Precise Point Positioning and Path to Mass-Market Applications

Yang Gao, University of Calgary

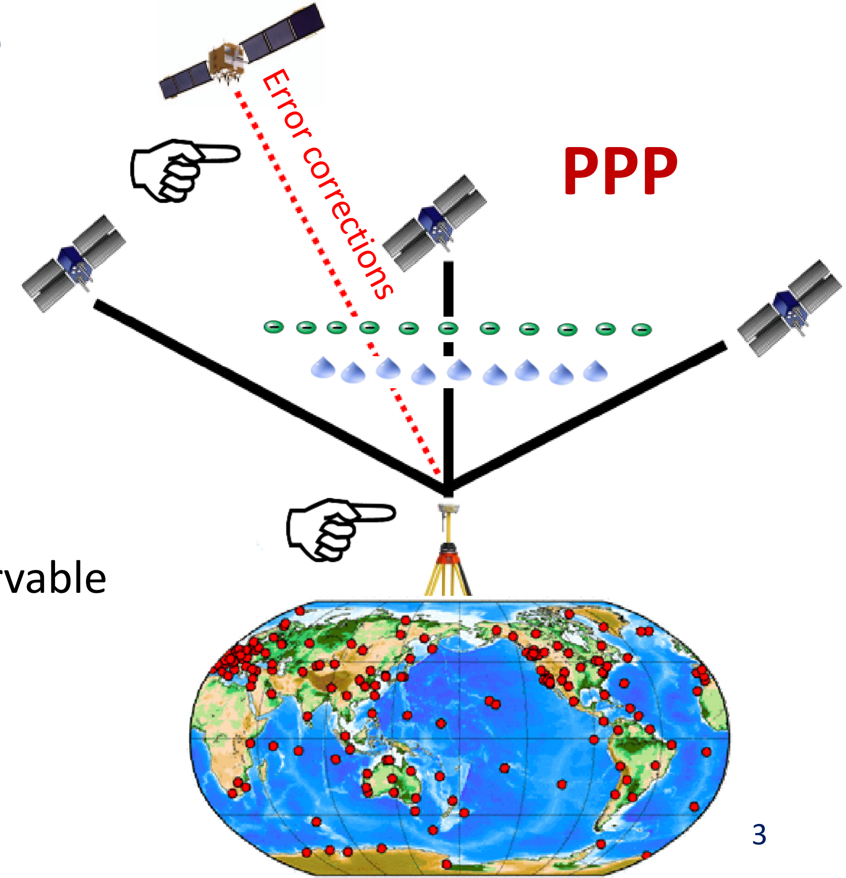
ION Alberta Section
Calgary, Alberta, Canada, May 5, 2020

Outline

- Precise Point Positioning (PPP)
- Mass-market Opportunity for PPP
- Technology Advances and Gaps
- Path to Mass-market Applications
- Latest Progress
- Summary and Looking Ahead

precise positioning with a single GNSS receiver!

- ✓ State-Space (SSR) Error Corrections
  - Orbit and clock corrections
  - Atmospheric corrections
  - Bias corrections
  - …
- ✓ Advanced Positioning Algorithms
  - Phase measurements as principal observable
  - Positioning models
  - Integer ambiguity resolution
  - Augmentation techniques
  - …



PPP Applications

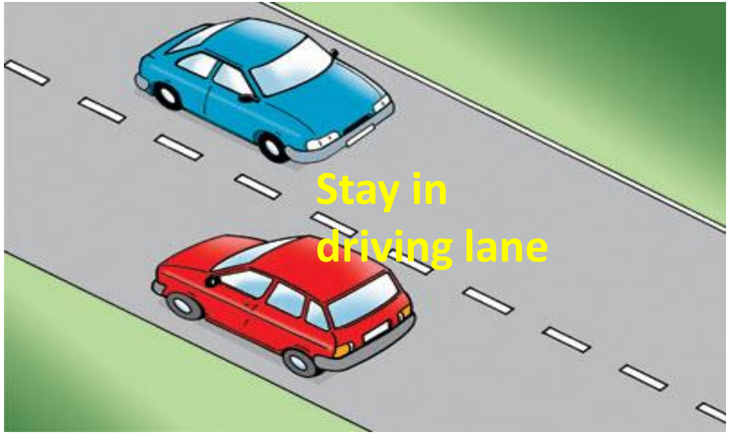
- ✓ **offshore dynamic positioning**
- ✓ **agriculture**
- ✓ **scientific and engineering applications**
  - Geodetic positioning
  - Airborne mapping
  - Deformation monitoring
  - Meteorology
  - Space weather
  - Timing
  - …

Beyond positioning

Mass-market opportunity for PPP

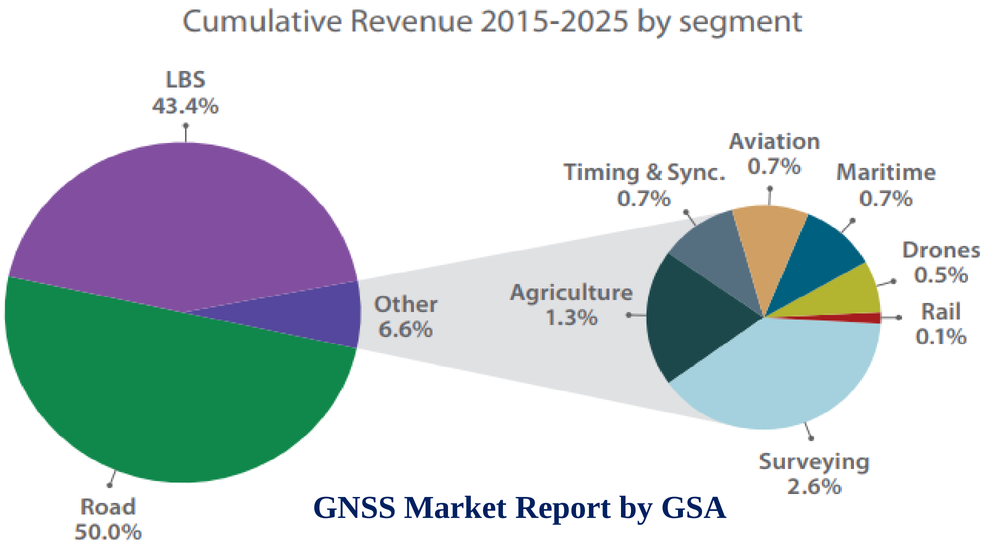
Market demand

Many mass-market applications require precise position information



Mass-market Opportunity for PPP

Market size



GNSS Market Report by GSA

Road and LBS dominate all other market segments in terms of cumulative revenue (93%)

~ 6 billion GNSS devices in 2017
~ 8 billion by 2020

Mass-market Opportunity for PPP

Industry move

"Most interesting in the location technology competitive landscape is the involvement of Internet giants Google and Alibaba" -- ABI Research (Oct, 2016)

Carrier phase measurements available from smartphones (2016)

Correction services business (2016)

Broadcom announces world's first dual frequency GNSS receiver (2017)

Xiaomi released world's first smart phone with dual-frequency GPS (2018)

Softbank plans satnav precise positioning services (2019)

? 2020

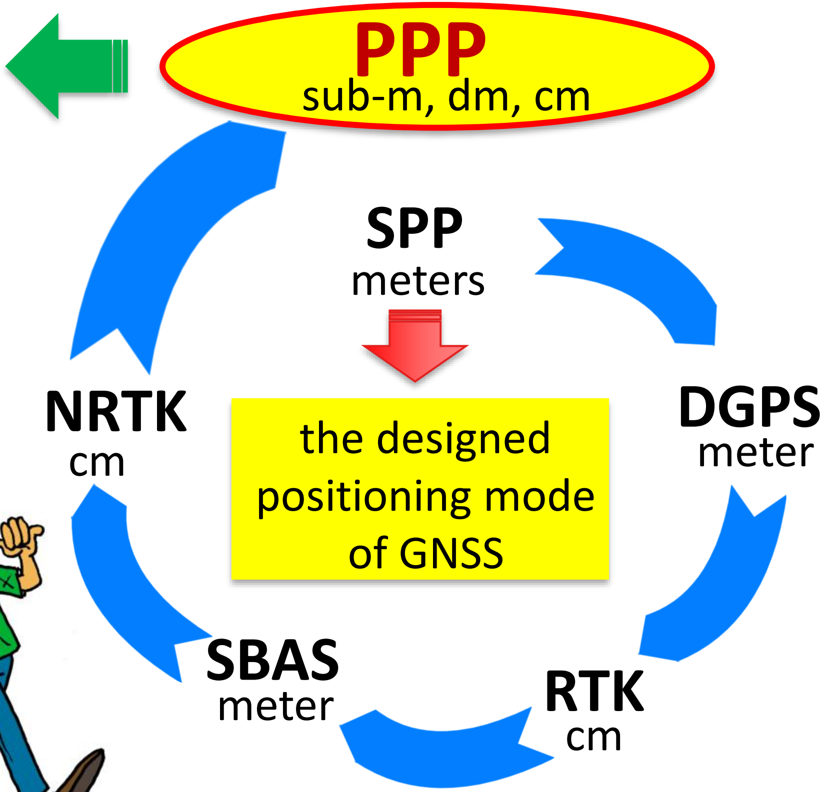
They break down the barriers between professional and consumer markets

Mass-market Opportunity for PPP

SCHULICH School of Engineering

PPP is a desired precise positioning approach for mass-market applications

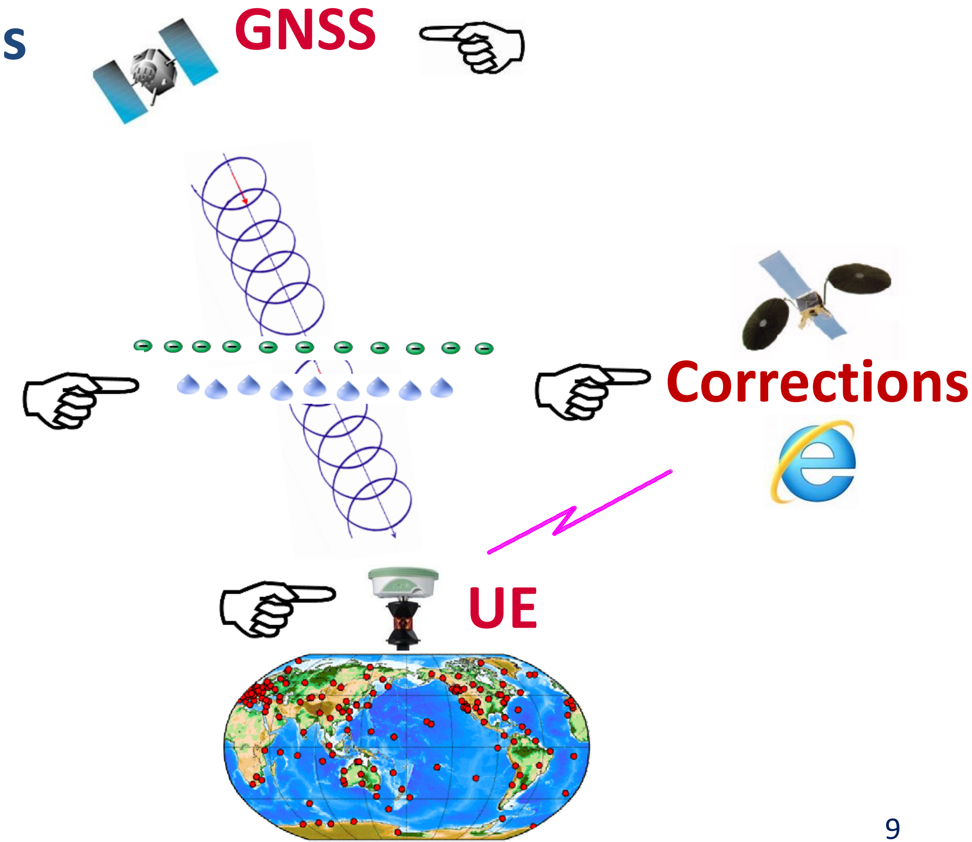
- ✓ single receiver operation like SPP
- ✓ no baseline length limitation
- ✓ cost-effectiveness
- ✓ positioning models supporting scalability (signals, accuracies and services)



PPP Technology Advances and Gaps

Advances made in all aspects with increased adoption

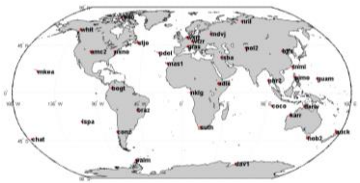
- ✓ Multi-constellations and multi-frequencies
- ✓ SSR corrections and services
- ✓ Positioning models
- ✓ Integer ambiguity resolution
- ✓ Global, regional and local augmentation techniques
- ✓ …

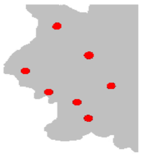
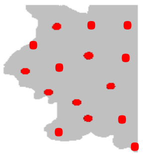


PPP Technology Advances and Gaps

Continuing evolution of PPP techniques

PPP-RTK



PPP (global network) → **PPP (wide-area network)** → **PPP (regional network)** → **PPP (Local network)**

~ 0.5 h | ~20 min | ~min | ~sec

cm-level

Convergence/AR time

Positioning platform/environment

- ✓ Low-dynamics
- ✓ Open-sky

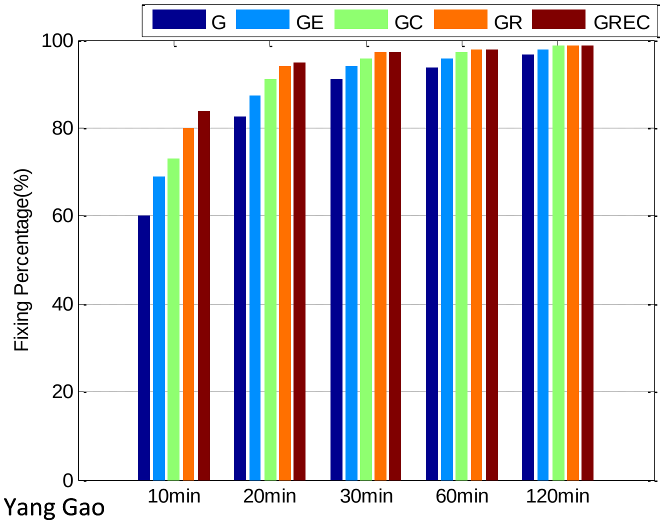
Algorithm development often based on IGS data and simulated dynamics

The gap: mass-market applications are in high dynamics modes and environments with poor visibility, multipath, loss of corrections

Applications

- ✓ Long convergence time
- ✓ post-mission allowed
- ✓ re-surveys allowed

Low availability for mass-market applications



The gap: mass-market applications require real-time, instant and continuous precision solutions

PPP Technology Advances and Gaps

Positioning receivers

- High-end receivers
- Expensive

- Low-cost
- higher noise level
- poor oscilator
- sensitive to dynamics
- frequent cycle slips
- biases in mesurmeents
- small antenna

The gap: existing precise positioning techniques are not designed to work with low-cost sensors

Path to Mass-Market Applications

Importance of "instant precision"

Precise positioning techniques that require convergence time are not applicable to mass-market applications

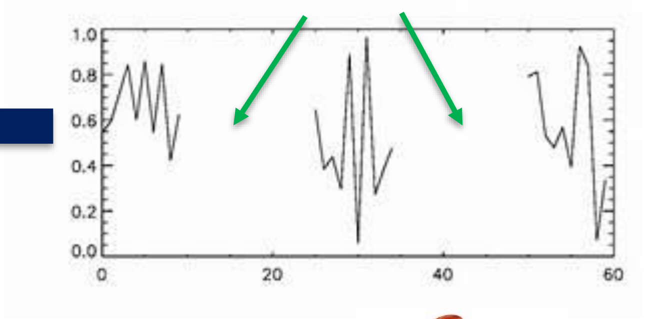
Instant PPP:
precise positioning techniques without convergence

Path to Mass-Market Applications

Importance of "continuous precision"

Precise positioning techniques that provide low availability are not applicable to mass-market applications

precise solution not available



Instant PPP:
precise positioning techniques without convergence

Continuous Precision:
multi-sensor integration

Path to Mass-Market Applications

Importance of "trusted precision"

Precise positioning techniques unable to provide integrity data are not applicable to mass-market applications

Instant PPP → Continuous Precision → Trusted Precision →

Importance of “innovation”

Mass-market precise positioning demands novel solutions to support mass-market precise positioning

- Beyond “tuning of existing”, “incremental improvement” “simulated kinematic”, “IGS data”, “aviation integrity”, ……
- Accelerate PPP products and services development with measured milestones
- Develop new business and service models

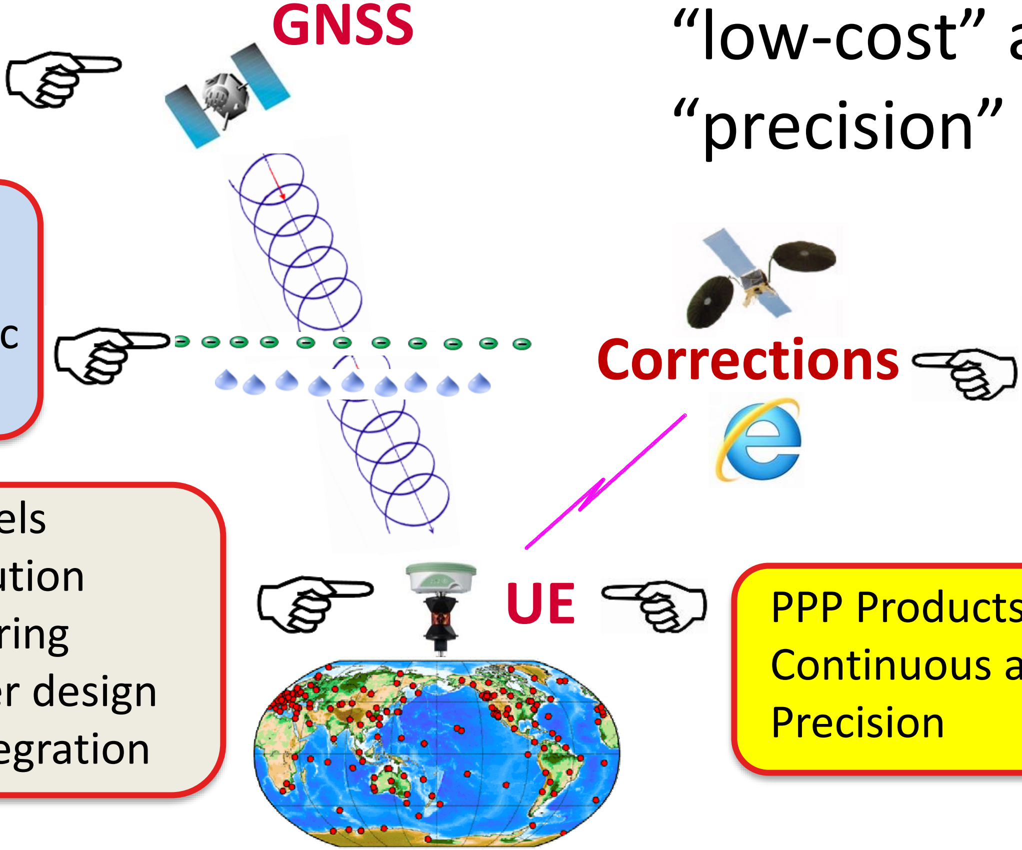
Latest Progress

"low-cost" and "precision"

Navigation messages

- Global ionospheric models
- Regional atmospheric augmentation

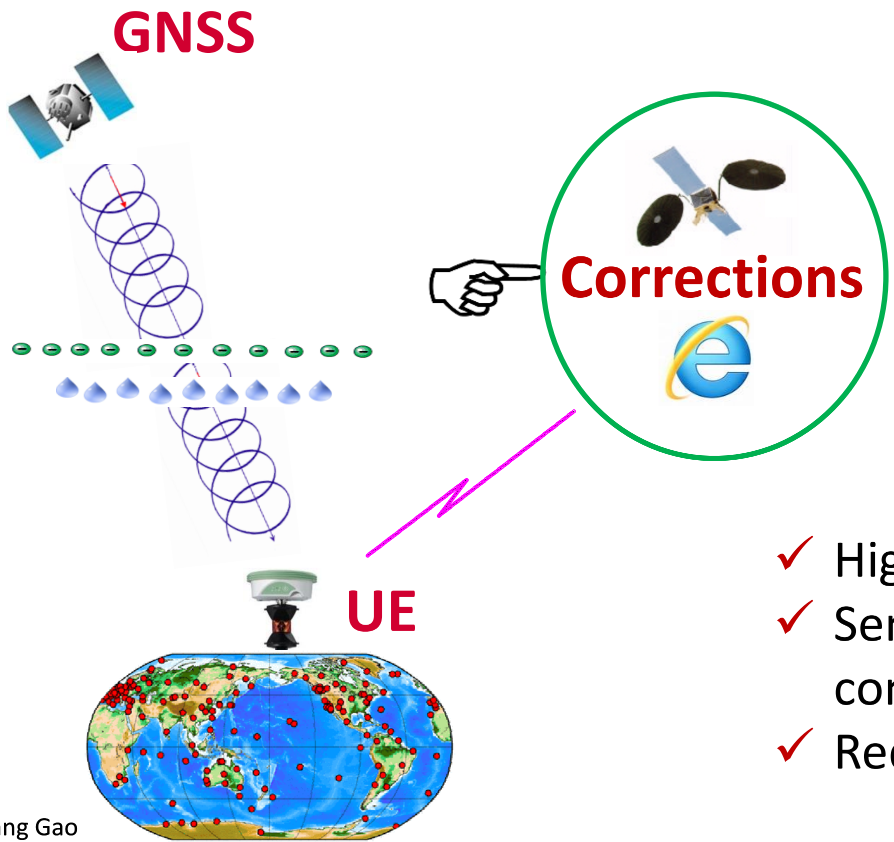
- Positioning models
- Ambiguity resolution
- Integrity monitoring
- Low-cost receiver design
- Multi-sensor integration



High Scalability and Availability Correction Messages

PPP Products for Instant, Continuous and Trusted Precision

Latest Progress



Correction messages have to be broadcast to users at high update rate (e.g. orbit/clock corrections @ 5 s)

- ✓ High comm bandwidth/cost
- ✓ Sensitive to correction loss (server, comm link, environment)
- ✓ Reduced precision availability

Latest Progress

The gap: mass-market applications are in high dynamics modes and environments with poor visibility, multipath, loss of corrections

There is a need to reduce update rate of corrections with scalability to support mass-market applications

- ✓ Low comm bandwidth/cost
- ✓ Resistant to correction loss
- ✓ Increased precision availability

→ Broadcasting initial conditions

Orbit Initial Conditions:

→position: $\mathbf{r}_0 = \mathbf{r}(\mathrm{t}_0)$

→velocity: $\dot{\mathbf{r}}_0 = \dot{\mathbf{r}}(\mathrm{t}_0)$

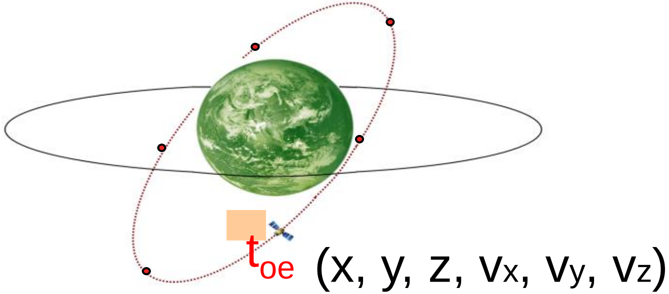
→Others

$$\ddot{\mathbf{r}} = -\mathrm{GM}\frac{\mathbf{r}}{|\mathbf{r}|^3} + \mathbf{a}(\mathrm{t}, \mathbf{r}, \dot{\mathbf{r}}, \mathrm{SRP}, \ldots) + \ldots$$

$$\mathbf{r} = \mathbf{r}(\mathbf{t}_0) + \int_{\mathbf{t}_0}^{\mathbf{t}} \left[\dot{\mathbf{r}}(\mathbf{t}_0) + \int_{\mathbf{t}_0}^{\mathbf{t}} \ddot{\mathbf{r}}(\mathbf{t})\mathbf{dt} \right] \mathbf{dt}$$

update rate by hours

daily update rate



Clock initial conditions:

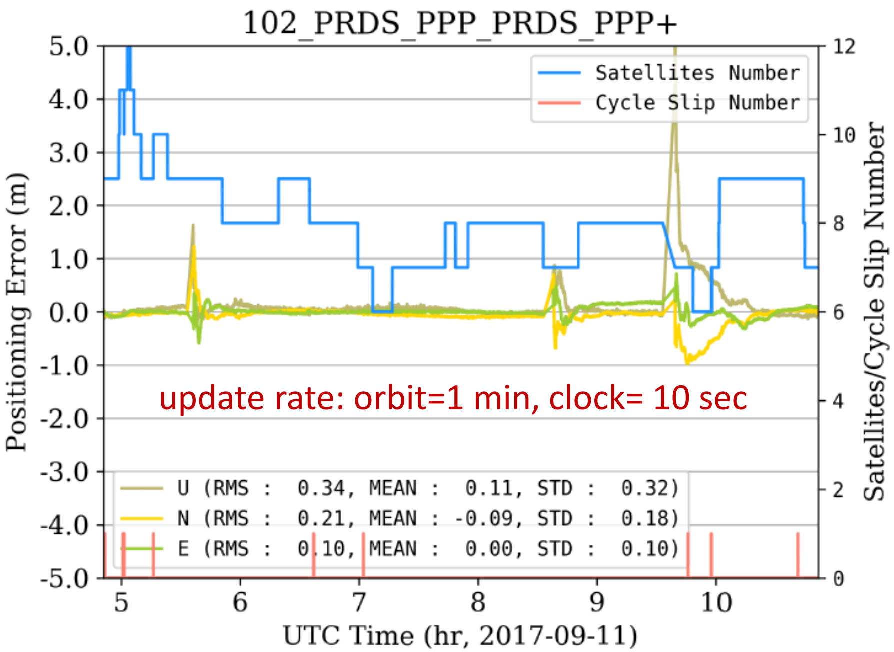
→polynomial: $\mathbf{p}_0 = \mathbf{p}(\mathrm{t}_0)$

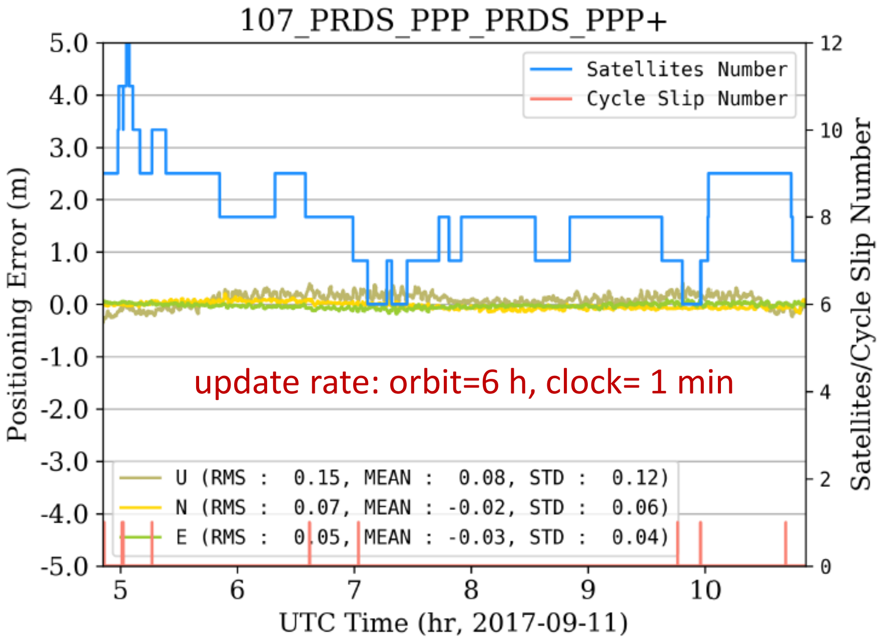
→harmonics: $\mathbf{h}_0 = \mathbf{h}(\mathrm{t}_0)$

→others

$$\mathrm{c} = \mathrm{c}(\mathbf{p}(\mathrm{t}_0), \mathrm{dt}) + \mathrm{c}(\mathbf{h}(\mathrm{t}_0), \mathrm{dt}) + \ldots$$

Latest Progress





Latest Progress

→ Broadcasting Improved Legacy Navigation Message (ILNAV)

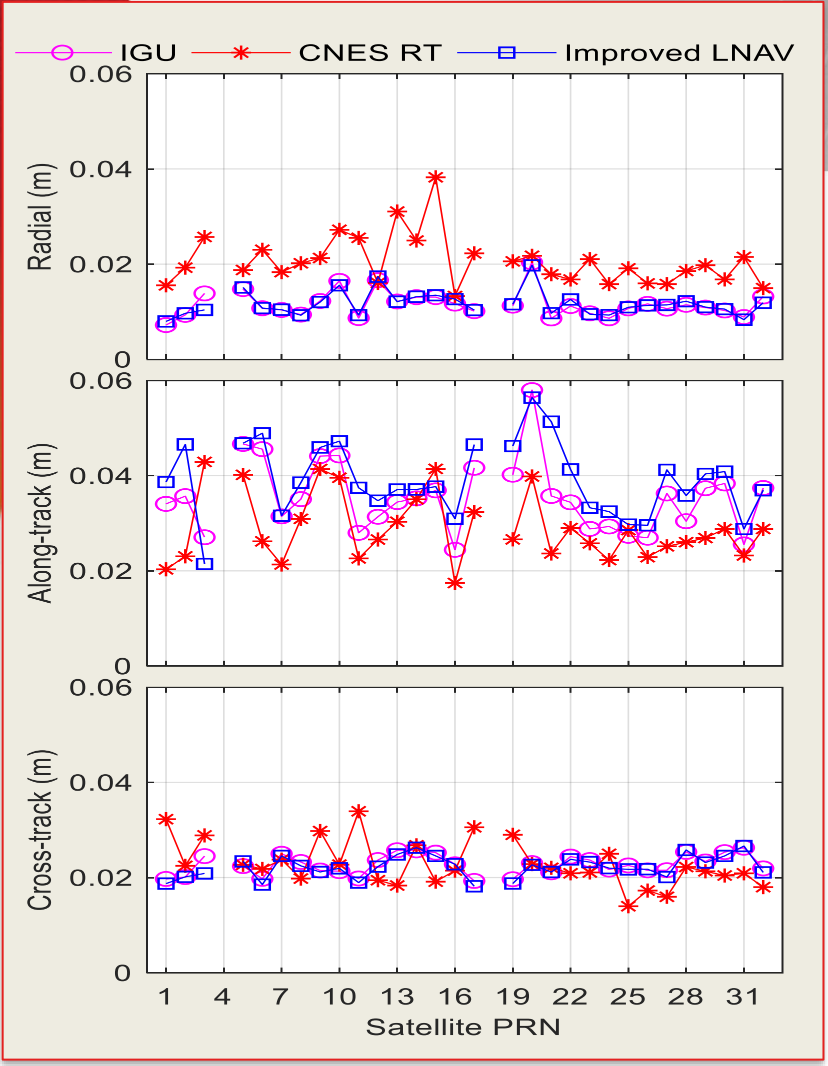
$$\begin{cases} t_{oe}, \sqrt{A}, e, i_0, \Omega_0, \omega, M_0, IDOT, \Delta n, \dot{\Omega}, C_{rc}, C_{rs}, C_{ic}, C_{is}, C_{uc}, C_{us} \\ t_{oc}, a_{f0}, a_{f1}, a_{f2} \end{cases}$$

- **Improved LNAV:** a high-precision version of the standard LNAV by leveraging the LNAV satellite orbit and clock representation
- ILNAV orbit and clock parameters are estimated using real-time precise products
- Follow RTCM message type 1019 for dissemination

ILNAV can support scalable and reduced update rate of orbit and clock corrections.

Fully consistent representation, dissemination, and user algorithms as standard LNAV

Latest Progress

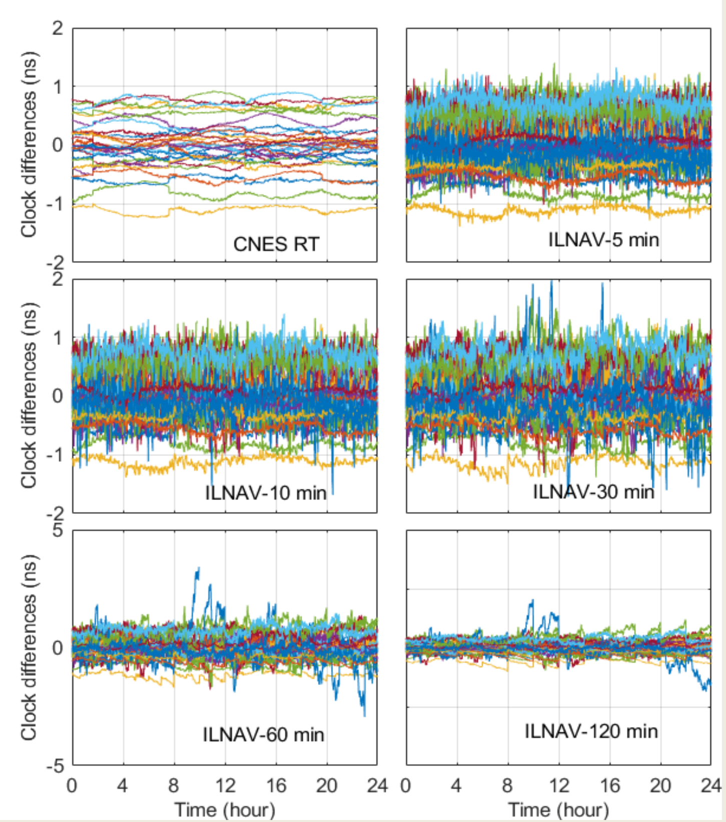


ILNAV orbit accuracy (m)

Orbit type	R	A	C	3D
IGU	0.011	0.035	0.022	0.043
CNES RT	0.020	0.028	0.022	0.041
Improved LNAV	0.012	0.039	0.023	0.047

ILNAV can provide precise satellite orbit corrections with 3D accuracy better than 0.05 m

Latest Progress

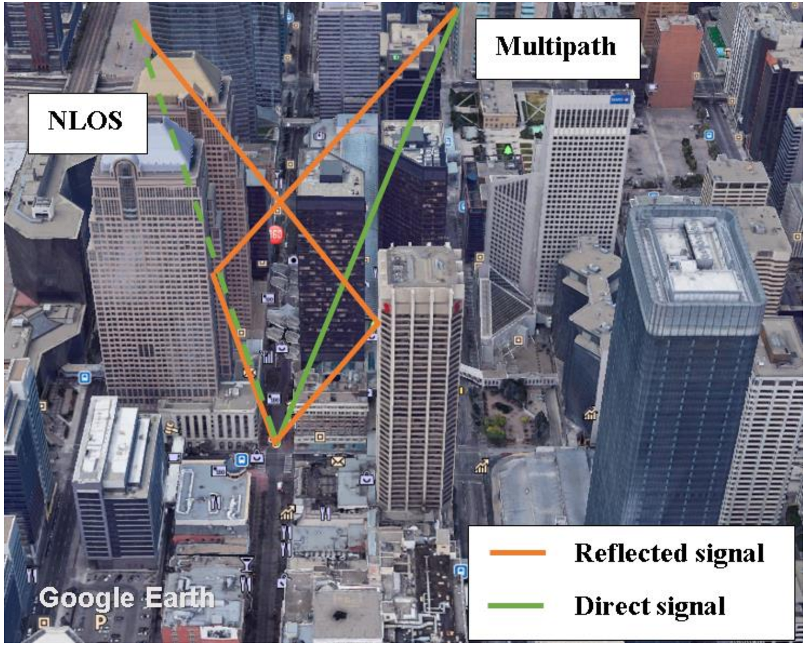


ILNAV clock accuracy (m)

Update interval	IIF Rb	IIF Cs	IIR/M Rb	Average (all)
5 minutes	0.024	0.069	0.046	0.040
10 minutes	0.027	0.097	0.052	0.047
30 minutes	0.034	0.168	0.062	0.060
1 hour	0.045	0.247	0.072	0.074
2 hours	0.067	0.354	0.092	0.101
CNES RT	0.021	0.024	0.021	0.021

ILNAV can provide clock corrections better than 0.1 m with update interval of 1 hour.

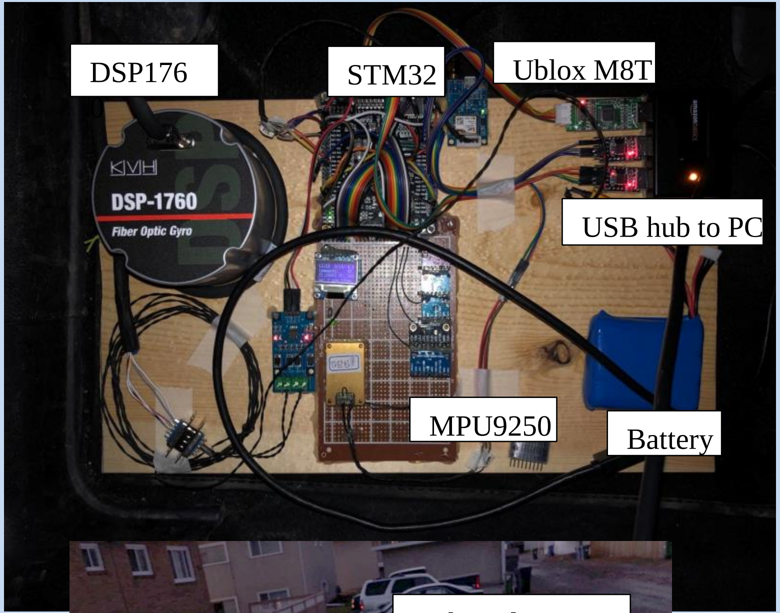
Importance of "continuous precision"

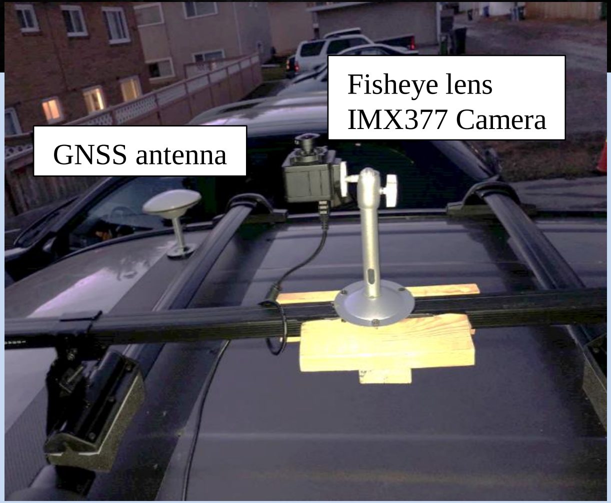


Tight integration of GNSS and SLAM to enable continuous precise positioning in Urban Environments

- ✓ Mitigate multipath errors
- ✓ Restore GNSS NLOS observations
- ✓ Increase precision availability

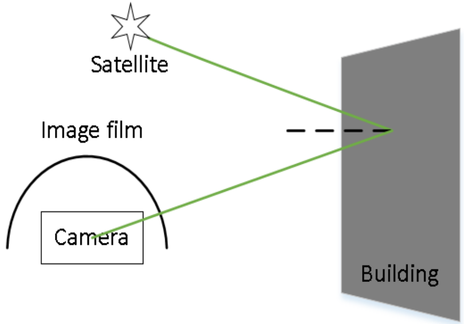
Pushing "precision" into urban environments


DSP176
STM32
Ublox M8T
USB hub to PC
MPU9250
Battery
DSP-1760
Fiber Optic Gyro

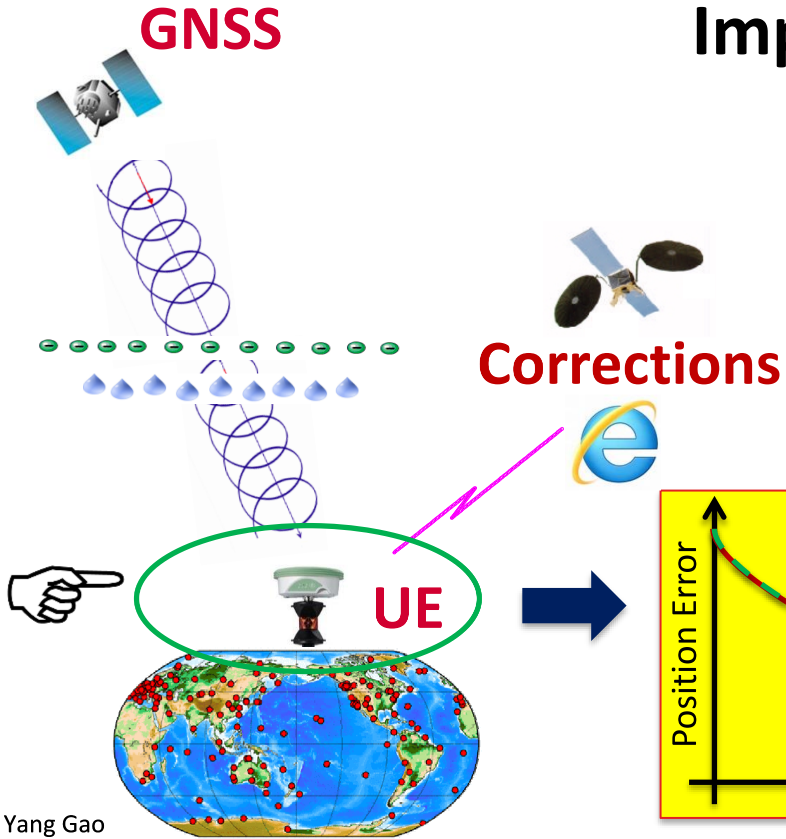

Fisheye lens
IMX377 Camera
GNSS antenna


Robust ray tracing

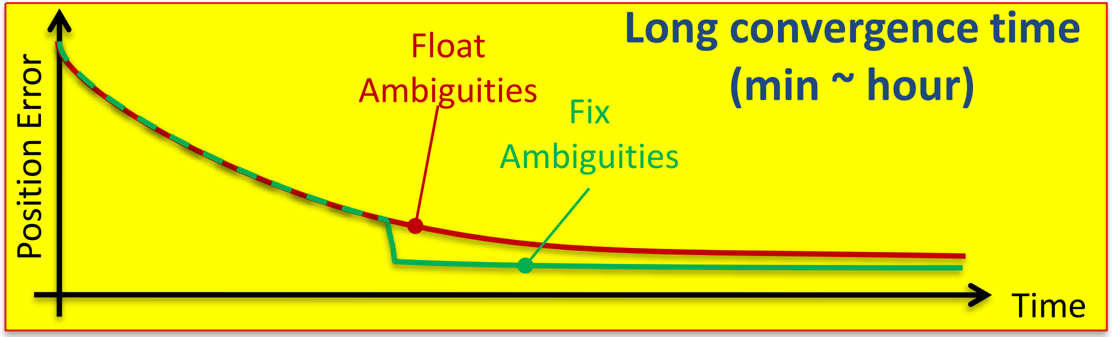

correct
incorrect


Satellite
Image film
Camera
Building

Latest Progress



Importance of "instant precision"



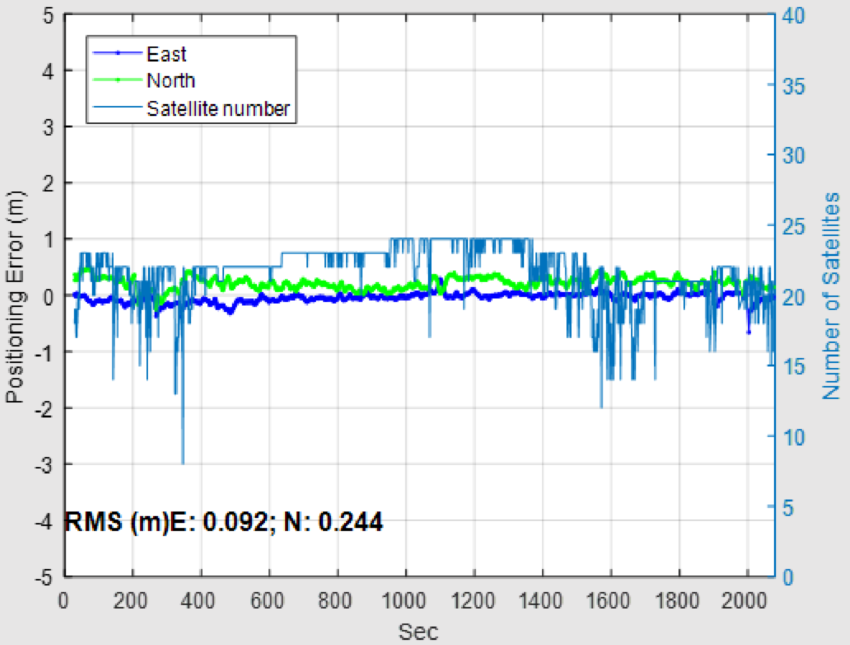
Instant PPP (IP3)

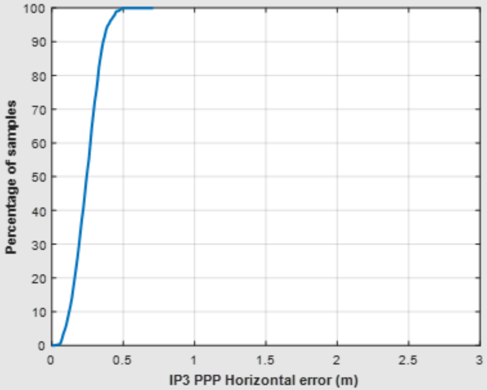
- ✓ Fast convergence within seconds
- ✓ Support single and dual frequency
- ✓ Support all GNSS constellations
- ✓ Worldwide availability of consistent navigation solutions
- ✓ Insensitive to the latency and loss of corrections
- ✓ Firmware library can be customized for different receivers/processors

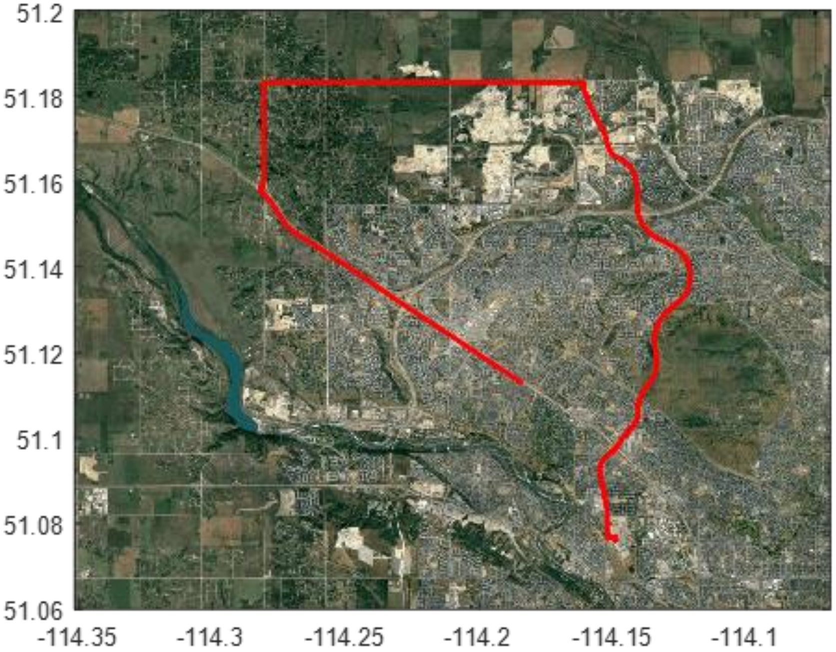
PPI’s Low-cost Precision GNSS Solution

Profound Positioning

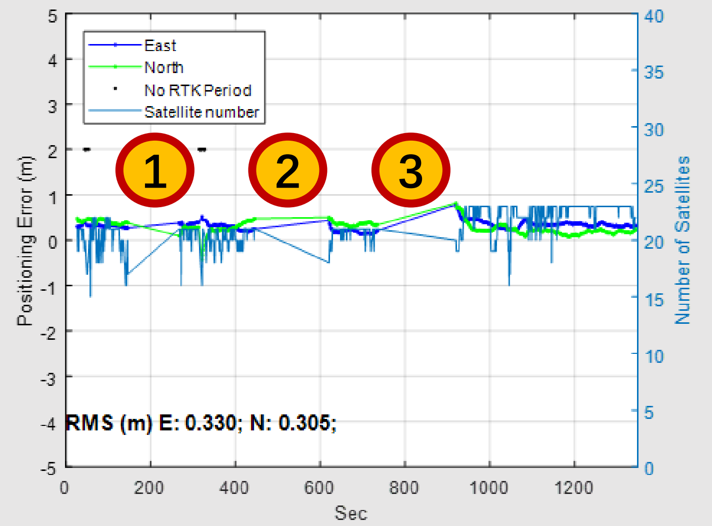
Tests in sub-urban areas

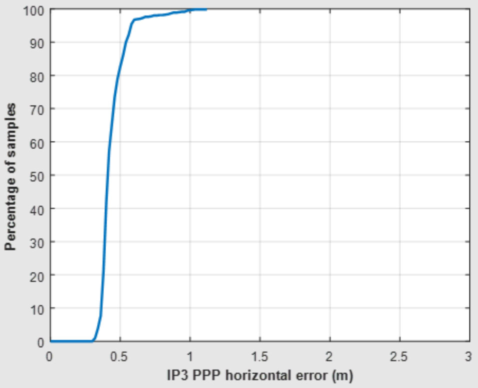


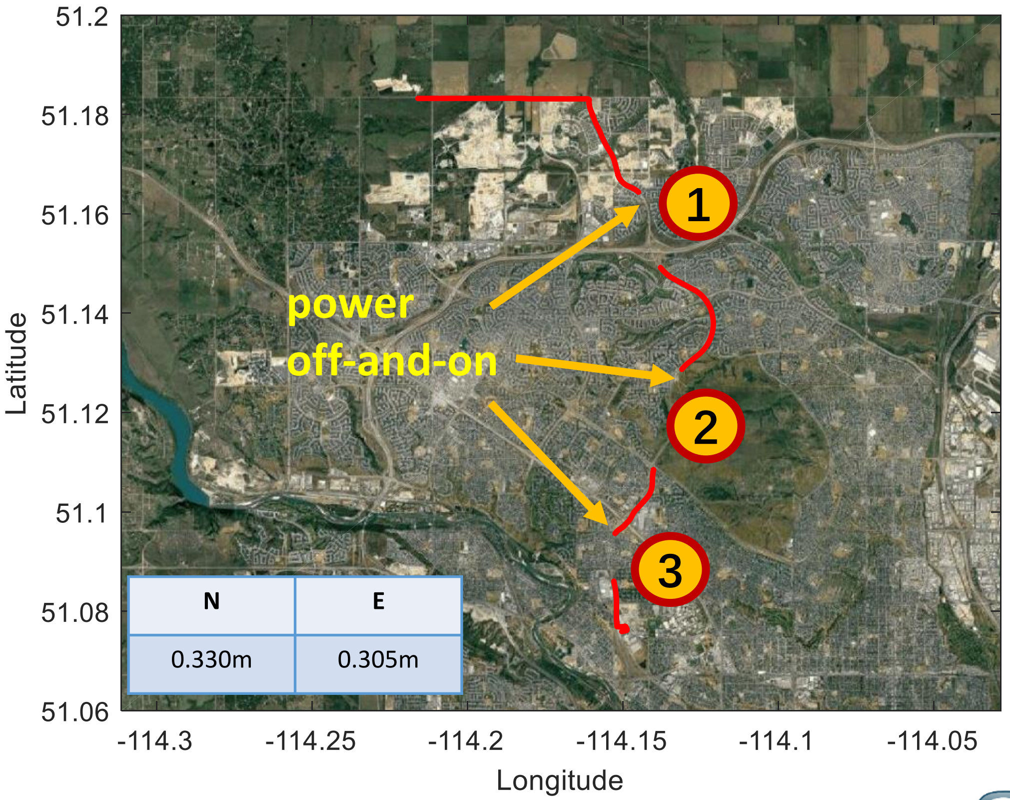




Power-off-and-on convergence test

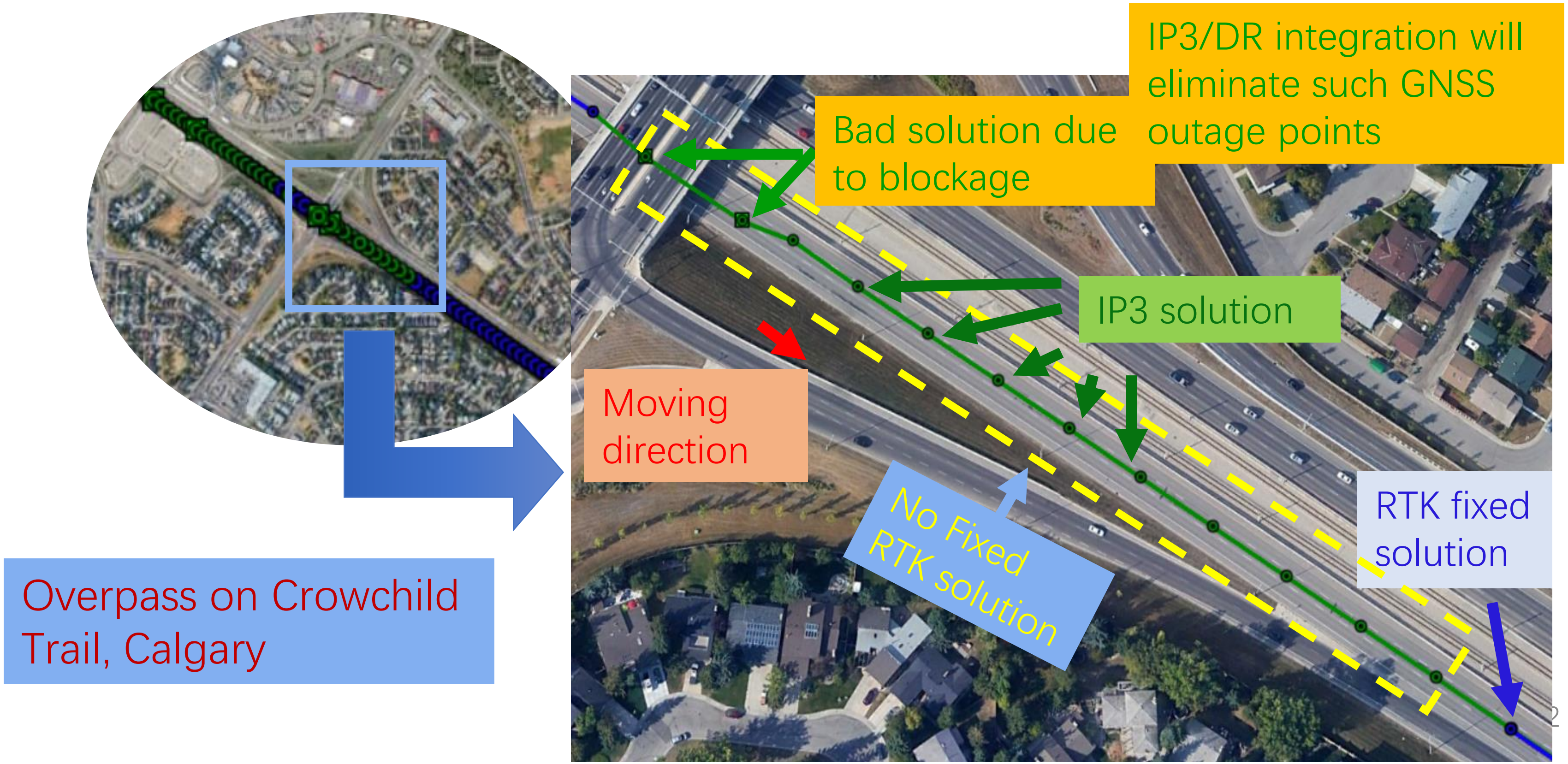






N	E
0.330m	0.305m

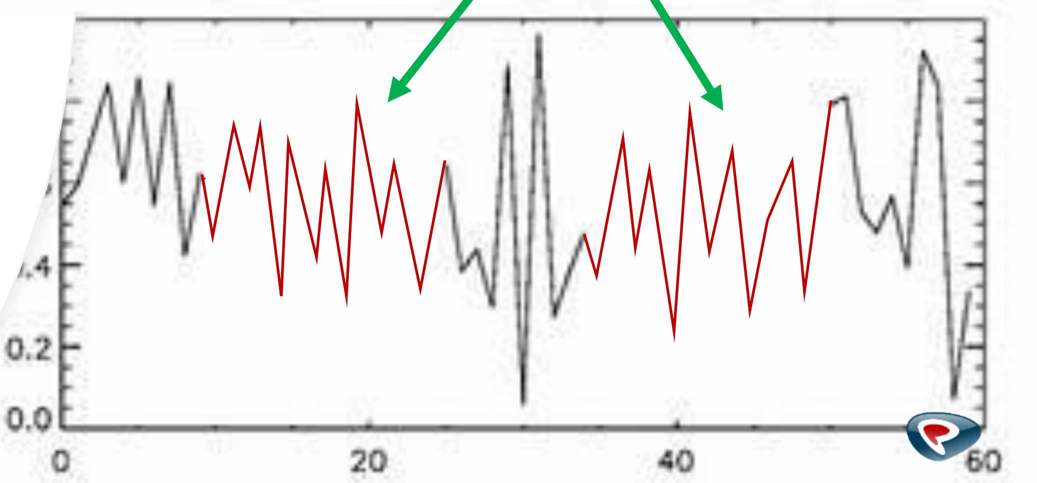
Fast re-convergence after passing bridge



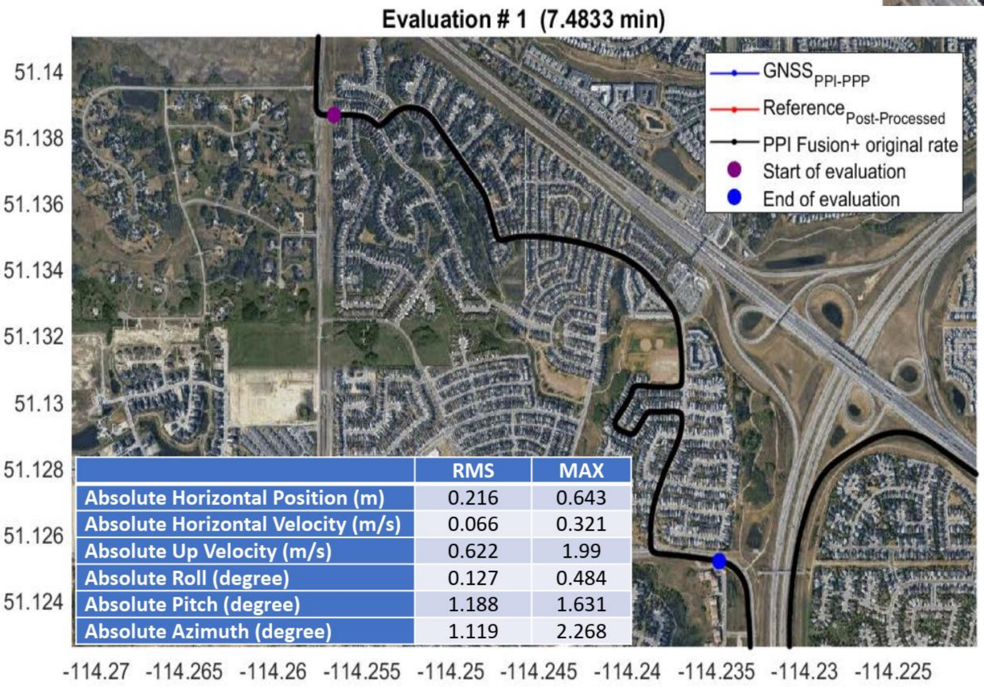
multi-sensor integration system

“continuous precision”
“trusted precision”

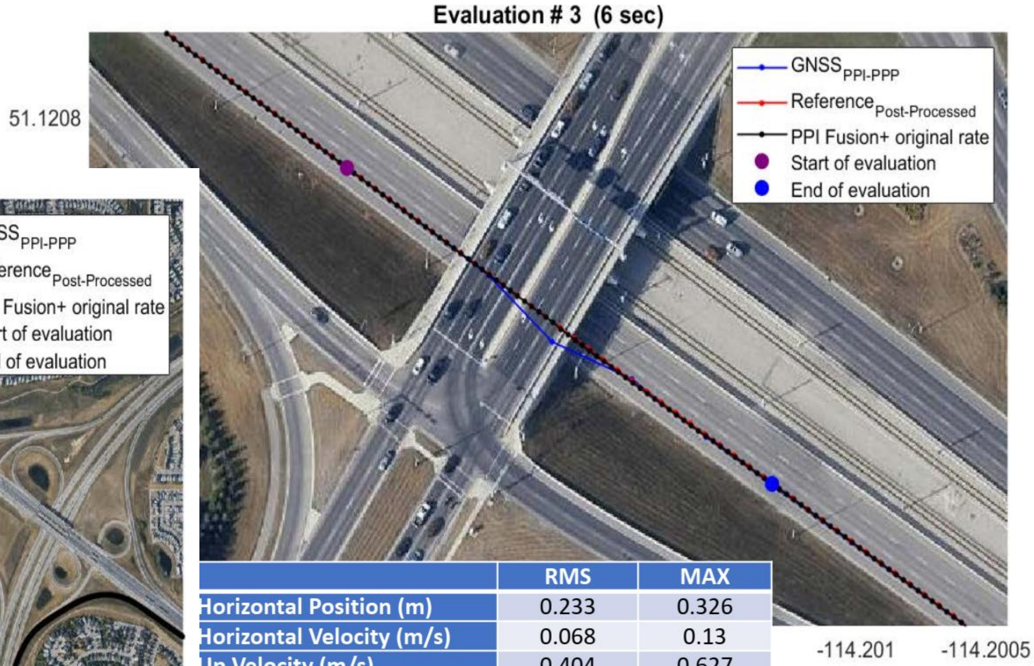
continuous precise solutions



Tests in sub-urban areas

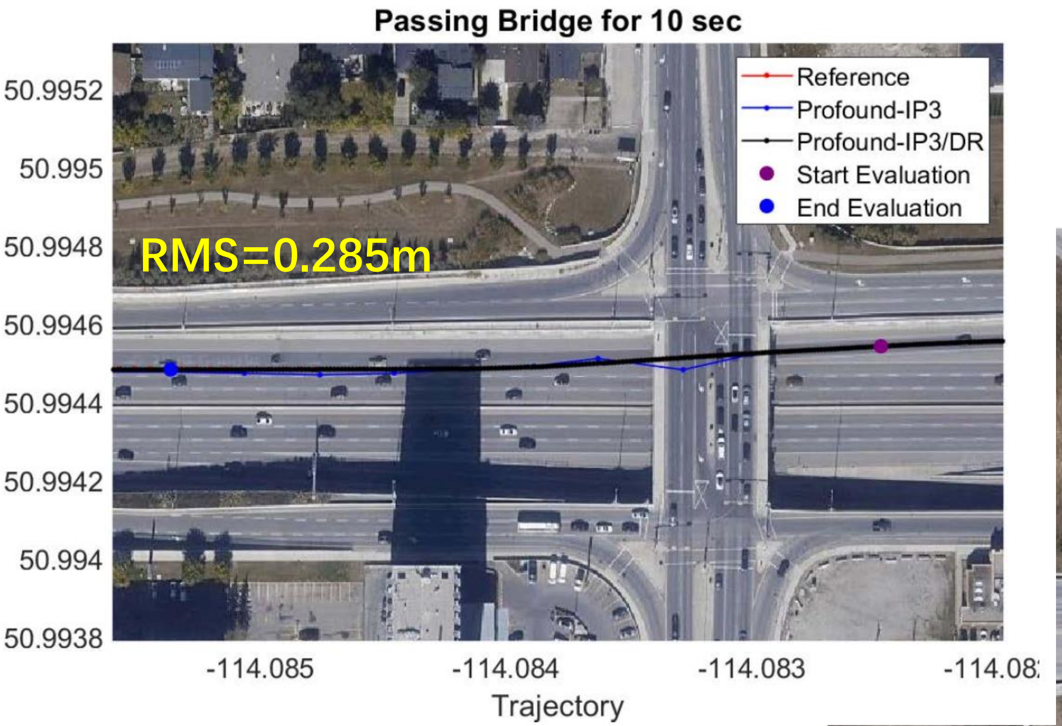


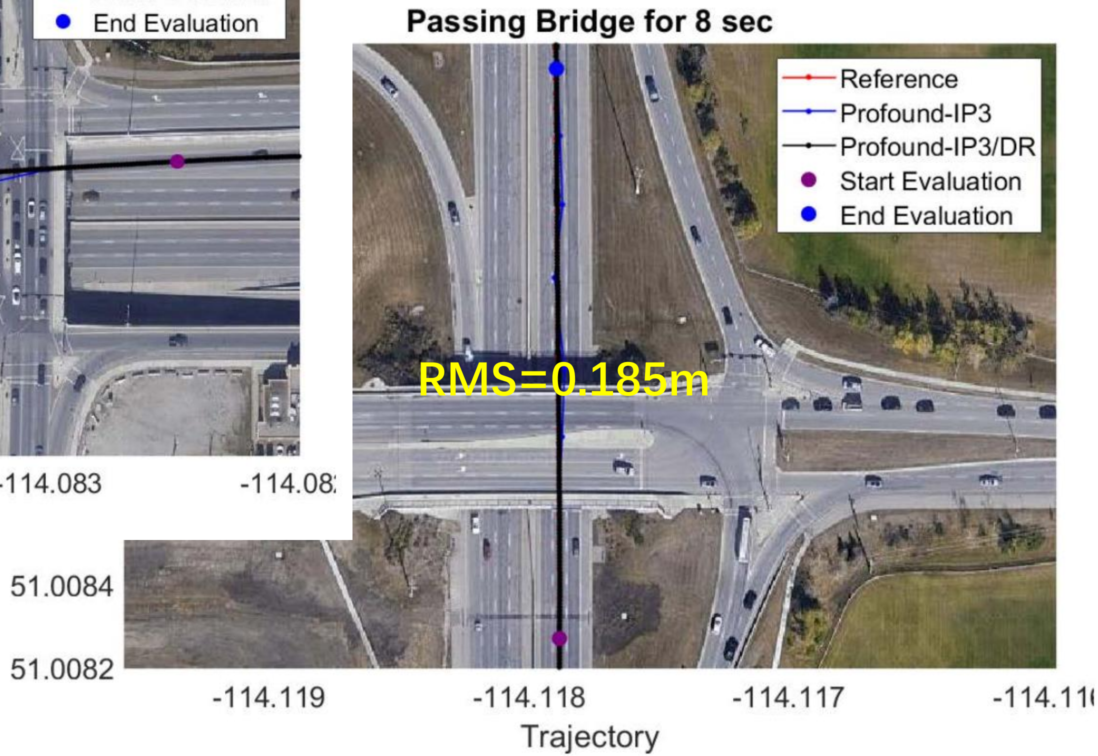
	RMS	MAX
Absolute Horizontal Position (m)	0.216	0.643
Absolute Horizontal Velocity (m/s)	0.066	0.321
Absolute Up Velocity (m/s)	0.622	1.99
Absolute Roll (degree)	0.127	0.484
Absolute Pitch (degree)	1.188	1.631
Absolute Azimuth (degree)	1.119	2.268



	RMS	MAX
Horizontal Position (m)	0.233	0.326
Horizontal Velocity (m/s)	0.068	0.13
Up Velocity (m/s)	0.404	0.627
Roll (degree)	0.061	0.138
Pitch (degree)	2.069	2.224
Azimuth (degree)	0.801	0.835

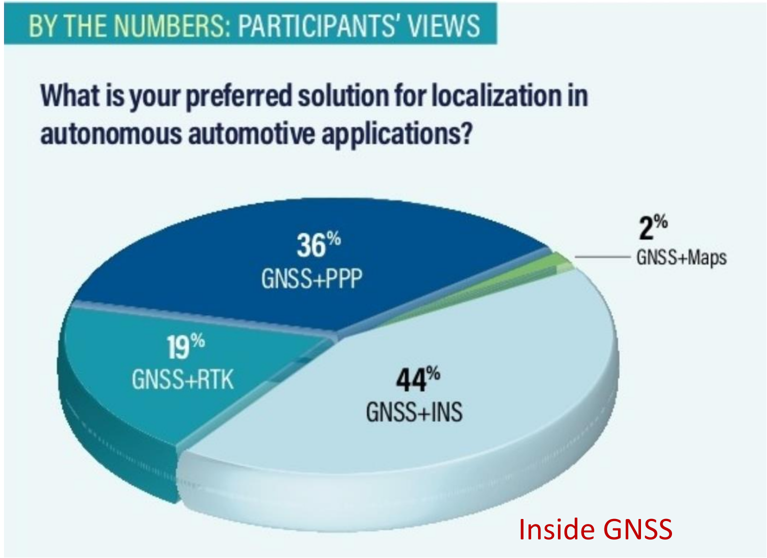
Passing Bridges





Summary

- Mass-market applications are an emerging opportunity for PPP technology with strong industry demand
- PPP is a desired precise GNSS positioning technique for mass-market applications.
- Instant, continuous and trusted precision is important for mass-market applications
- Technology innovations are required to eliminate the gaps and accelerate PPP products and services development



Looking Ahead

ICTC and CAVCOE release White Paper "Preparing for the Era of Connected and Autonomous Vehicles in Canada" – March 2020

"The COVID-19 pandemic and social distancing measures have raised the profile worldwide on the importance of connected and autonomous vehicles (CAV) ….."

Namir Anani, ICTC President & CEO.

By 2030, our lives, cities, society and infrastructure will be significantly different.