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Cycle Slip Detection and Fixing by MEMS IMU/GPS Integration for Mobile Environment RTK-GPS

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Background

RTK-GPS under Open Sky

RTK-GPS on Downtown Street

● Fixed Solution ● Float Solution by Google

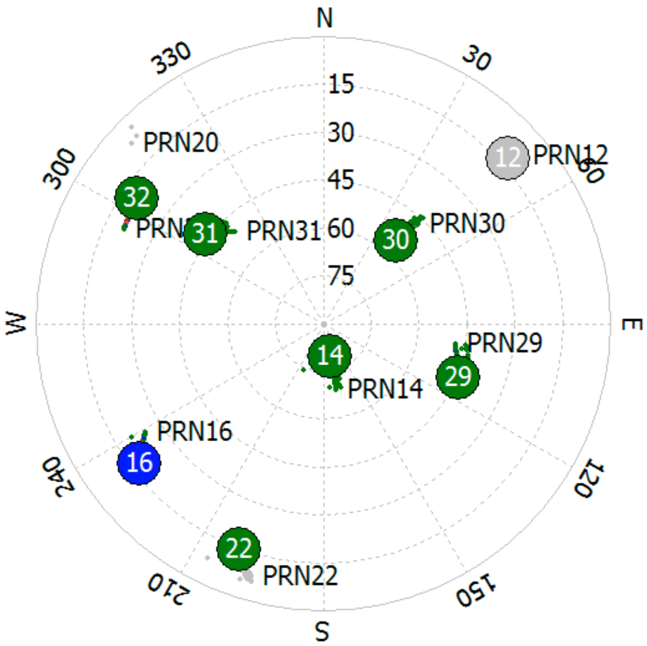
Mobile RTK-GPS in Urban Area

- A lot of issues to be resolved:
  - Multipath (code, carrier-phase)
  - Signal outage/data gap
  - False tracking in receiver
  - Communication link interruption
  - …
  - Cycle slip

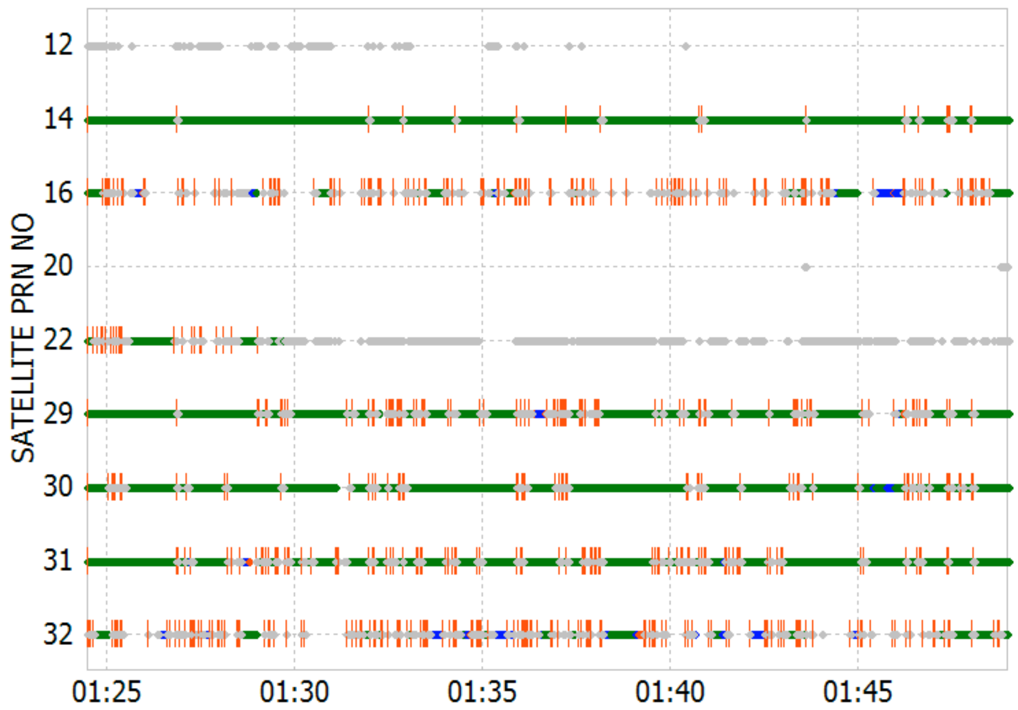
Cycle Slip

- Discontinuity in the carrier-phase measurement caused by loss-of-lock of signal tracking in a GPS receiver
- Integer cycle (or +half cycle) jump appears in carrier-phase ambiguity
- Most slips are caused by signal obstructions due to surrounding obstacles, like buildings, trees, bridges, poles, cars,…
- Far more slips in the mobile condition

Cycle Slip in Urban Area

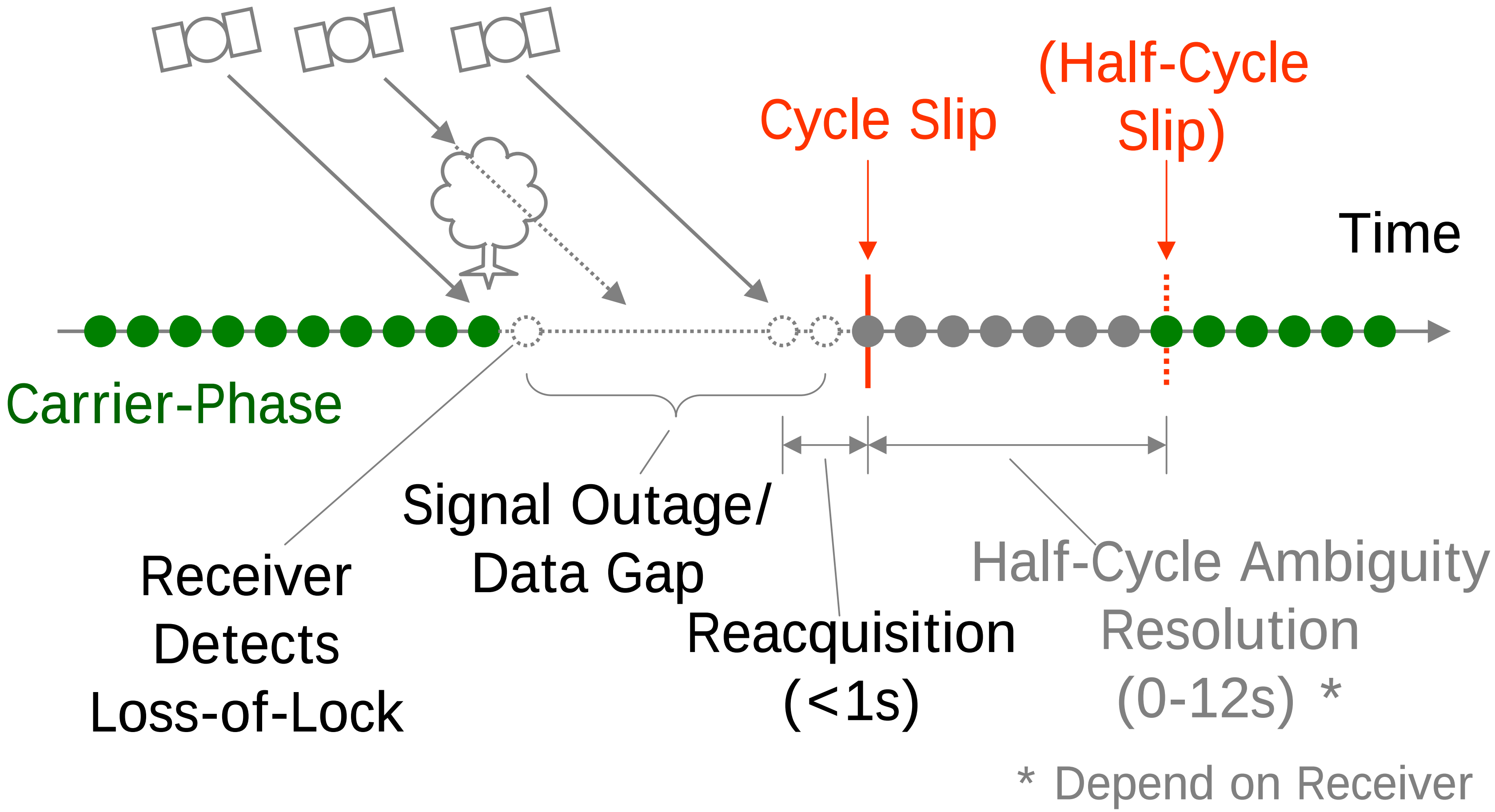


Sky Plot of Satellites

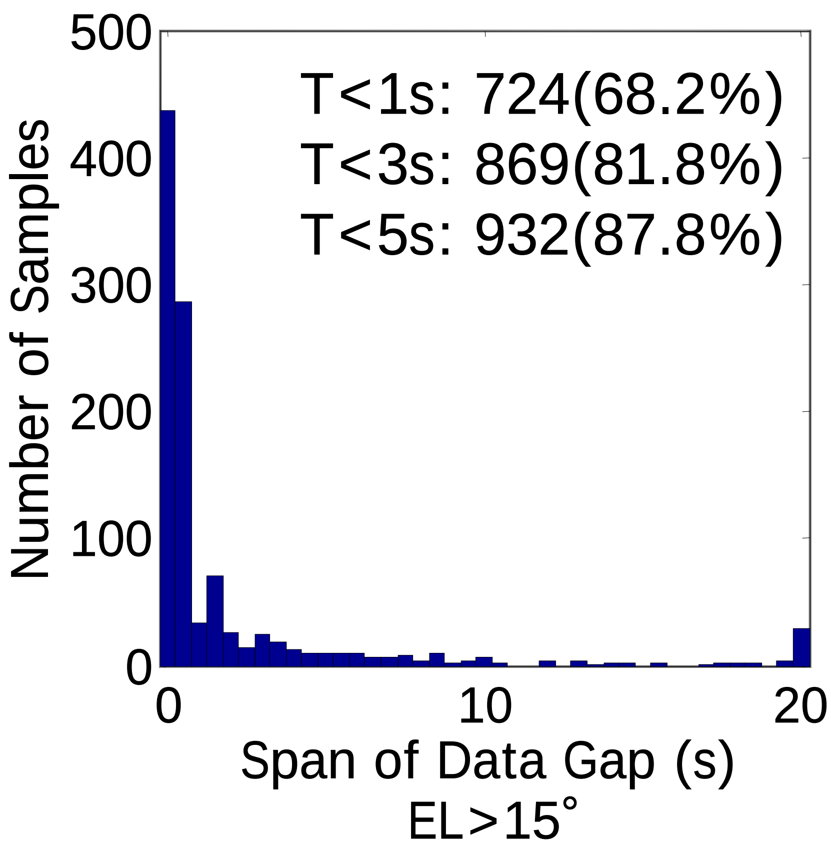


: Cycle Slips

Typical Cycle Slip Pattern



Statistics of Cycle Slips



- Most data gaps are shorter than 10 s.
- With short data gaps, cycle slips could be fixed aided by INS?
- If slips fixed, availability of solution could be much improved.

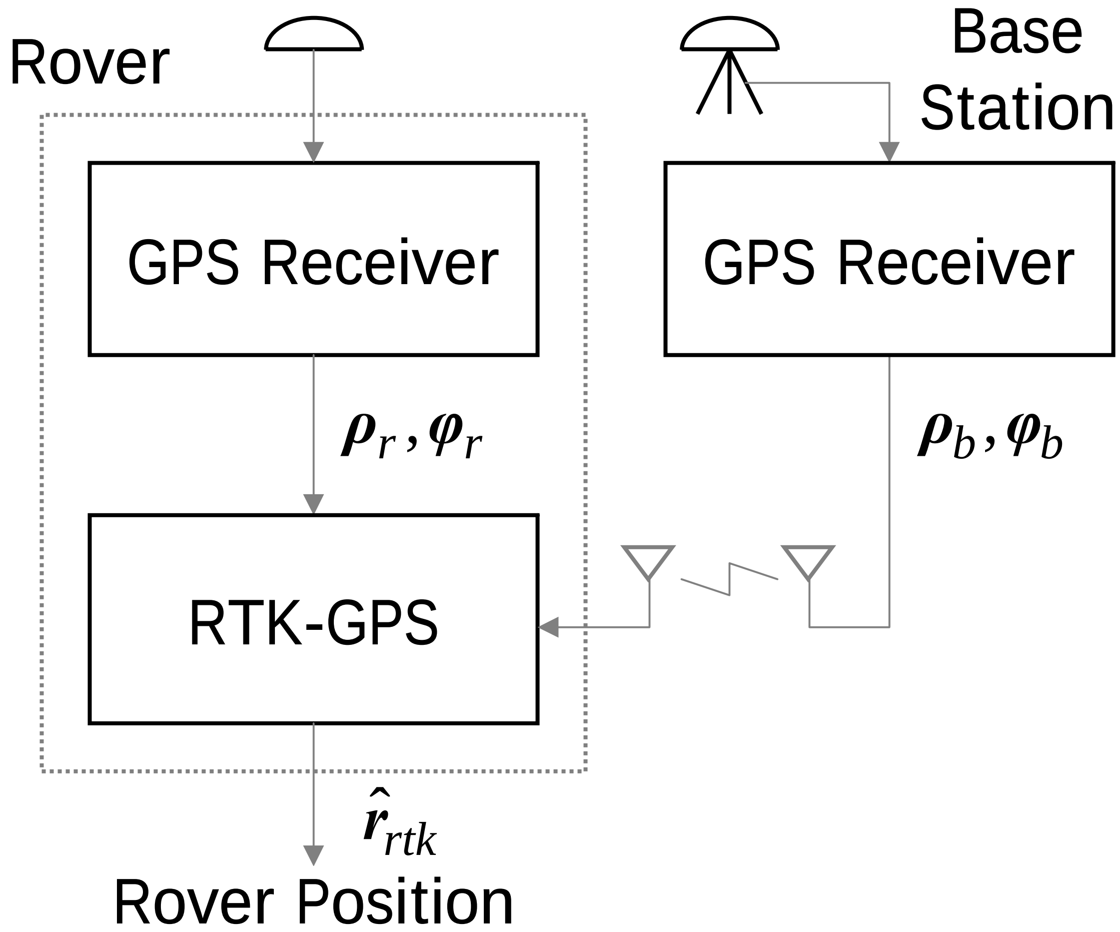
Cycle Slip Detection

- Various ways:
  - Receiver loss-of-lock indicator or lock-time
  - Detect jump of L1-L2 Geometry-Free LC
  - Phase prediction with delta-range
  - Innovation test in navigation filter …
- Combination of multiple methods to ensure the reliability
- It’s effective aided by INS?

Cycle Slip Fixing

- Most receivers have no cycle slip fixing. If detecting a slip, just reinitialize and restart the ambiguity estimation.
- Someone employ “slip-free” solutions, like instantaneous AR. But its performance greatly depends upon the quality of code observables. May not be practical under ill multipath environment.
- It’s hard, but feasible aided by INS?

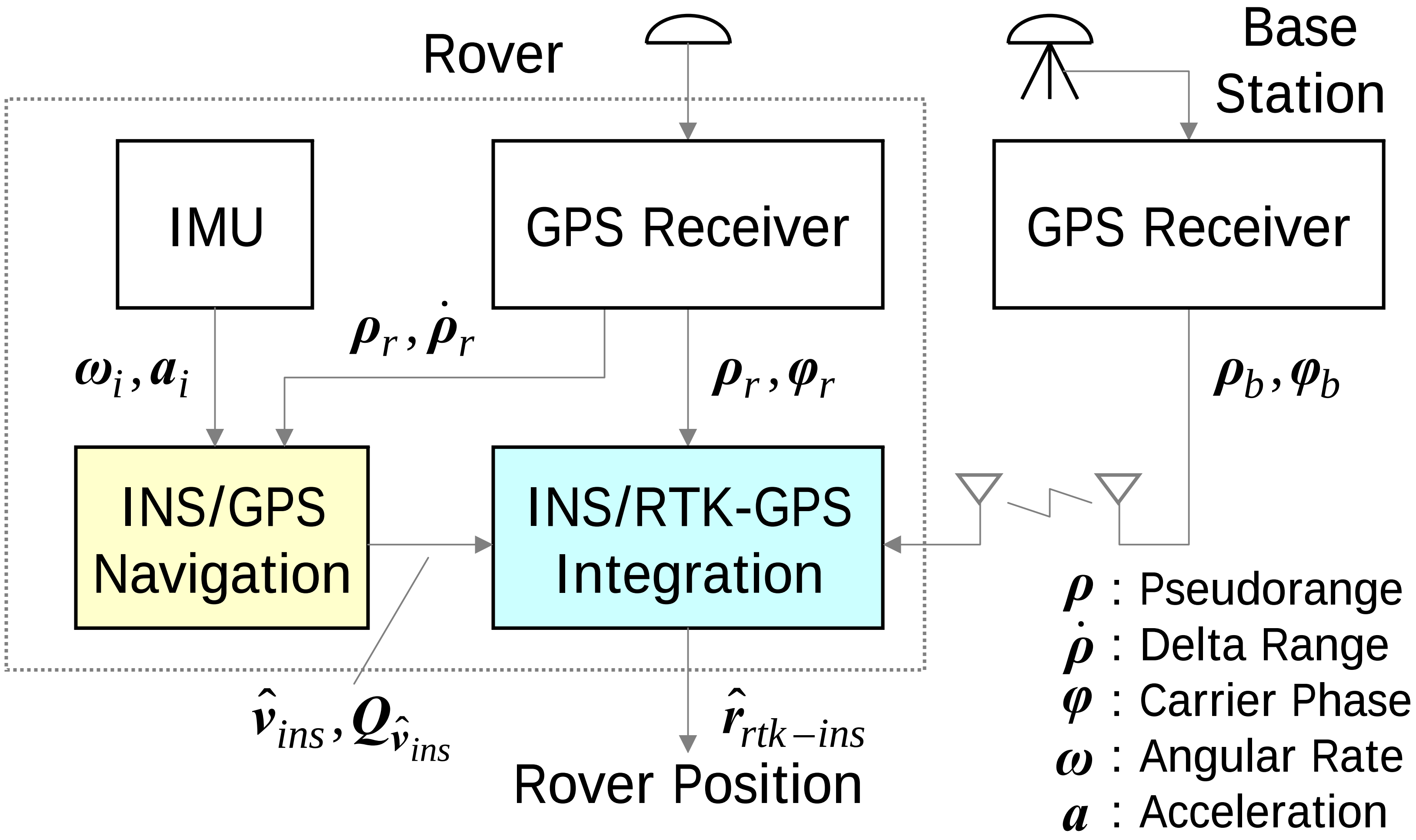
Conventional RTK-GPS



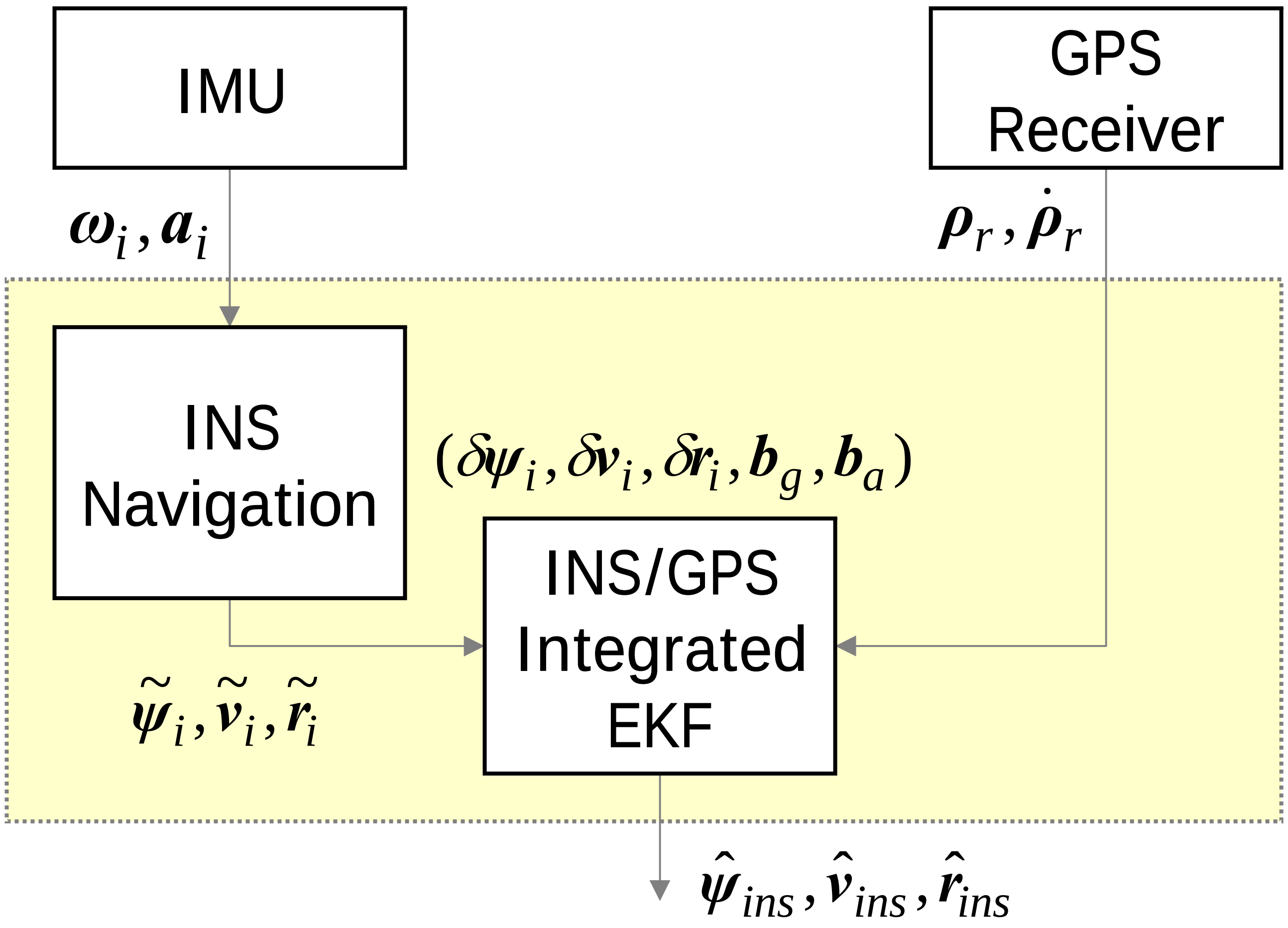
ρ : Pseudorange

φ : Carrier Phase

INS Aided RTK-GPS



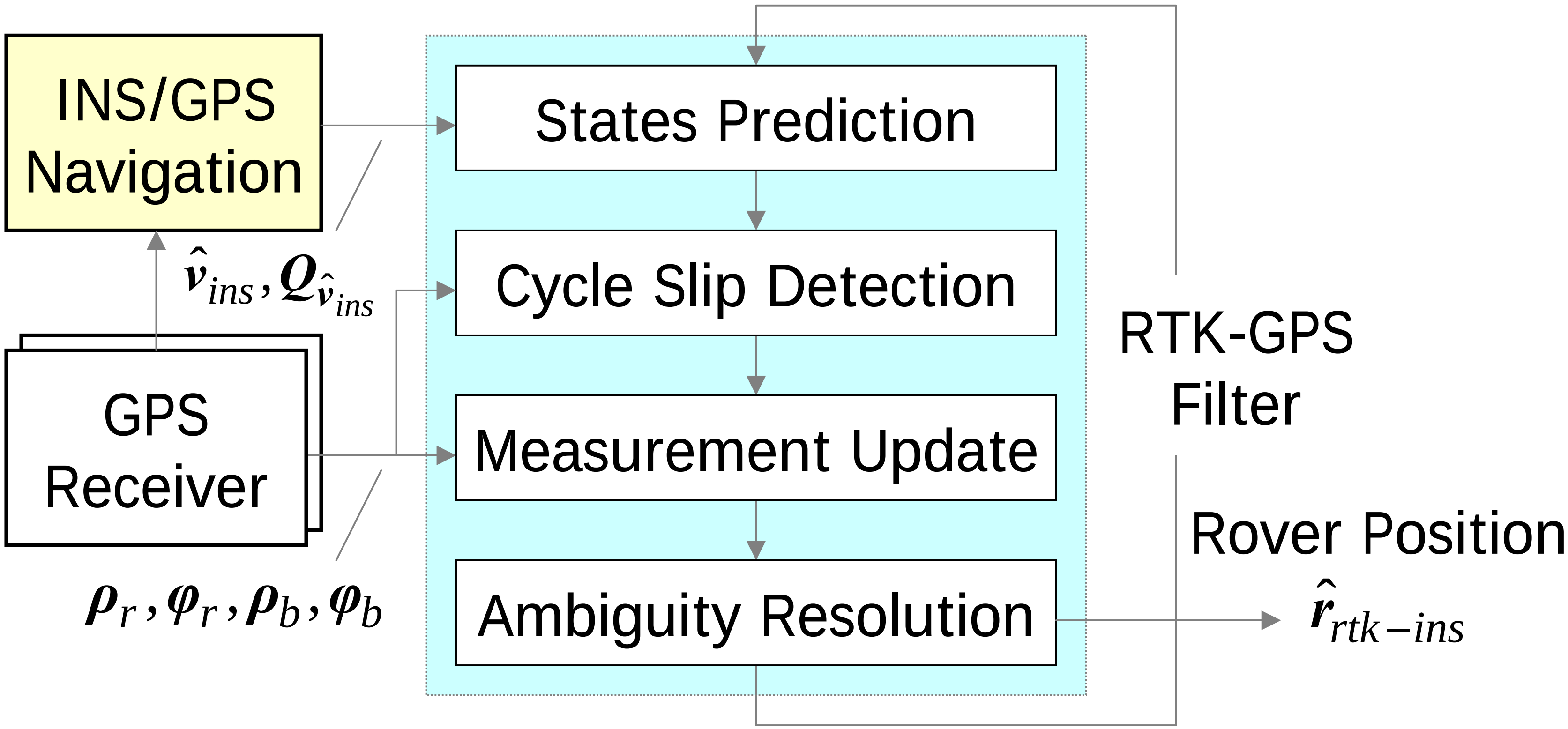
INS/GPS Navigation



INS/RTK-GPS Integration

$$\hat{\boldsymbol{r}}_k(-) = \hat{\boldsymbol{r}}_{k-1}(+) + (\hat{\boldsymbol{v}}_{ins,k} + \hat{\boldsymbol{v}}_{ins,k-1})(t_k - t_{k-1})/2$$

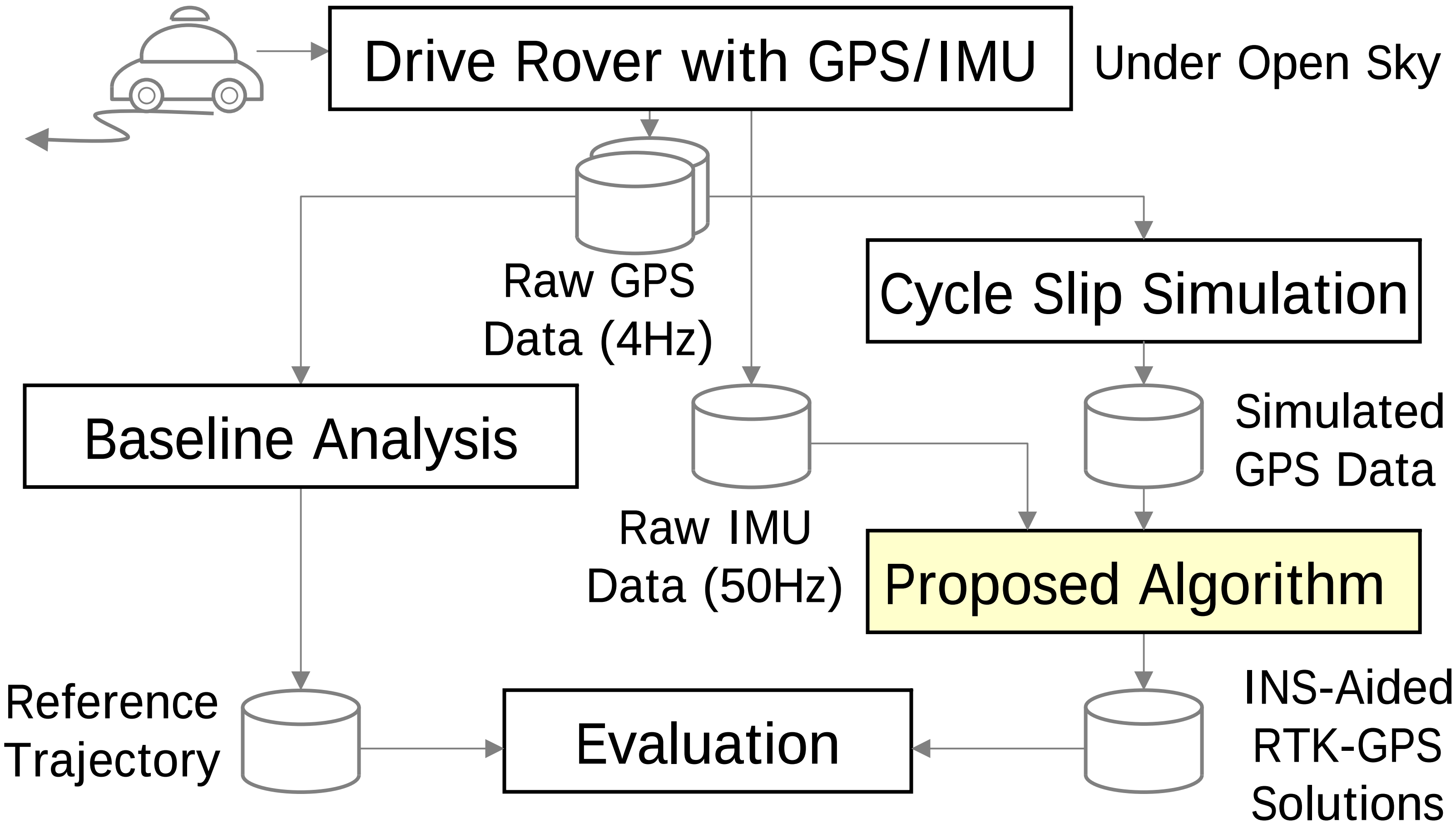
$$\boldsymbol{P}_{r,k}(-) = \boldsymbol{P}_{r,k-1}(+) + (\boldsymbol{Q}_{\hat{\boldsymbol{v}}_{ins},k} + \boldsymbol{Q}_{\hat{\boldsymbol{v}}_{ins},k-1})(t_k - t_{k-1})/2$$



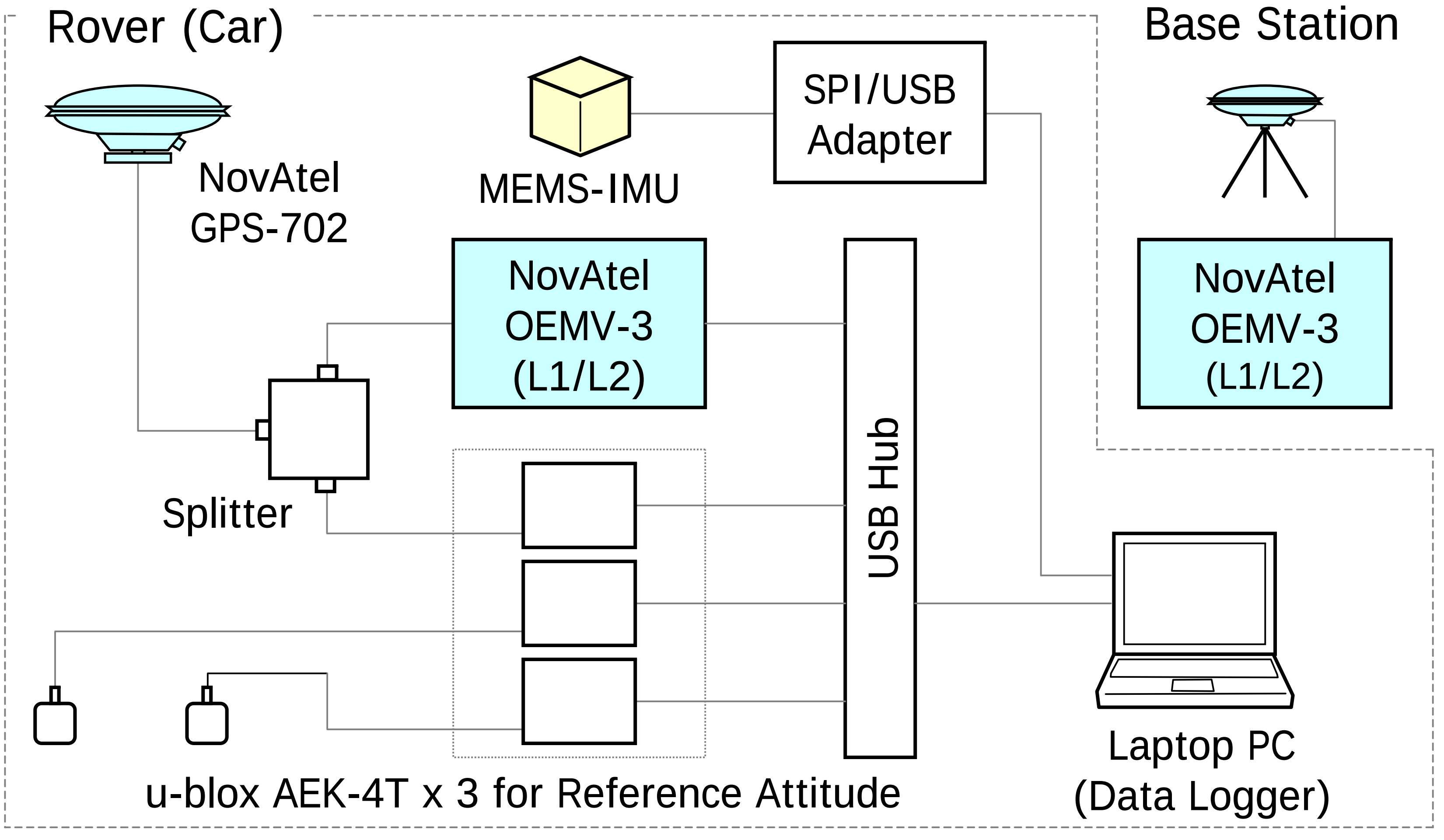
Cycle Slip Detection/Fixing

- Cycle slip detection
  - Innovation test in RTK-GPS Filter
  - Test threshold is determined by position covariance with INS velocity covariance
- Cycle slip fixing
  - Slip amounts are estimated as float values with predicted position aided by INS
  - Estimated slips are resolved into integer values in usual RTK-GPS ILS solver process

Experiments



Configuration



MEMS-IMU

- Analog Devices ADIS16354
  - Tri-axis Gyros+Accelerometers
  - 23 x 23 x 23 mm
  - Range: ±300°/s, ±1.7g
  - Embedded ADC/Filter, SPI I/F
  - Factory calibrated sensitivity, alignment with temperature sensors
  - Price: $700/sample

Snapshots

Reference Trajectory

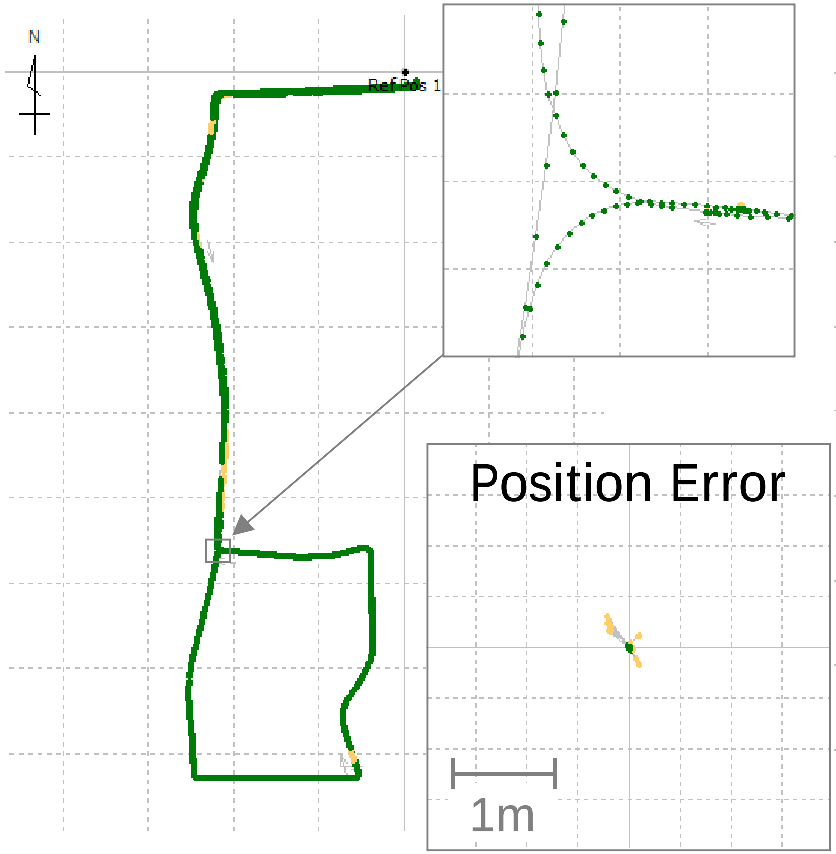
2008-09-05
5:42:00-
5:49:30 GPST
7min 30s

Baseline
Length:
0.0-0.9 km

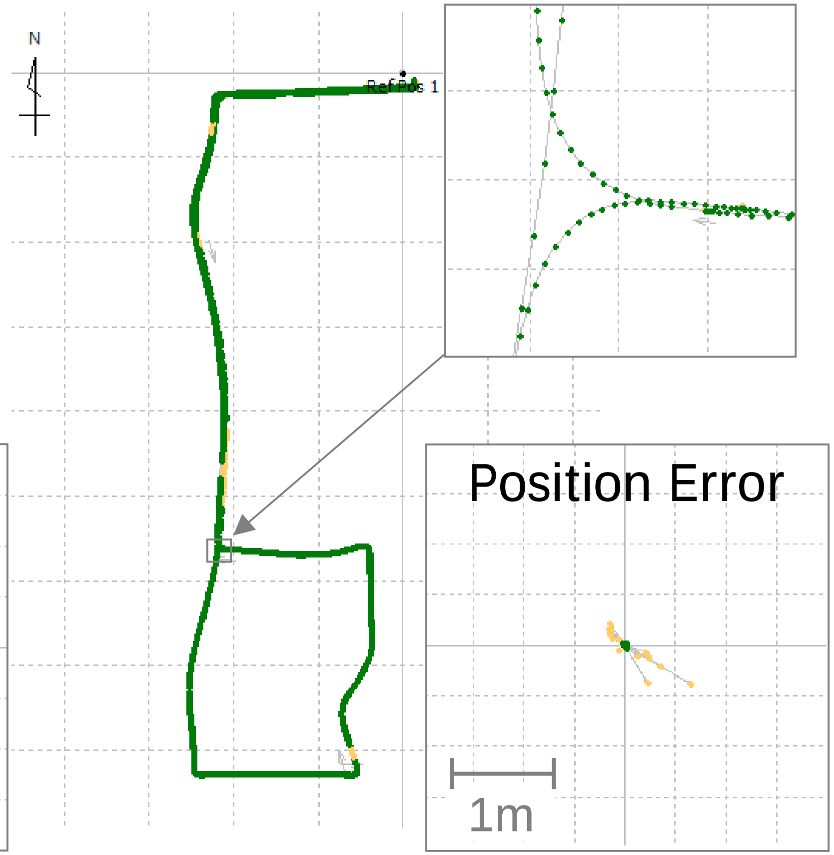
Simulated Cycle Slips

(1) A Few Cycle Slips

Without INS



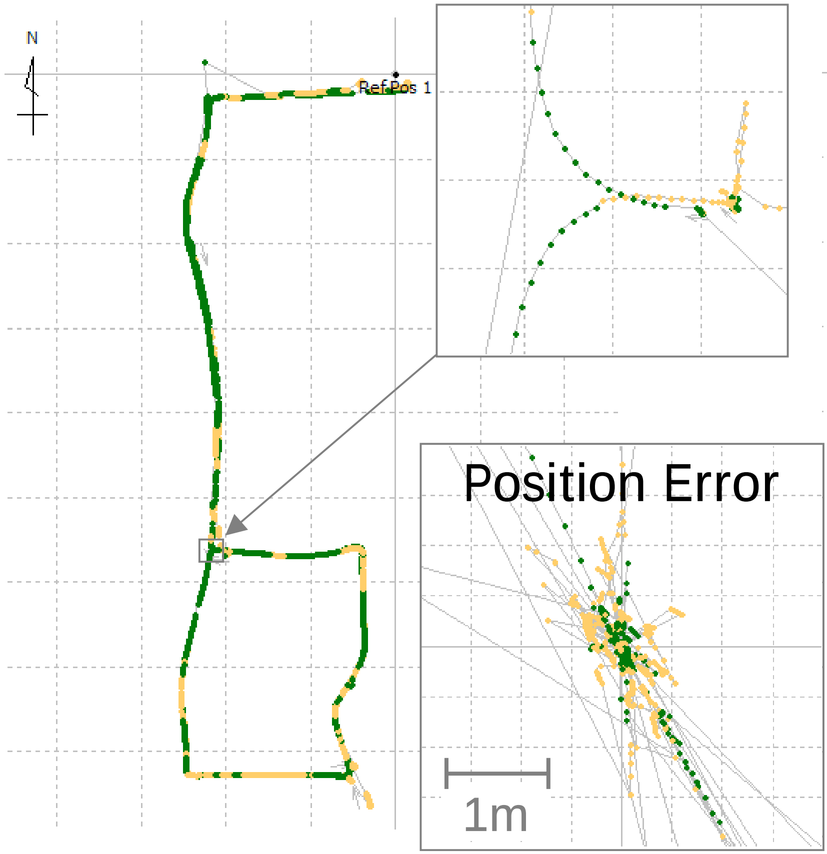
With INS



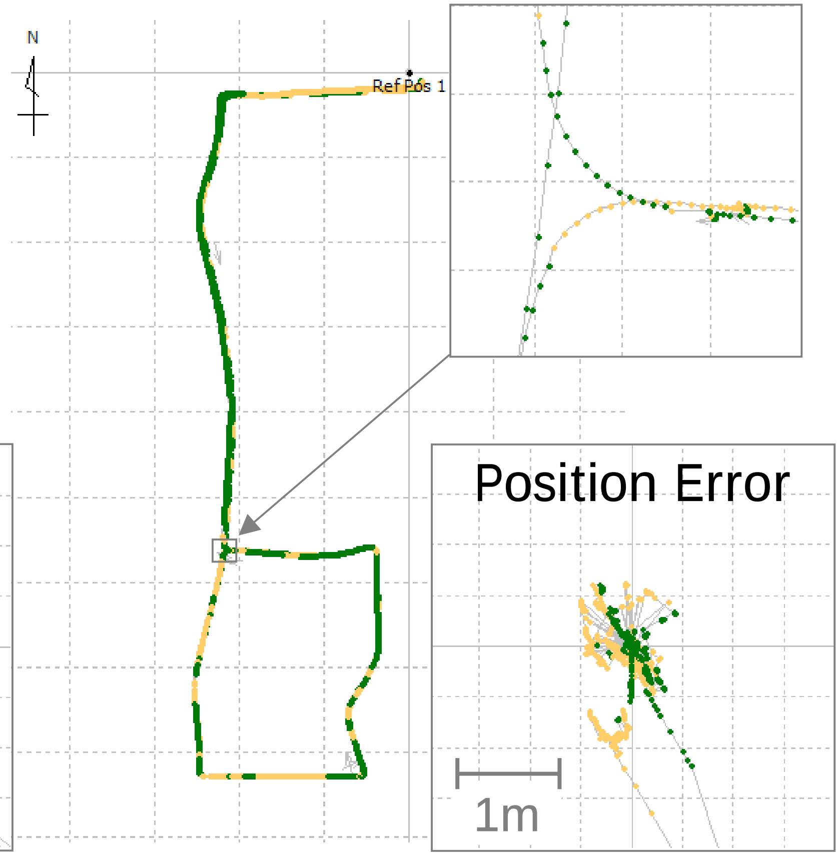
● Fixed Solution ● Float Solution

(2) Moderate Cycle Slips

Without INS

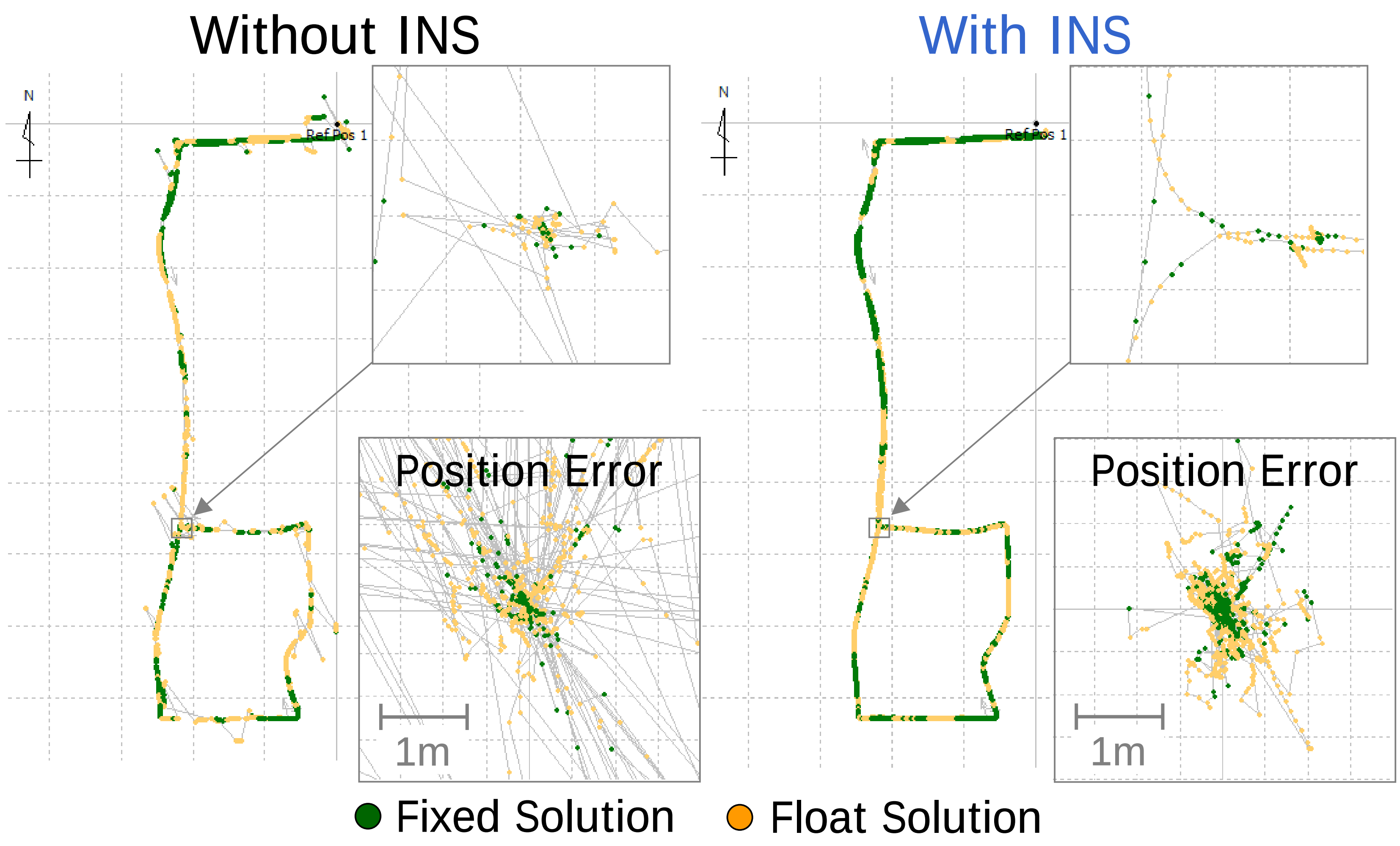


With INS



● Fixed Solution ● Float Solution

(3) Extreme Cycle Slips



Solution Availability/Accuracy

Case	Without INS			With INS		
	Availability of Fixed Sol. / RMS Error E-W,N-S,U-D (cm)					
(1) A Few Slips	92.9%			93.0%		
	0.3	0.4	0.5	0.3	0.4	0.6
(2) Moderate Slips	58.8%			64.5%		
	74.2	125.6	57.5	7.7	13.4	12.9
(3) Extreme Slips	28.4%			48.4%		
	346.6	573.4	306.4	16.2	24.3	26.3

Summary and Conclusions

- A simple integration scheme of GPS/INS Navigation to RTK-GPS filter is proposed
- Cycle slip detection and fixing aided by INS is feasible and effective especially on the condition with extreme cycle slips
- Needs more experiments in the real situations with ill multipath environment
- Direct integration of INS measurements to RTK-GPS filter improves the performance?