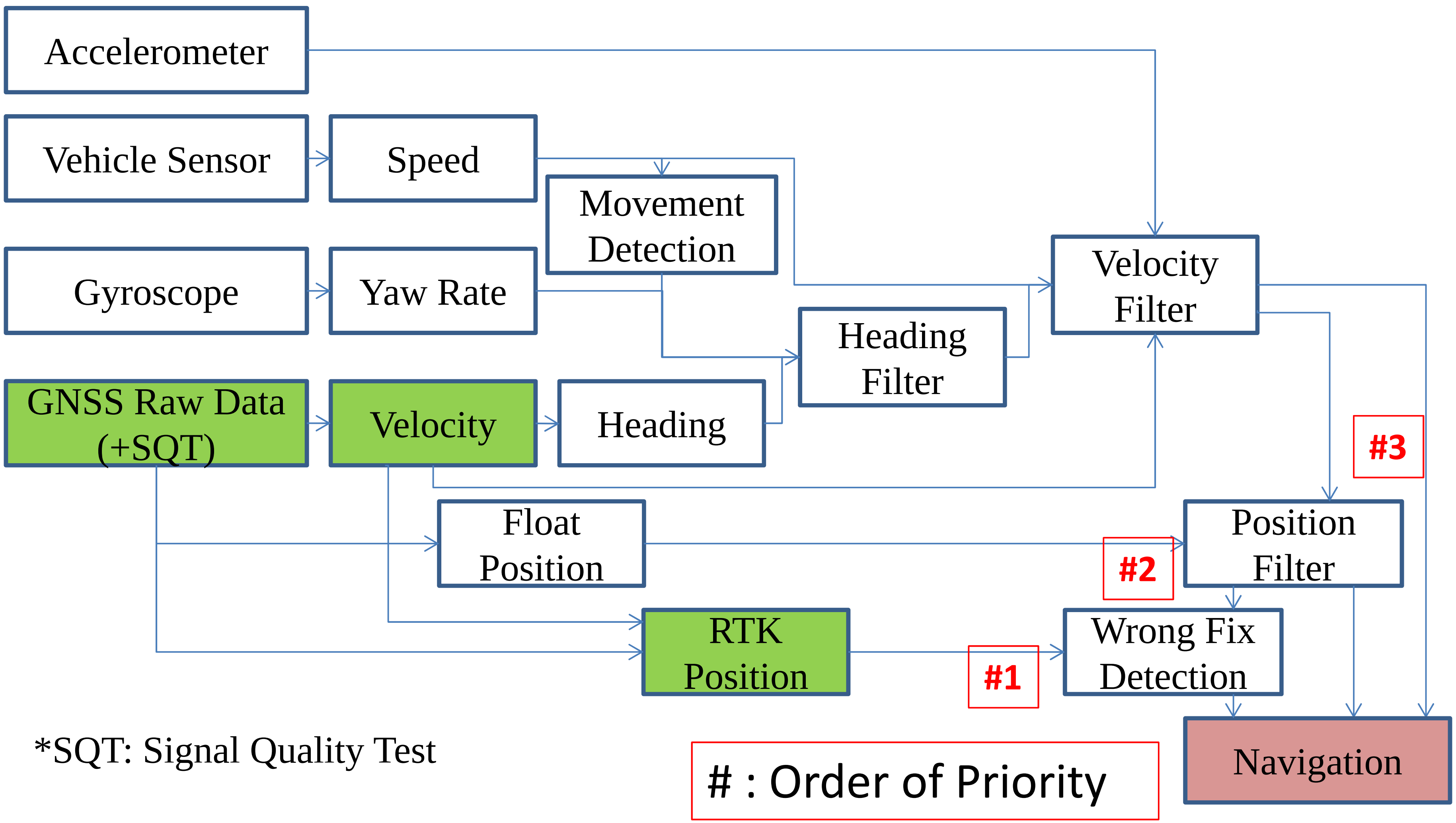
Reliable RTK still requires dual-frequency

Low cost

- Prospective accuracy in safety use for ITS like lane recognition is said under 1m with continuous positions

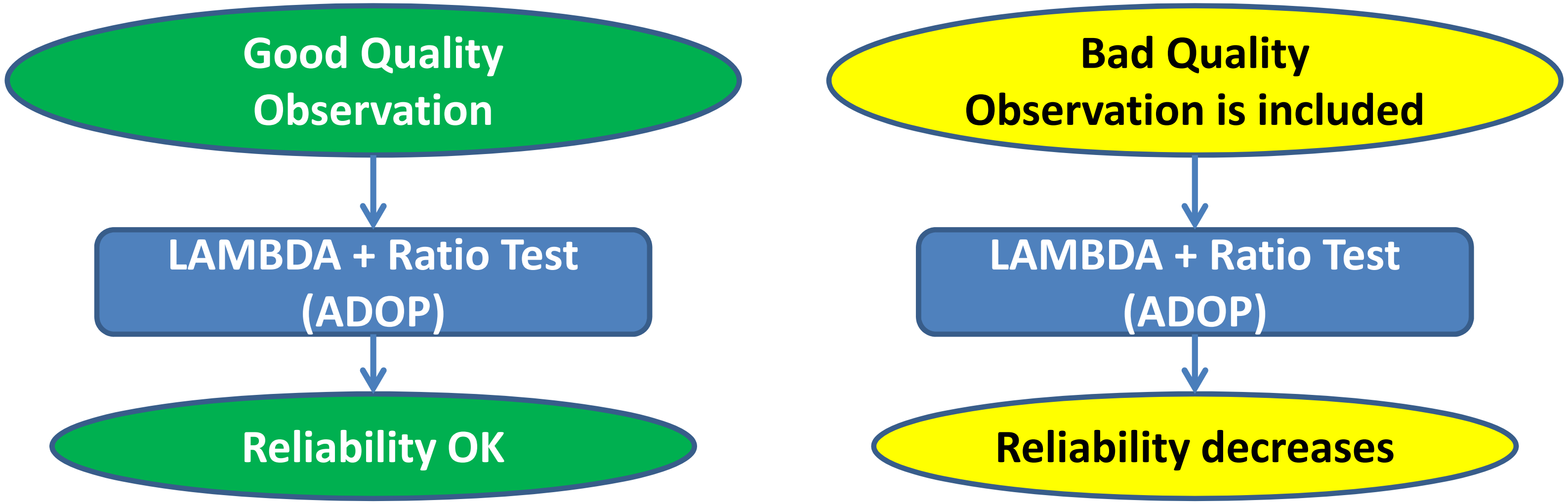


Algorithm of Loosely Coupled Integration



RTK

- Double-differenced observations
- LAMBDA method
- Ratio Test (>3) + ADOP



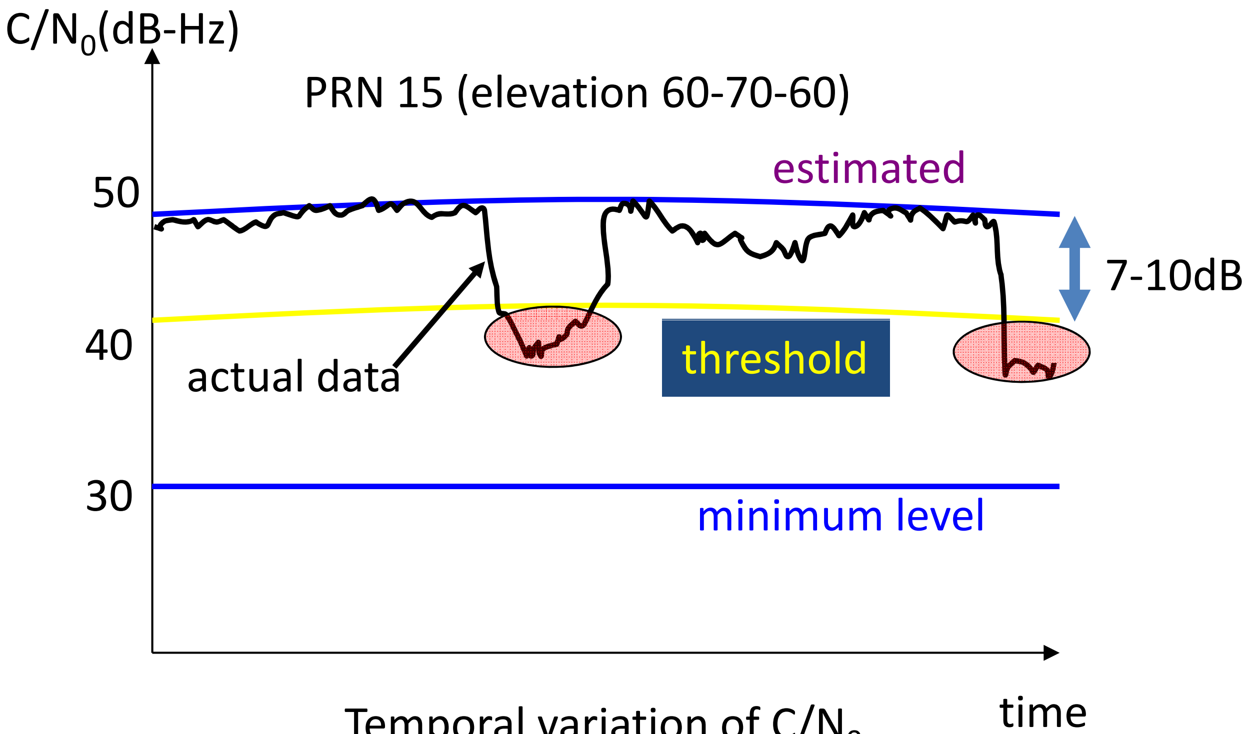
Signal Quality Test

(Detecting dominant multipath signal)

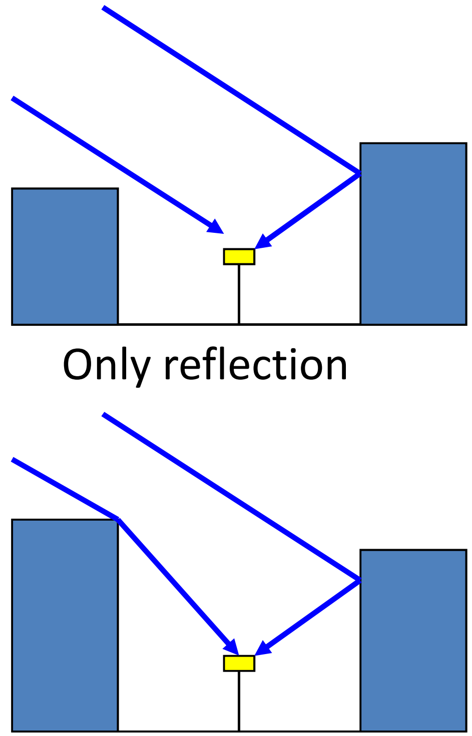
(Kubo *et al*, 2005)

(L1+L2, 2011)

- Detection method is very simple



Temporal variation of C/N_0

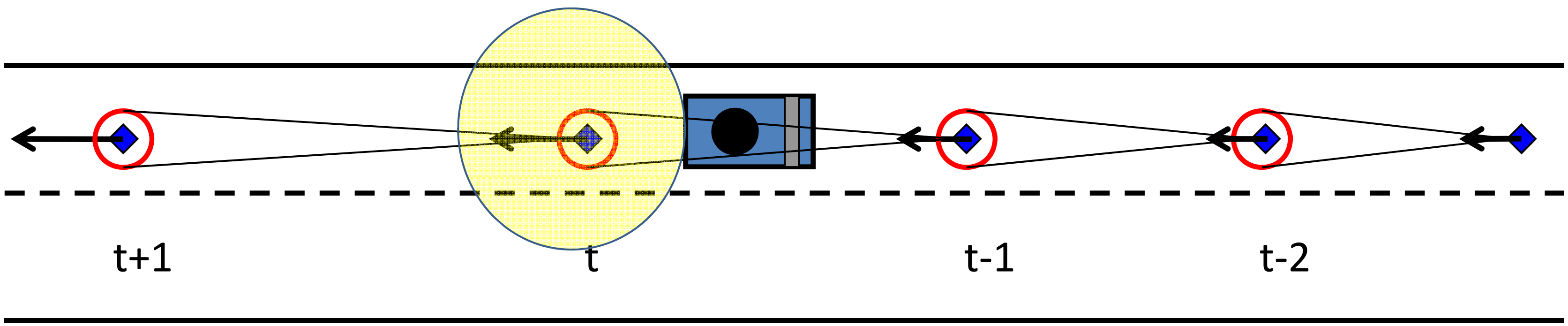


Diffraction and reflection (dominant multipath)

Ambiguity Resolution with Velocity-Information

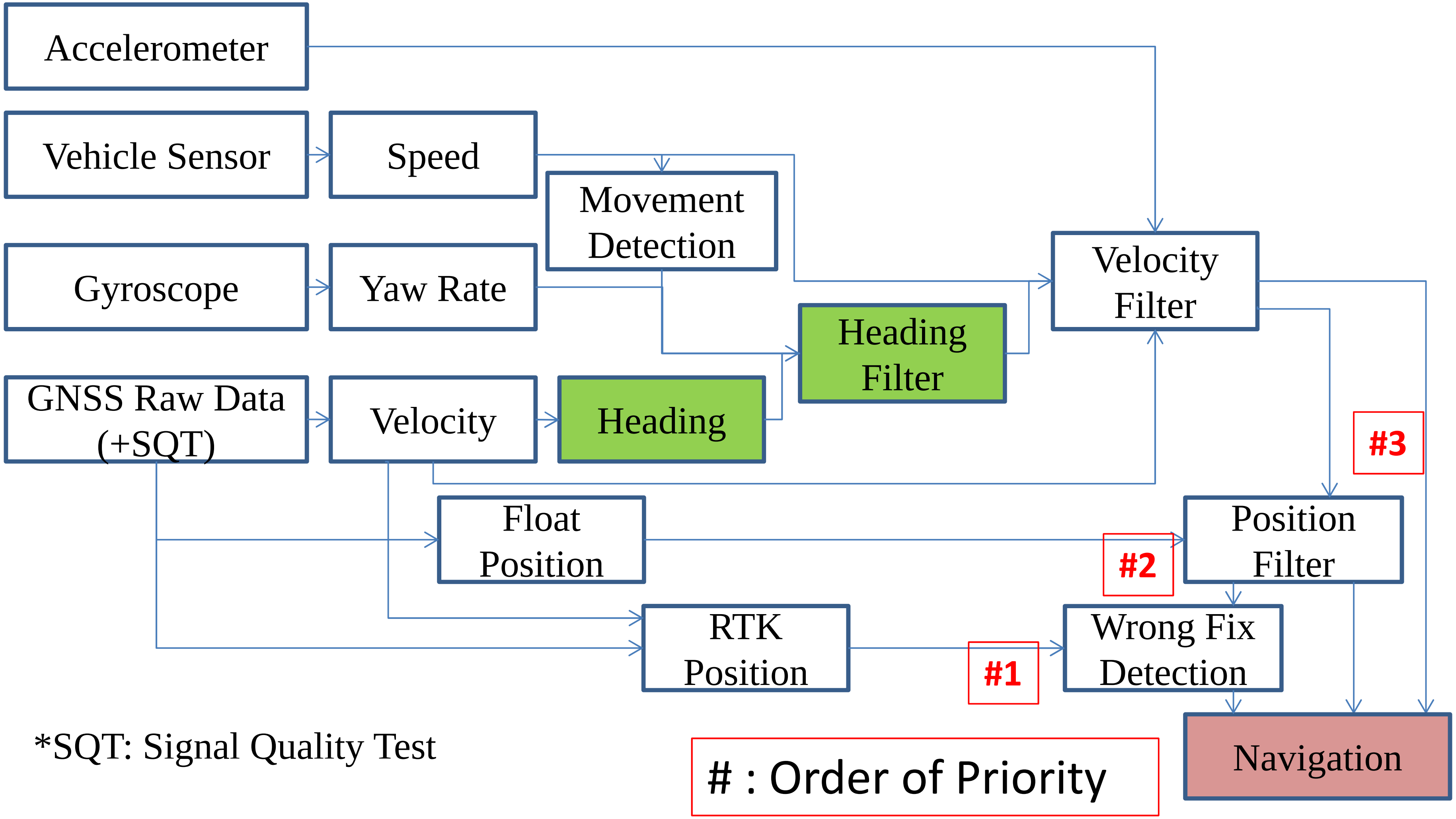
(Kubo *et al*, 2008)

- **RTK requires initial positions (=float solutions).**
- **Instead of normal float solution, expected position is used.**
- **Search space can be reduced dramatically.**



Expected Position(t) = Previous Fix Position(t-1) + (Velocity(t)+Velocity(t-1))/2

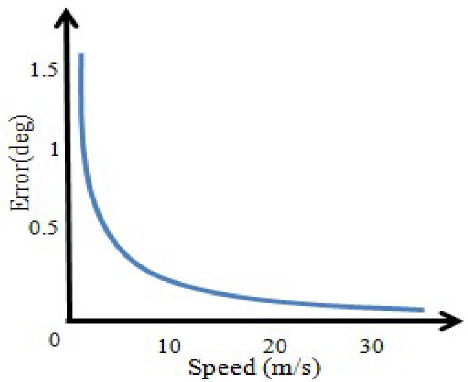
Algorithm of Loosely Coupled Integration



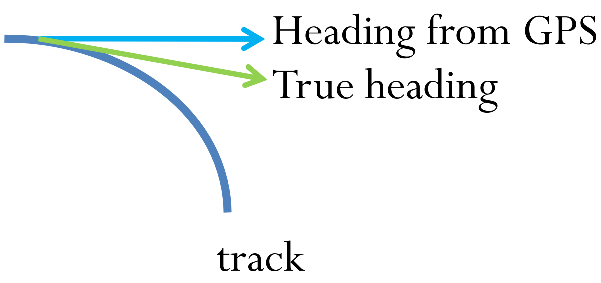
*SQT: Signal Quality Test

Heading from GPS Velocity

- We can not get the right heading when the vehicle is stationary or in a low speed
  - GPS velocity measurement has a few cm/s noise



- The heading error will increase when the vehicle is moving in a high yaw rate
  - GPS sampling is in a low rate



$$x_k = (\psi_{G_k}, \omega_{g_k})$$

$$x_{k+1} = F_k x_k + G w_k$$
$$y_k = H x_k + v_k$$

$$F = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix}$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k (y_k - H_k \hat{x}_{k|k-1})$$

$$\hat{x}_{k+1|k} = F_k \hat{x}_{k|k}$$

$$K_k = P_{k|k-1} H_k^T (H_k P_{k|k-1} H_k^T + R_k)^{-1}$$

$$P_{k|k} = P_{k|k-1} - K_k H_k P_{k|k-1}$$

$$P_{k+1|k} = F_k P_{k|k} F_k^T + G_k Q_k G_k^T$$

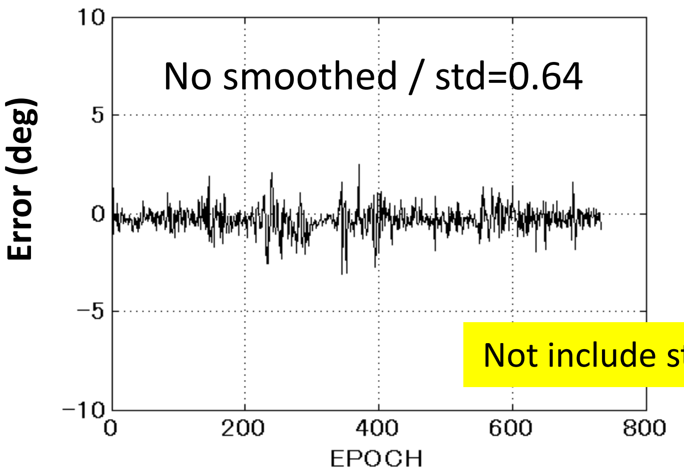
$$R = \begin{bmatrix} \sigma_{\Psi_G}^2 & 0 \\ 0 & \sigma_{\Psi_g}^2 \end{bmatrix}$$

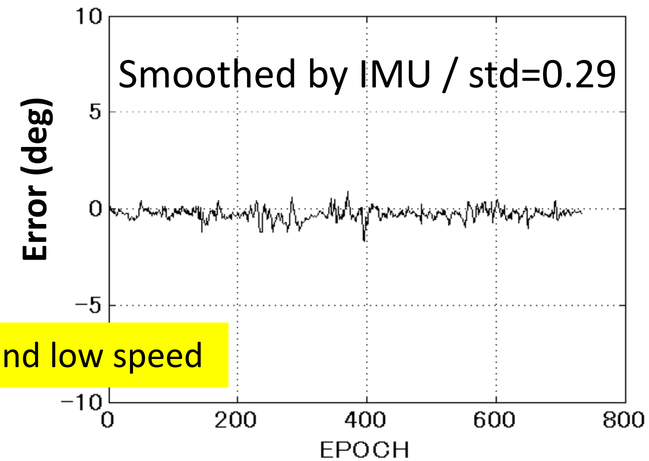
A new heading estimation algorithm

- Moving situations
  - Low speed (from vehicle speed sensor)
  - Normal speed with <u>low yaw rate and HDOP<5</u>
  - with <u>low yaw rate and HDOP>5</u>
  - with <u>high yaw rate and HDOP<5</u>
  - with <u>high yaw rate and HDOP>5</u>

Speed threshold : 1 m/s
Yaw rate threshold : 4 deg/s

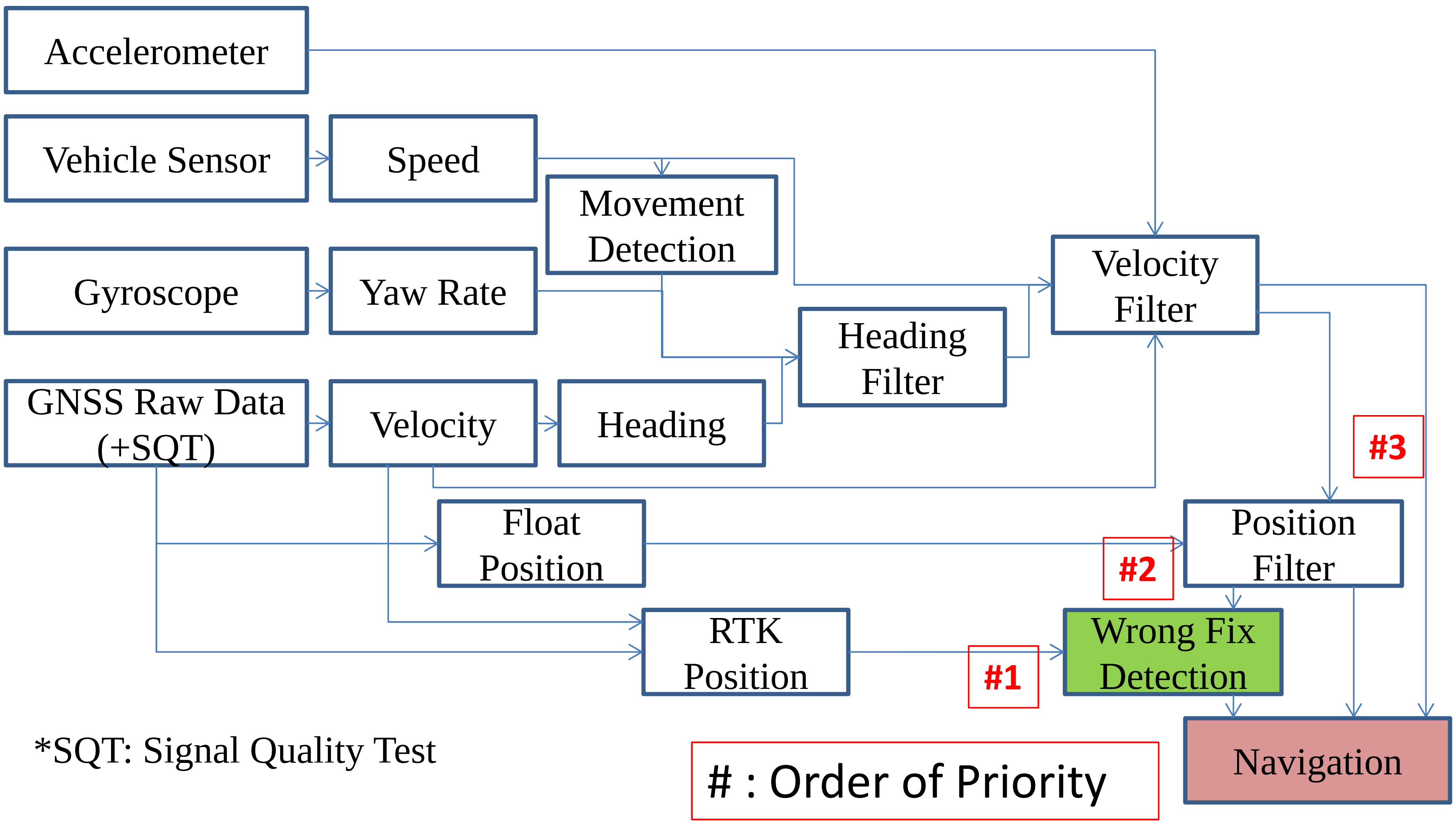
- The measurement covariance will be updated in each state.





Not include stop and low speed

Algorithm of Loosely Coupled Integration



Wrong fix Detection

- Calculate the change of the altitude

$$\Delta h = \int_{t1}^{t2} v \sin(\theta) dt$$

- θ is the pitch angle change deduced from a pitch rate gyro
- Velocity in vertical direction from GPS is also used
- Epochs of t1 and t2 are used when the RTK-GPS is available.
- Bad quality carrier-phase can be often received in t2 (re-tracking).

An example of the threshold of height

Automobile Experimental Tests

- **<u>Test1</u> (only RTK):** Tokyo（2011）
- **<u>Test2 (RTK+IMU+Speed):</u>** Nagoya（2010）

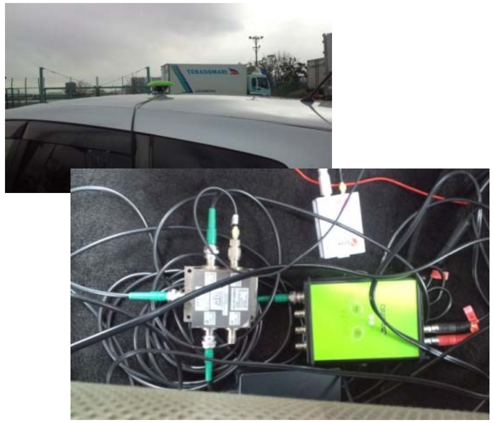
GPS Receiver	NovAtel OEM5 or JAVAD Delta (CS=100s)
Antenna	NovAtel GPS702 or JAVAD RegAnt
IMU	Crossbow IMU 440 (MEMS)
Speed sensor	Standard vehicle loaded wheel speed sensors
True position	POS/LV (Applanix) (positional accuracy - within 10cm/1min outage)
Baseline	within 10 km
Mask angle	15 degrees
HDOP threshold	10

Tokyo **(Test1)**

(Open 10%   Urban 50%   Dense 40%)

Around Tokyo Station

- Total period: 1hour
- Data rate: 5Hz
- JAVAD Delta+RegAnt
- Relatively wide road

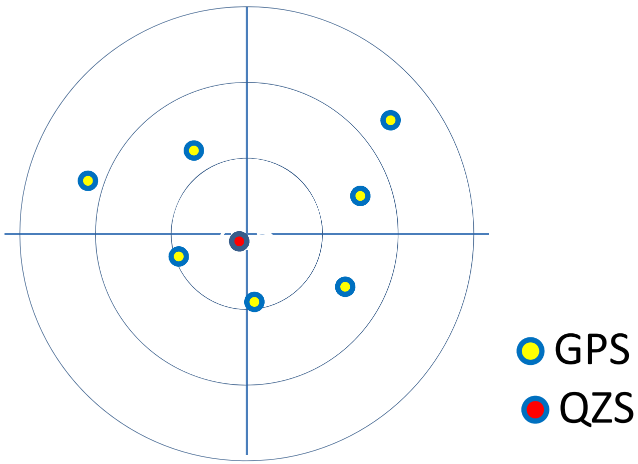


RTK Performance (**Test1**)

Availability and percentage within 50 cm in horizontal error

	GPS	GPS+QZS
DGPS	69.6%	84.7%
Normal RTK	17.6% (99.2%)	31.7% (99.7%)
+signal quality test	15.7% (99.8%)	36.0% (100%)
+velocity information	21.2% (99.8%)	43.5% (100%)

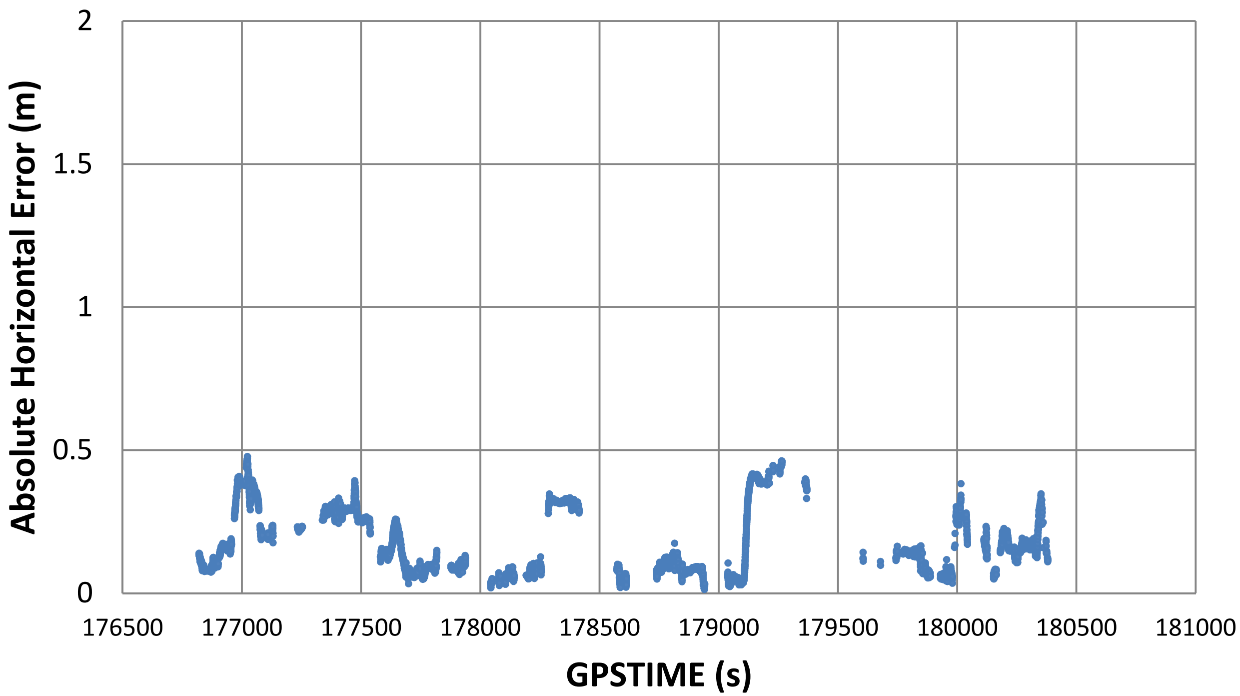
Total: 17800 epochs (5Hz)
(): percentage within 50 cm



Satellite Constellation

Temporal Horizontal Errors **(Test1)**

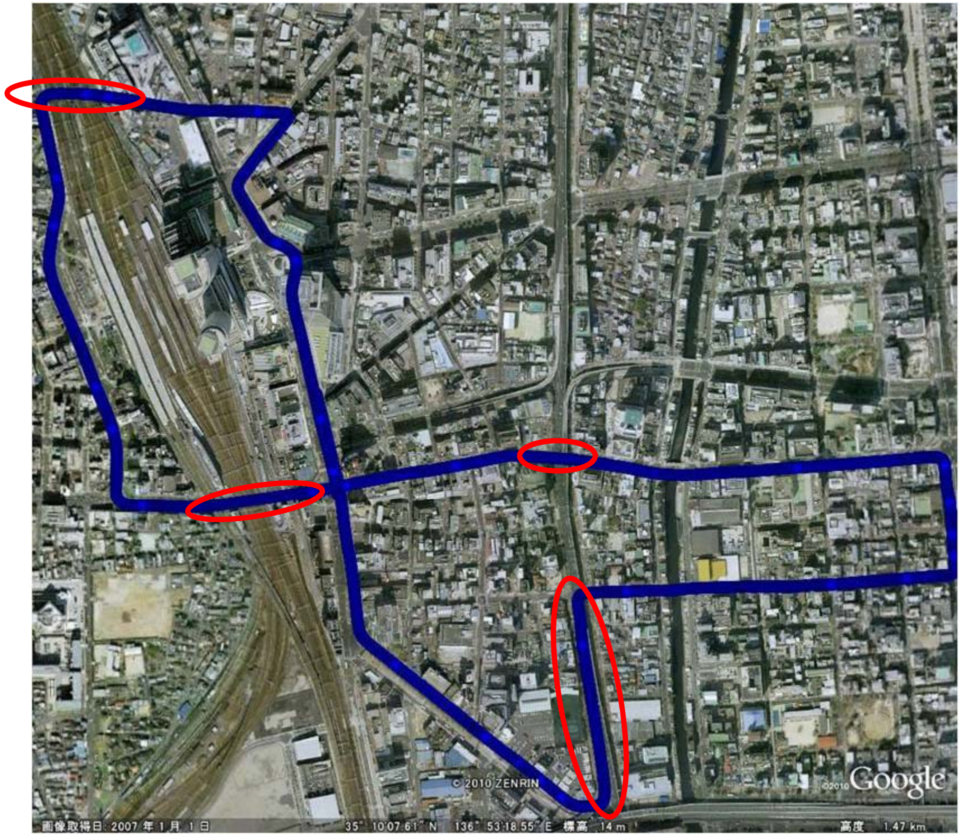
(GPS+QZS, Best case in RTK)



7737 / 17800 epochs

Nagoya **(Test2)**

(Open 0%   Urban 40%   Dense 50%   No-Sky 10%)



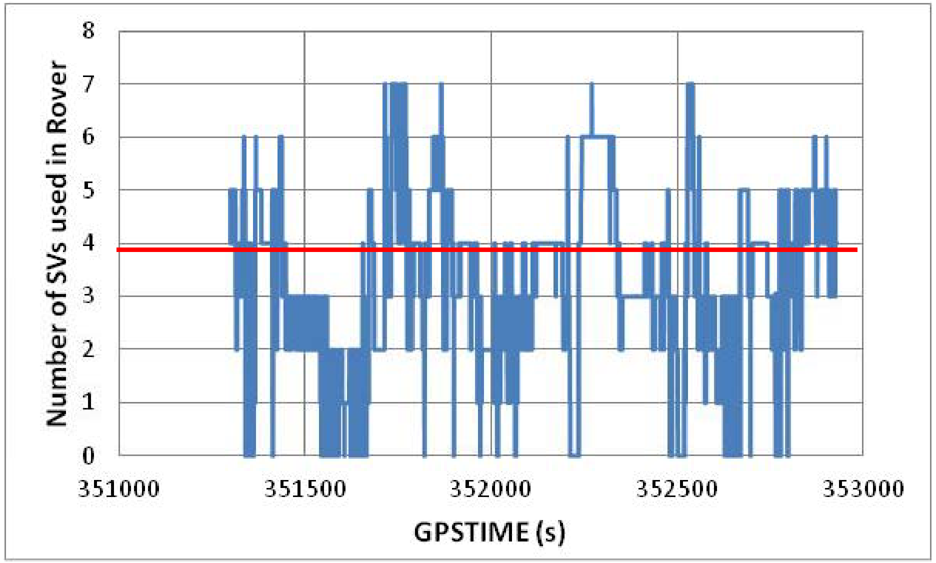
Test Route

No-Sky

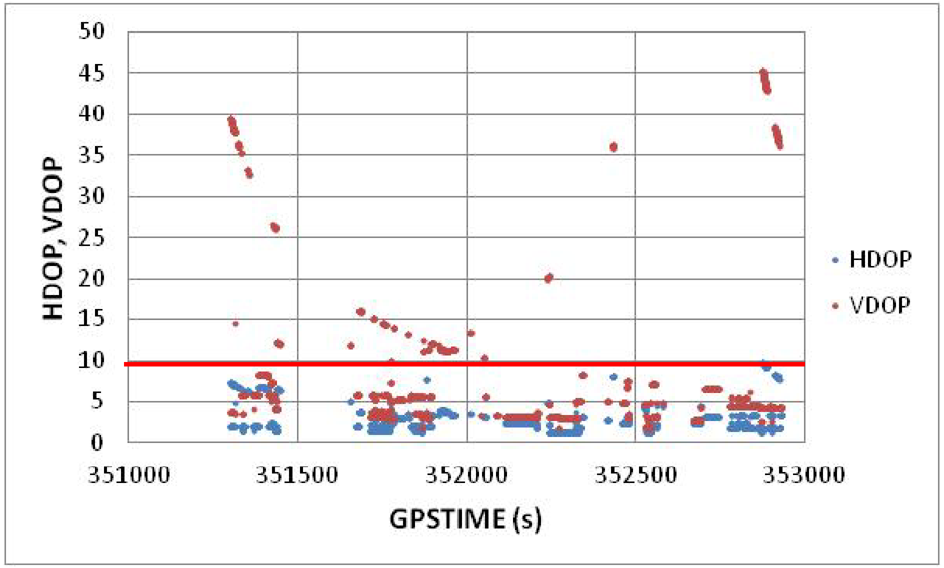
- QZS was not evaluated
- Total period: 27min
- NovAtel OEM5+ GPS702
- Data rate: 10Hz
- POS/LV was used to evaluate the precise temporal errors.
- Relatively wide road
- Good GPS Constellation
- Average speed was 3.5m/s

Number of Used Satellites **(Test2)**

- Average NUS in reference -> 7.1
- Average NUS in rover -> 3.2



L1 + L2 carrier phase are valid
Percentage with 4 or more satellites: 42%



Over 50 are not displayed

RTK Performance (**Test2**)

Availability and percentage within 1 m in horizontal error

	GPS
DGPS	51.0% (55.3%)
Normal RTK	12.4% (88.9%)
+signal quality test	13.0% (98.4%)
+velocity information	32.0% (94.8%)
+ADOP < 0.25	20.0% (99.8%)

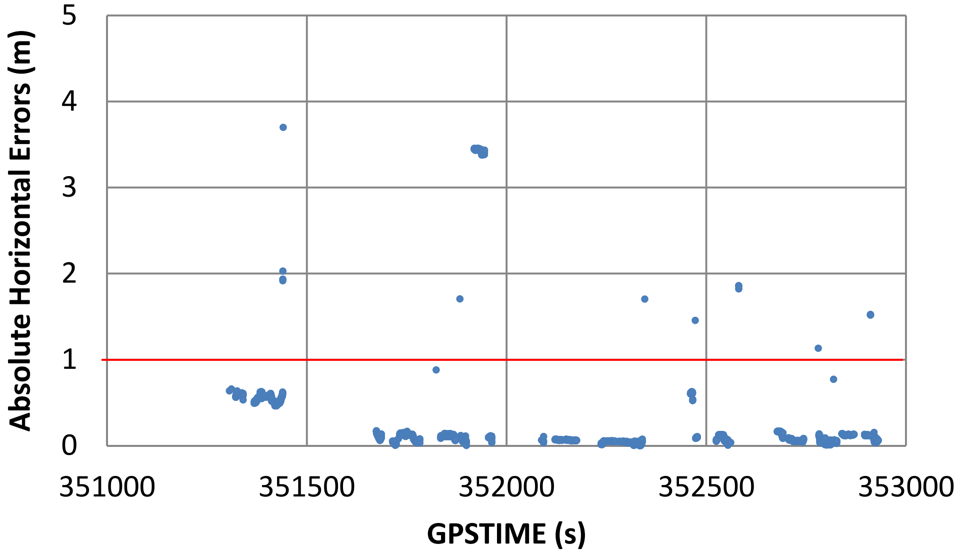
⇨ for integration

Total: 16270 epochs (10Hz)
(): percentage within 1 m

The rest of 68 % positions have to be generated from filtered DGPS or INS using our proposed integration method.

Wrong Fix Detection Summary **(Test2)**

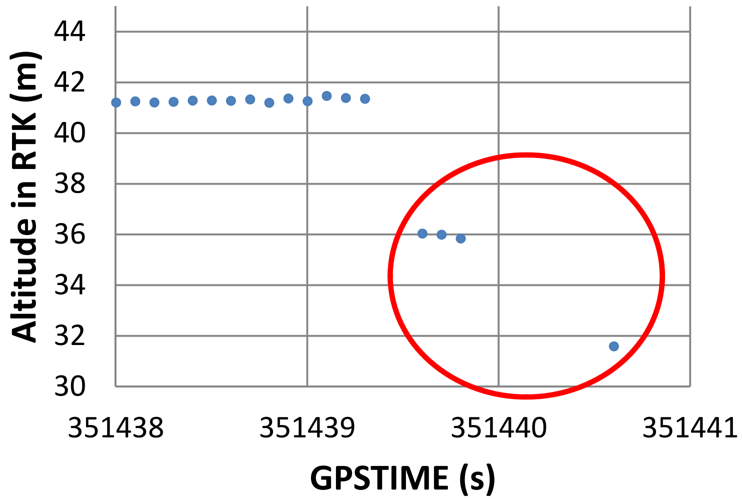
Temporal Horizontal Errors in RTK (32% of all)



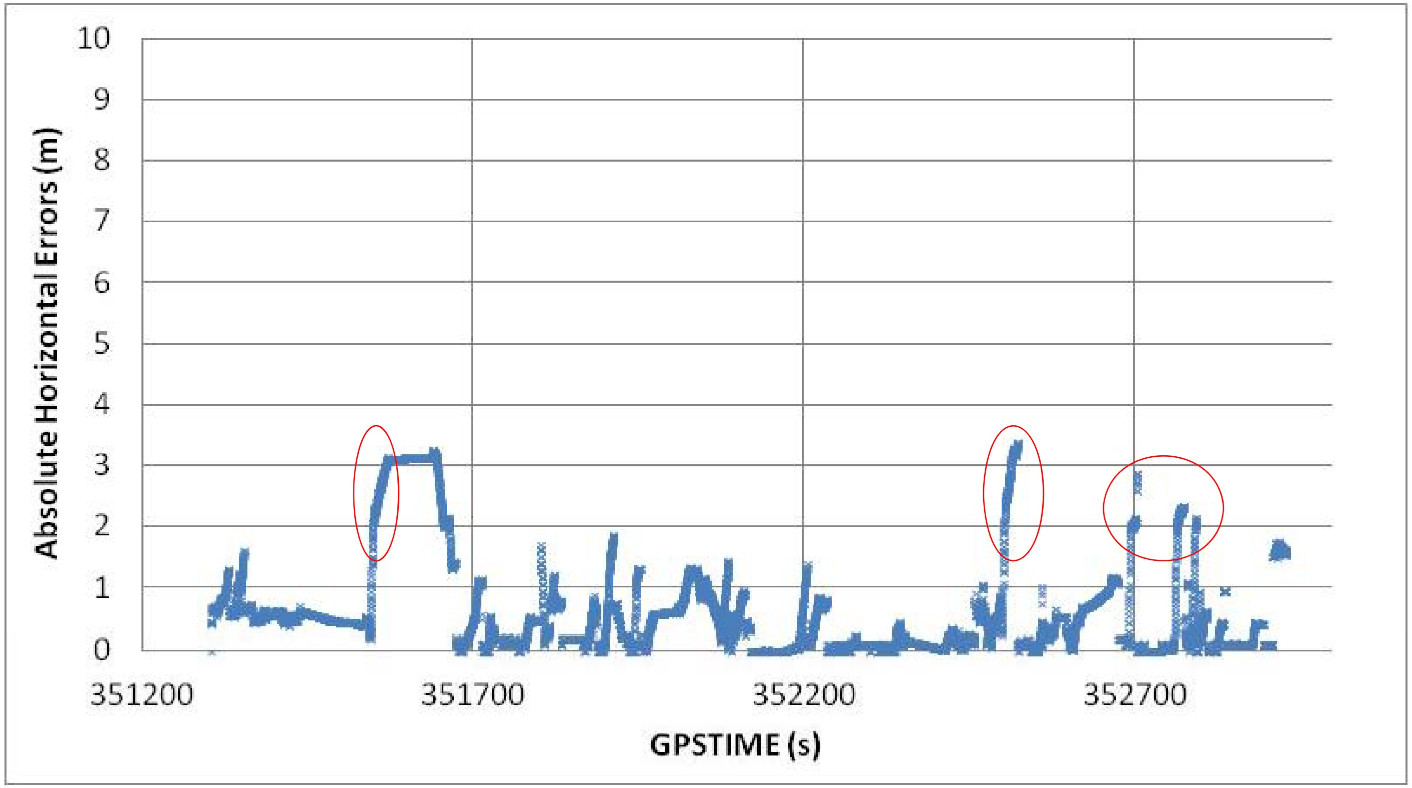
Horizontal Errors (m)	Statistics	
	Wrong fix	Detection
1m-2m	13	9
2m-3m	3	3
>3m	259	259

Most of wrong fixes were detected !

Actual Wrong Fix Detection Example

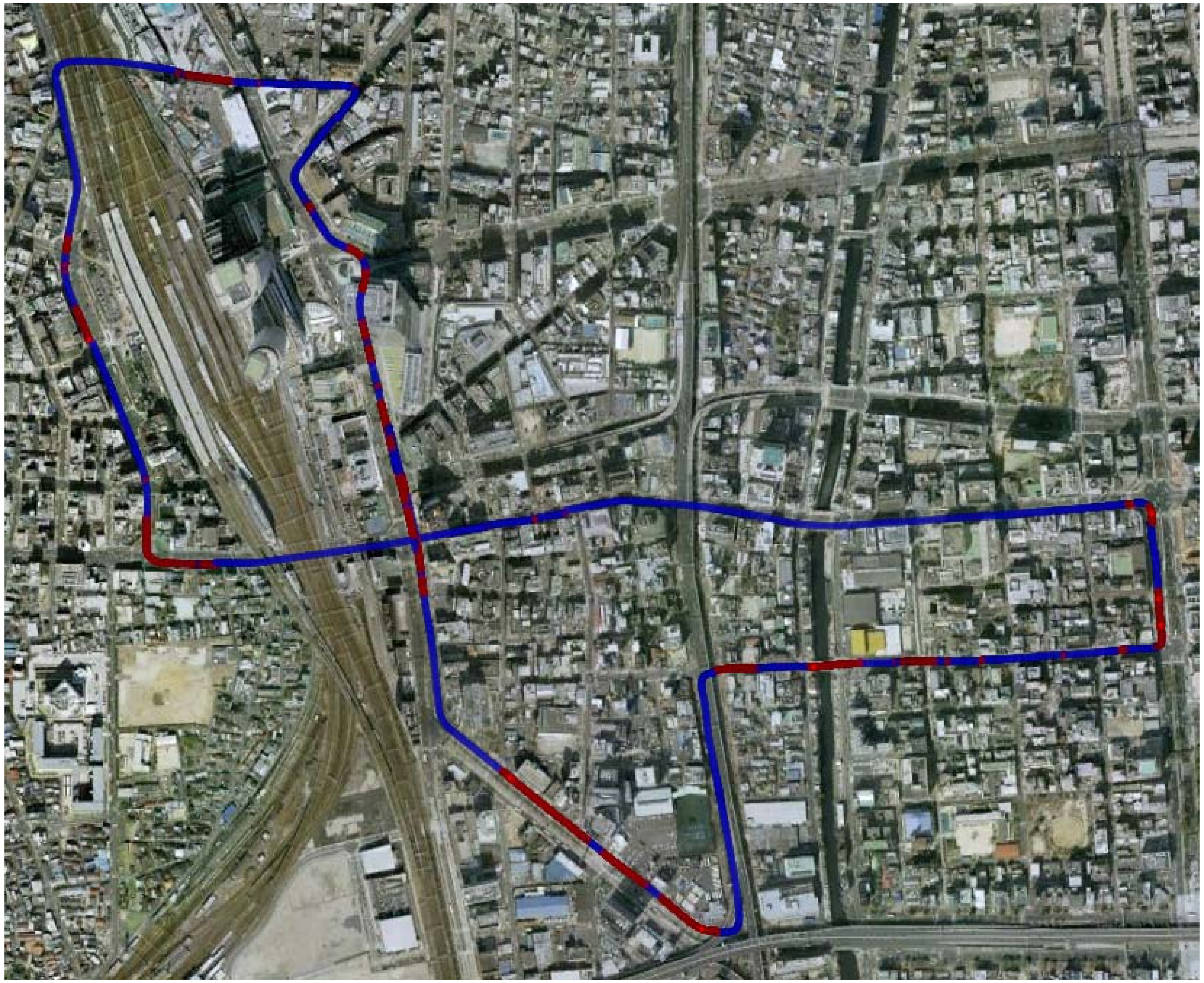


Total Performance **(Test2)**



Horizontal Errors (m)	Statistics	
	N	Percentage
<=1m	13379	**82.2**
>1m	2891	17.8

Total Horizontal Positions **(Test2)**



● RTK-GPS fixed positions

32% of all
(5219 of 16270epochs)

● Positions given by our proposed integration system

68% of all
(11051 of 16270epochs)

||

100 %

Summary

- Our proposed signal quality test and velocity use for the reliability and availability in RTK were quite effective in urban environment. However, there are still wrong fixes.
- Loosely coupled integration (GPS+IMU+Speed) method was proposed and availability was improved from 32% to 100%. Accuracy deterioration was small using IMU and Speed.
- Multi-GNSS and Multi-Frequency is clear in future. As QZS was effective in RTK, the performance of RTK in urban environment must be improved.
- What is an appropriate application in the level of 1m accuracy ?

Thank you for your attention !

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