14th South East Asia Survey Congress
15-17 August 2017
Brunei Darussalam

Bridging between RTK and PPP-RTK to Develop New Survey Period

Aug. 2017
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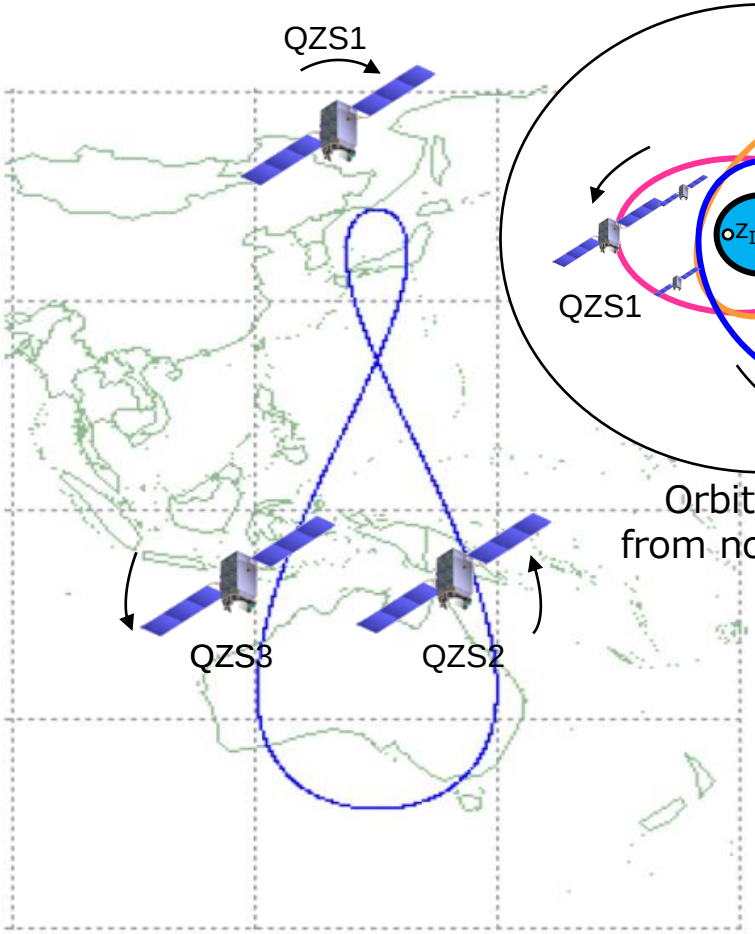
Study motivation and abstract

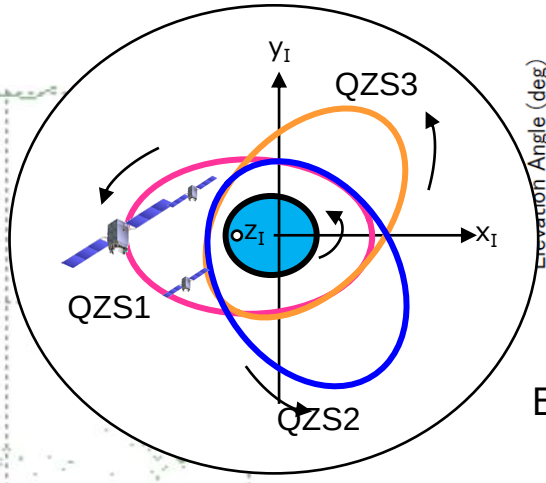
1. Cabinet Office of Japan will launch 3 QZS in 2017, and continuous service by 4 satellite constellation will start form April, 2018 . This service is expected to spread to South East Asia in the near future.
2. SPAC has been servicing cm class augmentation, named CMAS, for QZSS demonstration purpose mainly in Japan for past 6 years, and strongly supporting Japanese industry to utilize QZSS service, including cm class SSR augmentation carried by L6 from QZSS. This can service any number of users within 60kmX60km area by one set of augmentation data broadcasting.
3. SSR augmentation and its positioning method, PPP-RTK, seem still unfamiliar to RTK users as well as non-professional people. For easier understanding of PPP-RTK, we decided to clarify physical meaning of the method using simplified diagrams and comparison with RTK.
4. The understanding above gave us a hint to develop “L6 Adaptor” which receives CLAS/SSR augmentation data and drives existing RTK receivers with cm class accuracy. This feature is expanded to new service on smartphones.

CMAS: Centi-Meter-class Augmentation System
QZSS: Quasi-Zenith Satellite System
SSR: State Space Representation
RTK: Real Time Kinematic
PPR-RTK: Precise Point Positioning in RTK networks

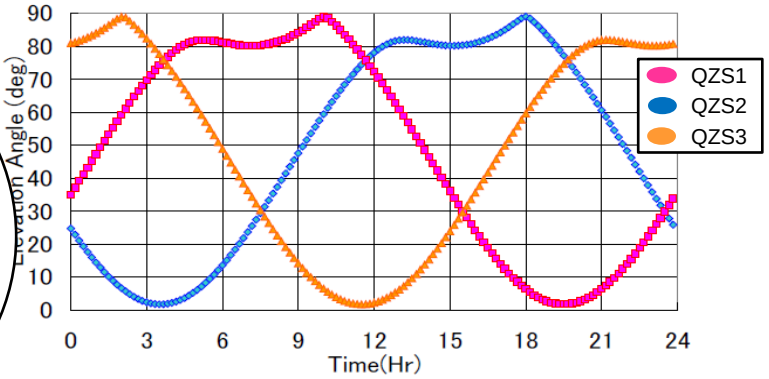
QZSS orbit and service area



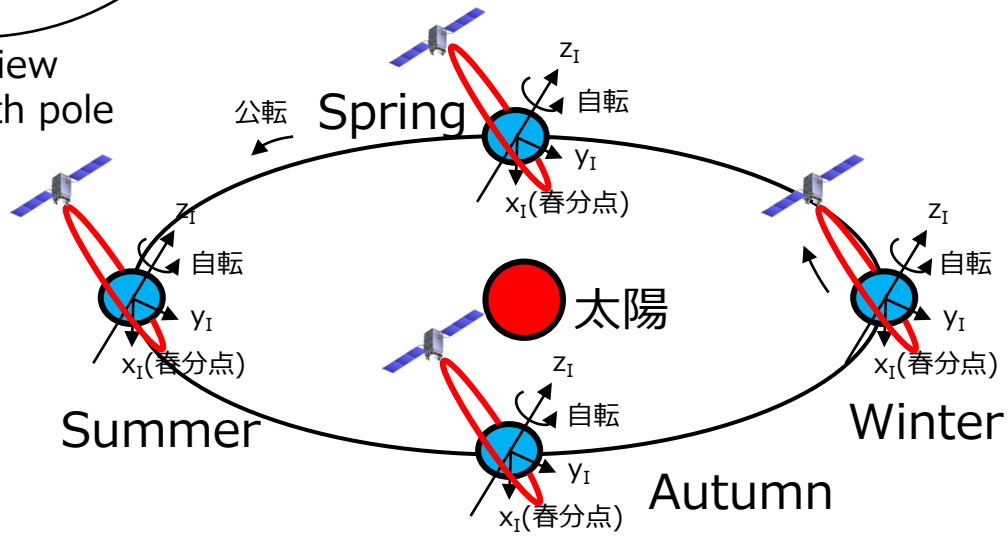
Earth surface trajectory
of nominal orbit



Orbit view
from north pole



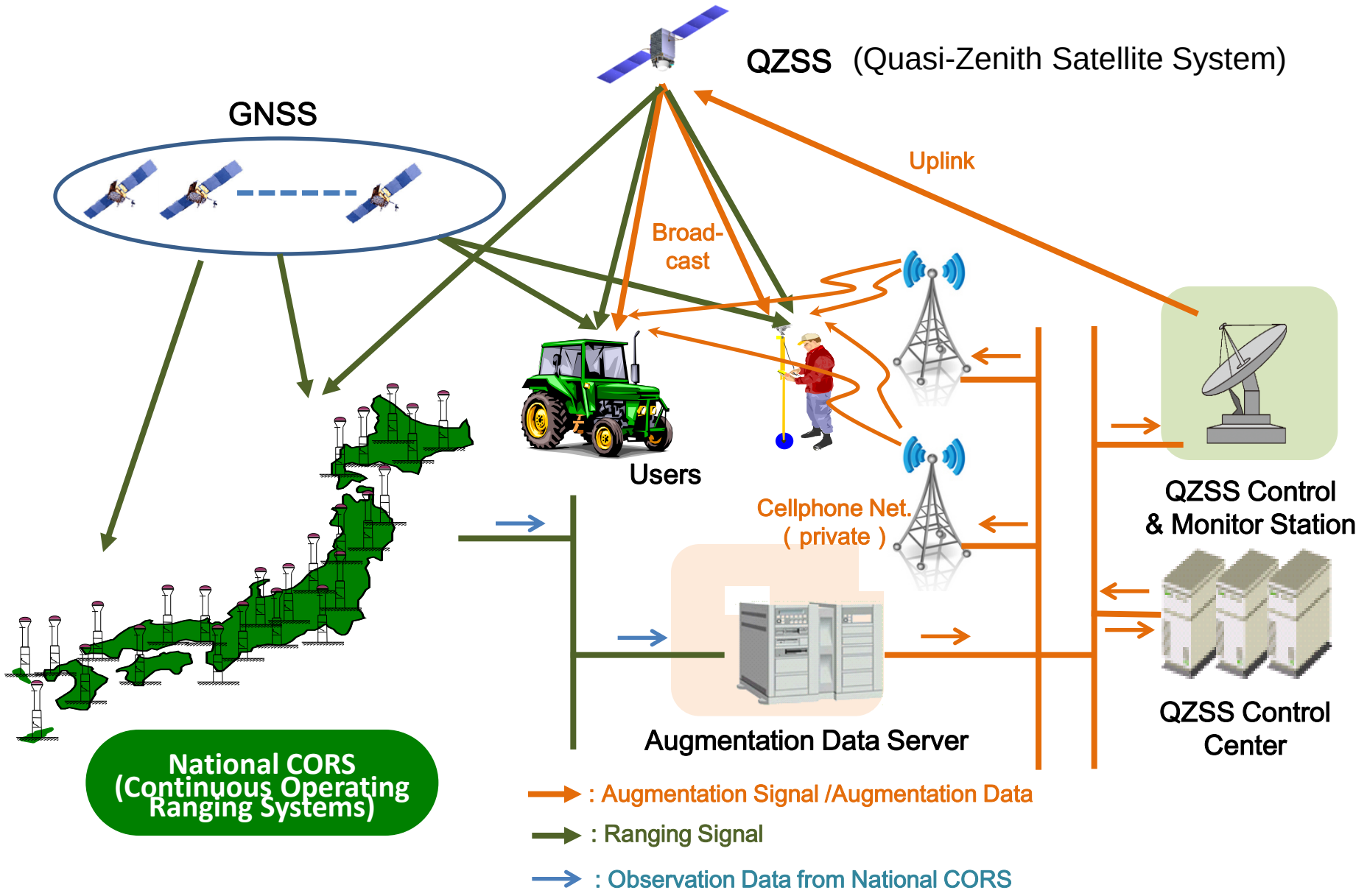
Elevation angle of each satellite at Tokyo



QZS at Inertial coordinate system

Ref. JAXA、“QZSS user Interface specification (IS-QZSS) Ver.1.8”、2016, Oct.3

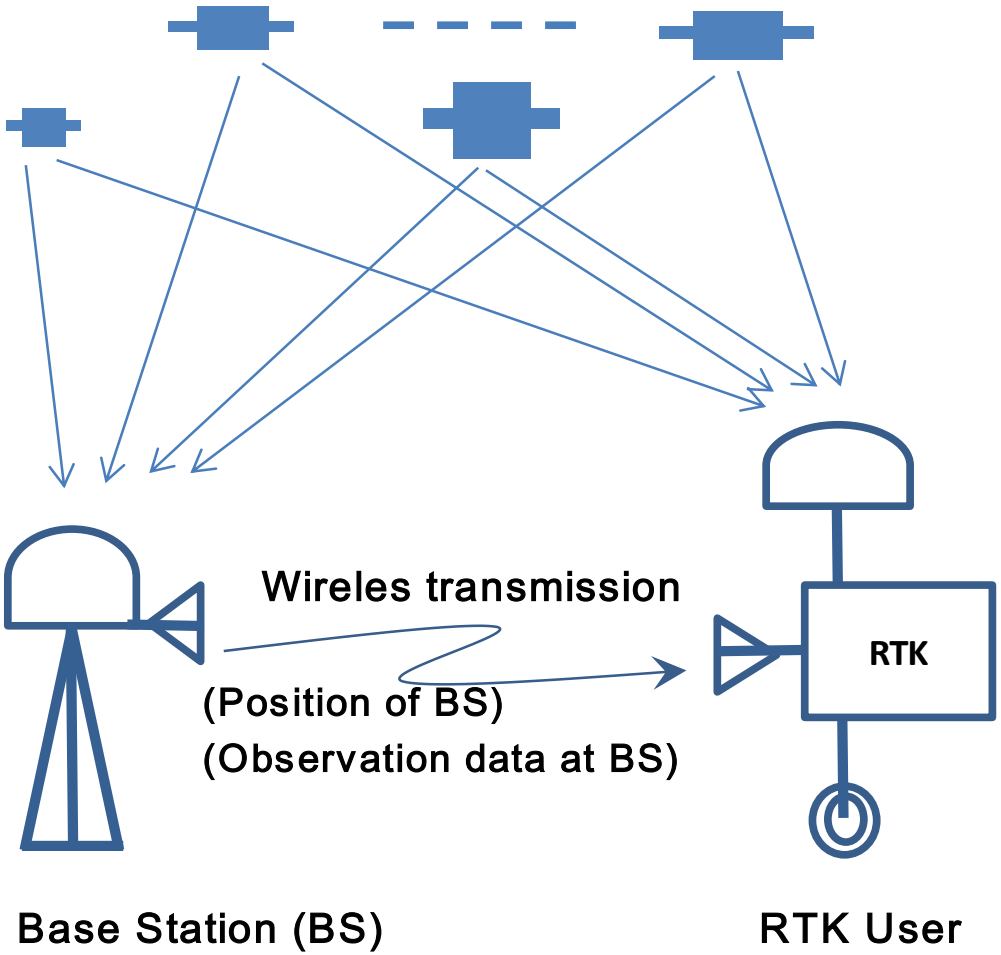
QZSS service in Japan



QZSS signal assignment

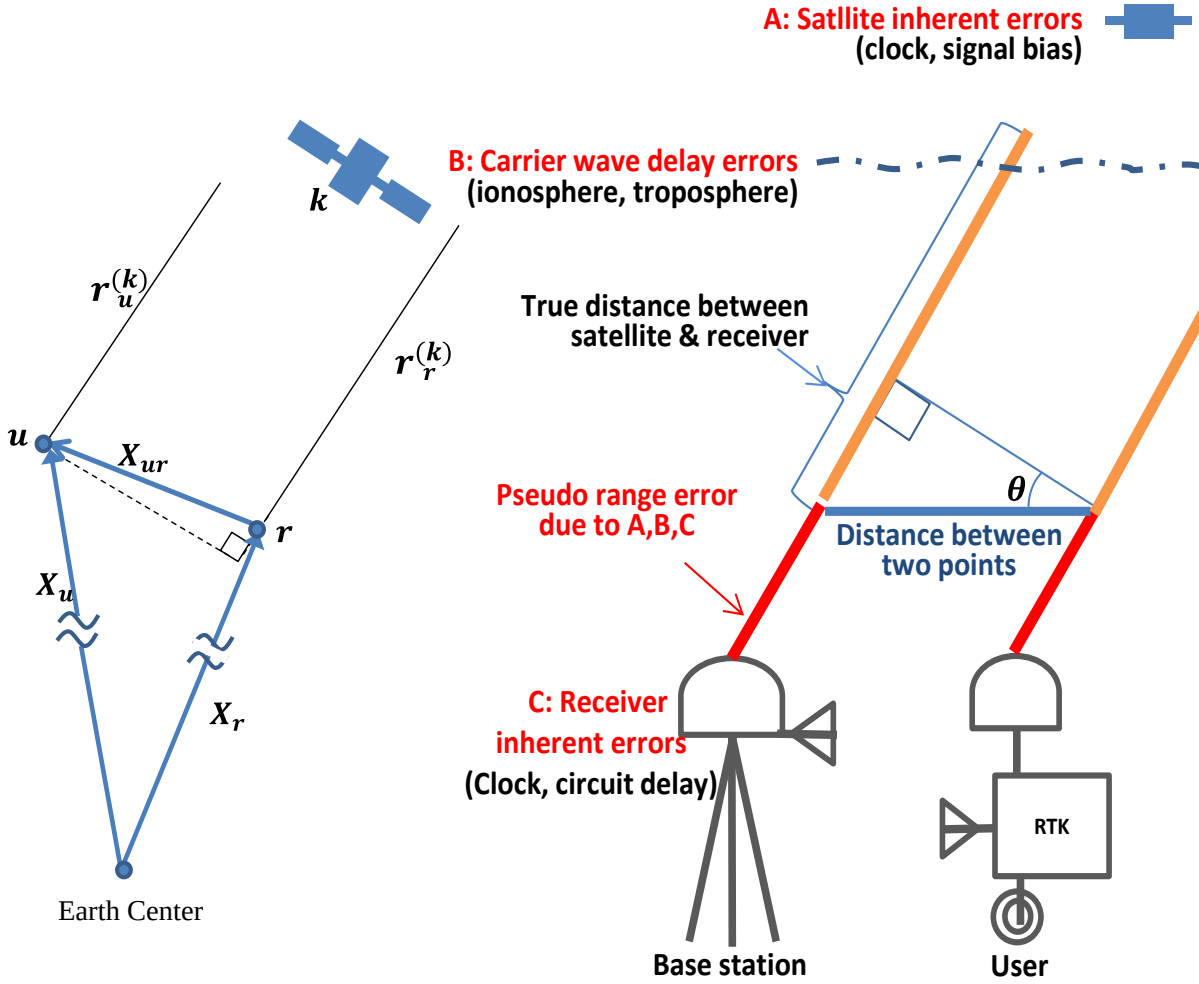
Signal	Carrier Band (MHz)	Channel	PRN Code, Modulation Method		Contents
L1C/A	1575.42	-	Same coding as GPS L1C/A, BPSK(1)		Ranging signal same as L1C/A, 50bps/50sps
L1C		L1CD	Same coding as GPS L1C, BOC(1,1)		Ranging signal same as L1C, 50bps/100sps
		L1CP	Same coding as L1C, TMBOC		Pilot signal
L1S		L1S	Same coding as GPS 1C/A, BPSK(1)		Sub-meter class augmentation signal & Short message, 250bps/500sps same as SBAS messsage
L1Sb		L1Sb	BPSK(1)		SBAS Broadcasting service (GEO satellite only)
L2C	1226.60	-	Same coding as GPS L2C, BPSK(1)	L2C(CM)	Ranging signal same as GPS L2C, 25bps/50sps
				L2C(CL)	
L5	1176.45	Ich	Same coding as GPS L5C, BPSK(10)		Ranging signal same as GPS L5C,50bps/100sps
		Qch	Same coding as GPS L5C, BPSK(10)		Data less
L5S		-	QPSK(10)		Positioning technology verification for QZO satellites)
L6	1278.75	L6b	Kasami Coding, BPSK(5)		Centi-meter class augmentation signal, 2000bps/250sps
S	2GHz band	-	-		Personnel Safety Check service (GEO satellite)

Principle of RTK (typical)



-typically cm class accuracy by relative measurement with respect to Base Station (BS) coordinate.
-BS is needed for each RTK user.
-BS coordinate must be pre-determined with necessary accuracy.
-Wireless transmission of observation data of BS and its coordinate is needed.
-No other infrastructure is needed.

Physical meaning of RTK

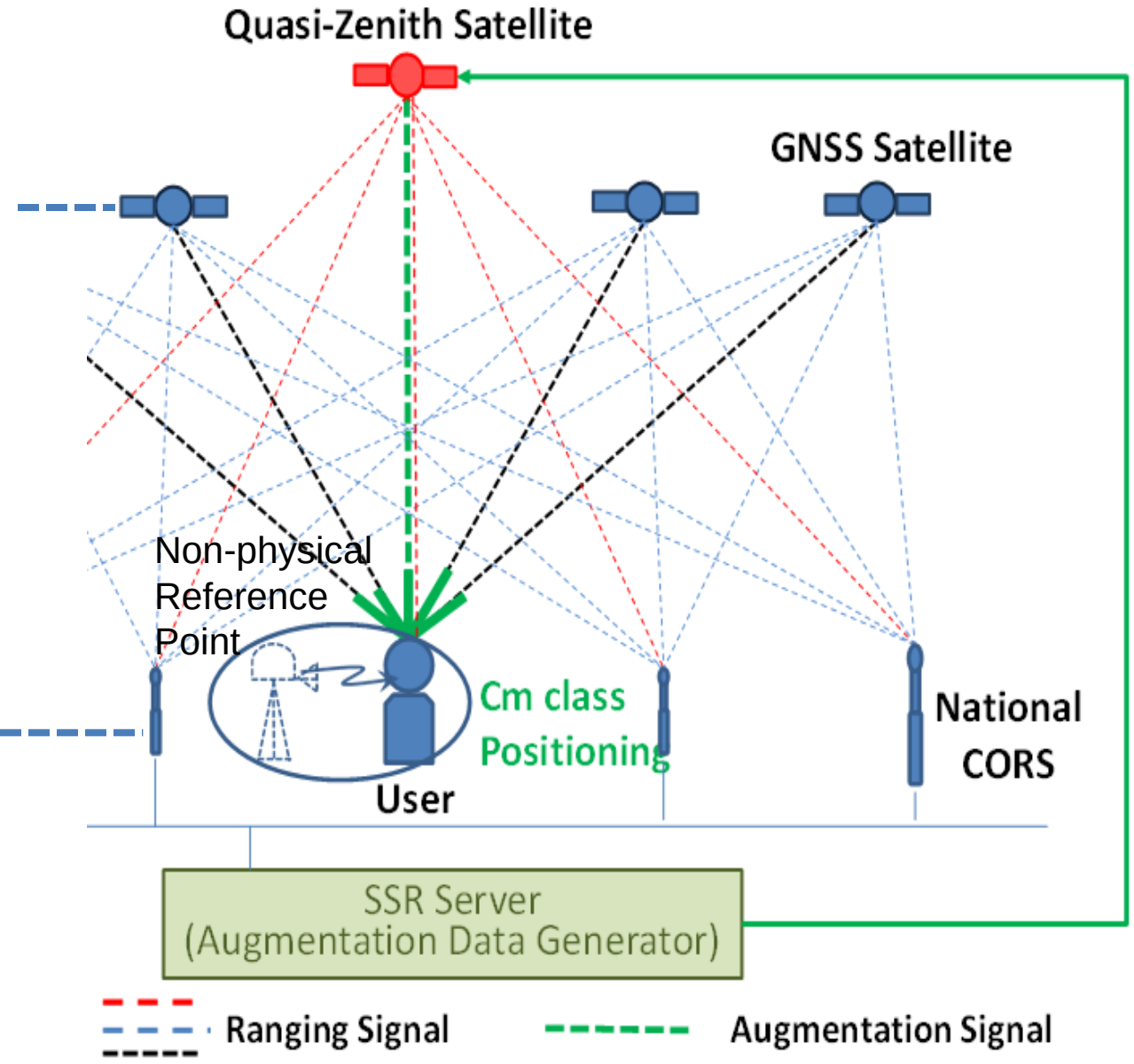


1. Take obs. data at RTK Rx & base station (physical reference point).
2. Both obs. data have almost same errors due due to sat. & earth environment.
3. Deduct one obs. data from the other and solve simultaneous eq. with 4 unknown ($\rho_{ur}^k(x,y,z)$ & $dt_{ru}(t)$) using ≥4 sat.
4. N_{ur}^k is obtained using LAMDA or LMS. Both obs. errors disappear in matrix operation of least sqr. method..

$$\Phi_r^k = \rho_r^k + c(dt_r - dT^k) - I_r^k + T_r^k + \lambda N_r^k + \varepsilon_{\phi r}^k$$
$$P_r^k = \rho_r^k + c(dt_r - dT^k) + I_r^k + T_r^k + \varepsilon_{pr}^k$$

$$\Phi_{ur}^k = \rho_{ur}^k + c\,dt_{ru} + \lambda N_{ur}^k + \varepsilon_{\phi ur}^k$$
$$P_{ur}^k = \rho_{ur}^k + c\,dt_{ru} + \varepsilon_{pur}^k$$

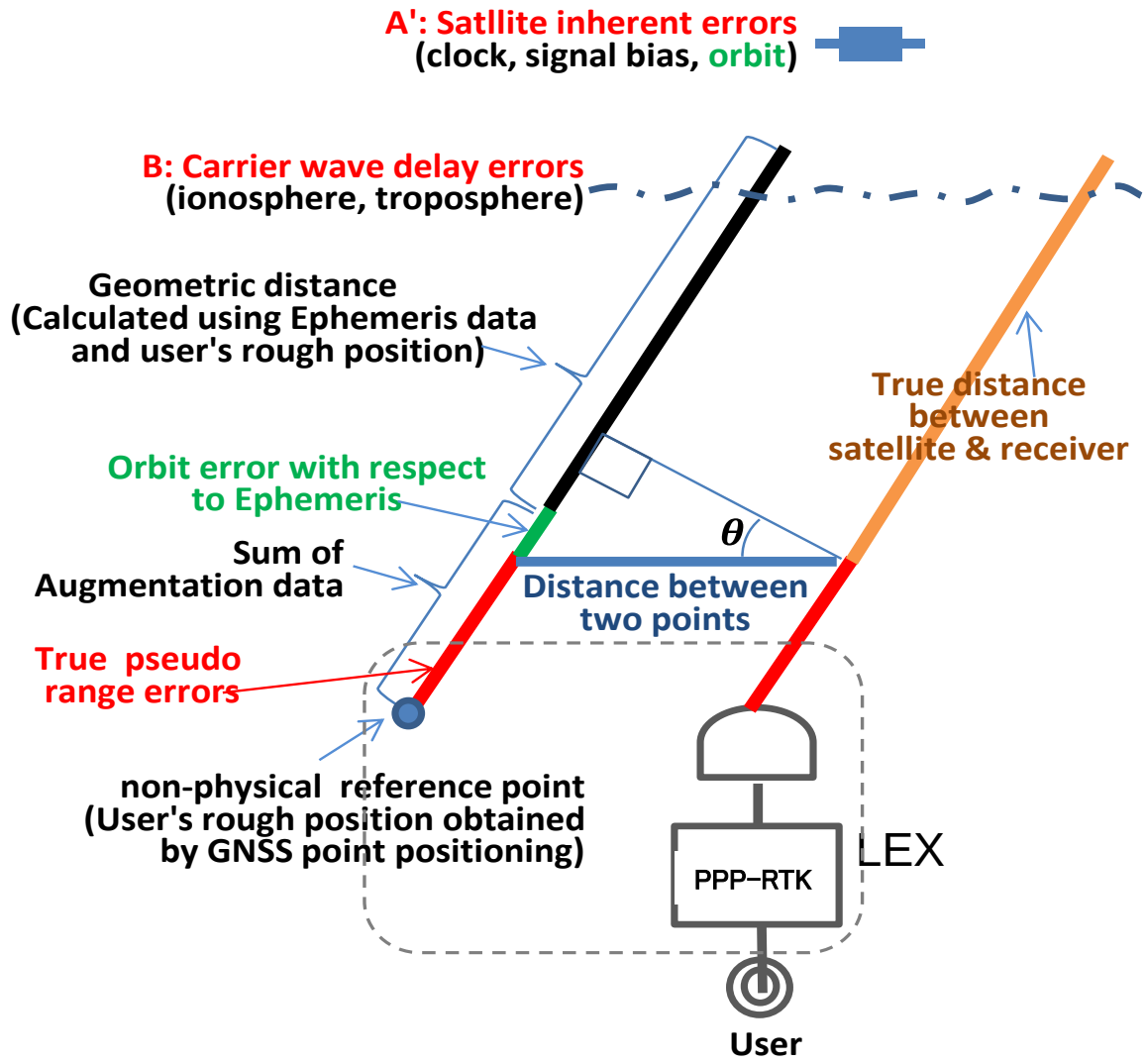
Principle of PPP-RTK



-No Base-station is needed.
-SSR server is needed as infra-structure.
-User receives L6 augmentation data from QZSS using RTK- PPP (LEX) Rx.
-In LEX Rx, non-physical reference point is made by calculation and functions as base station.
-In addition to normal range signals from QZSS, user can enjoy cm class point positioning.

Rx: Recerver

Physical meaning of PPR-RTK



1. Conduct GNSS point positioning and use its coordinate as that of non-physical reference point. (NRP).
2. Calculate artificial observation data at NRP using augmentation data & geometric distance.
3. NRP coordinate and artificial observation data are fed to RTK processor inside of LEX Rx.
4. Conduct RTK processing for cm class point positioning.

$$L_p = L_t + (E_A + E_B + E_C) = (\text{—} + \text{—}) + \text{—} = L_g + \sum E_D = \text{—} + (\text{—} + \text{—})$$

$$L_g = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} = \text{—}$$

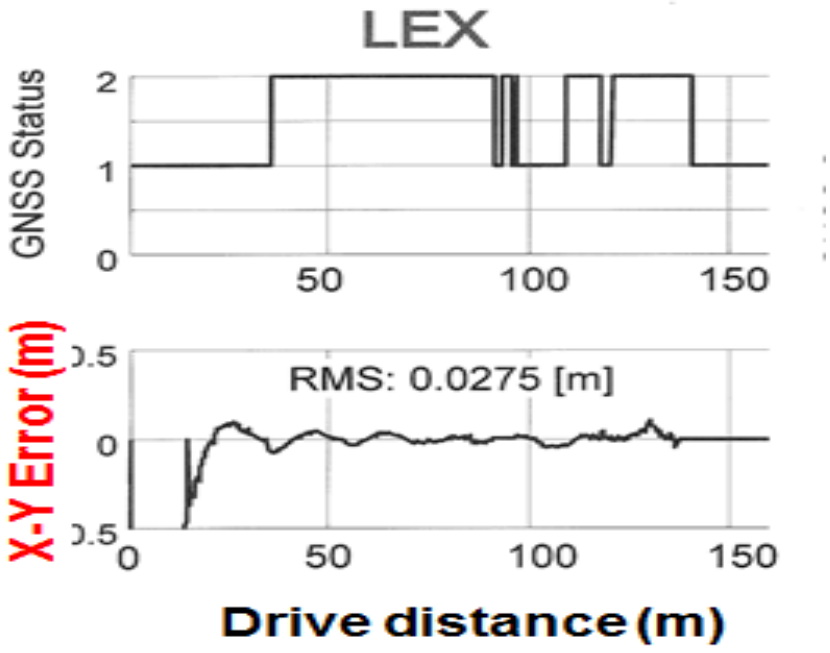
Sum of

Comparison of RTK and PPR-RTK

item	RTK	PPR-RTK
Basis	Base station	SSR server & National CORS
Data & communication between user and service provider (typical example)	Observation data and coordinate of base station by radio communication	Augmentation data sent from QZSS and/or multi-media broadcasting center
Serviceable user's number per data	One set of obs. data for one user (or multi user) typically within several km radius from base station	One set of augmentation data for any number of users within 60km square
Receiver	RTK receiver	PPR-RTK receiver (LEX)

PPR-RTK demonstration test in the Field

From Field test report by Hokkaido Univ. (& SPAC), Oct. 15,2014



PPR-RTK Test Result (Above)

-PPR-RTK (CMAS) showed 2.75cm RMS horizontal accuracy.

User voices on RTK driven auto-tractor

(Seed Planning, Market Research, Jul.27,2016)

-Due to many base stations, radio signals interferes and tractor's auto driving is disabled.

-Windbreak trees disturb radio signal.

-Base station is expensive.

QZSS L6 service is looked forward.

Motivation of L6 adaptor concept development

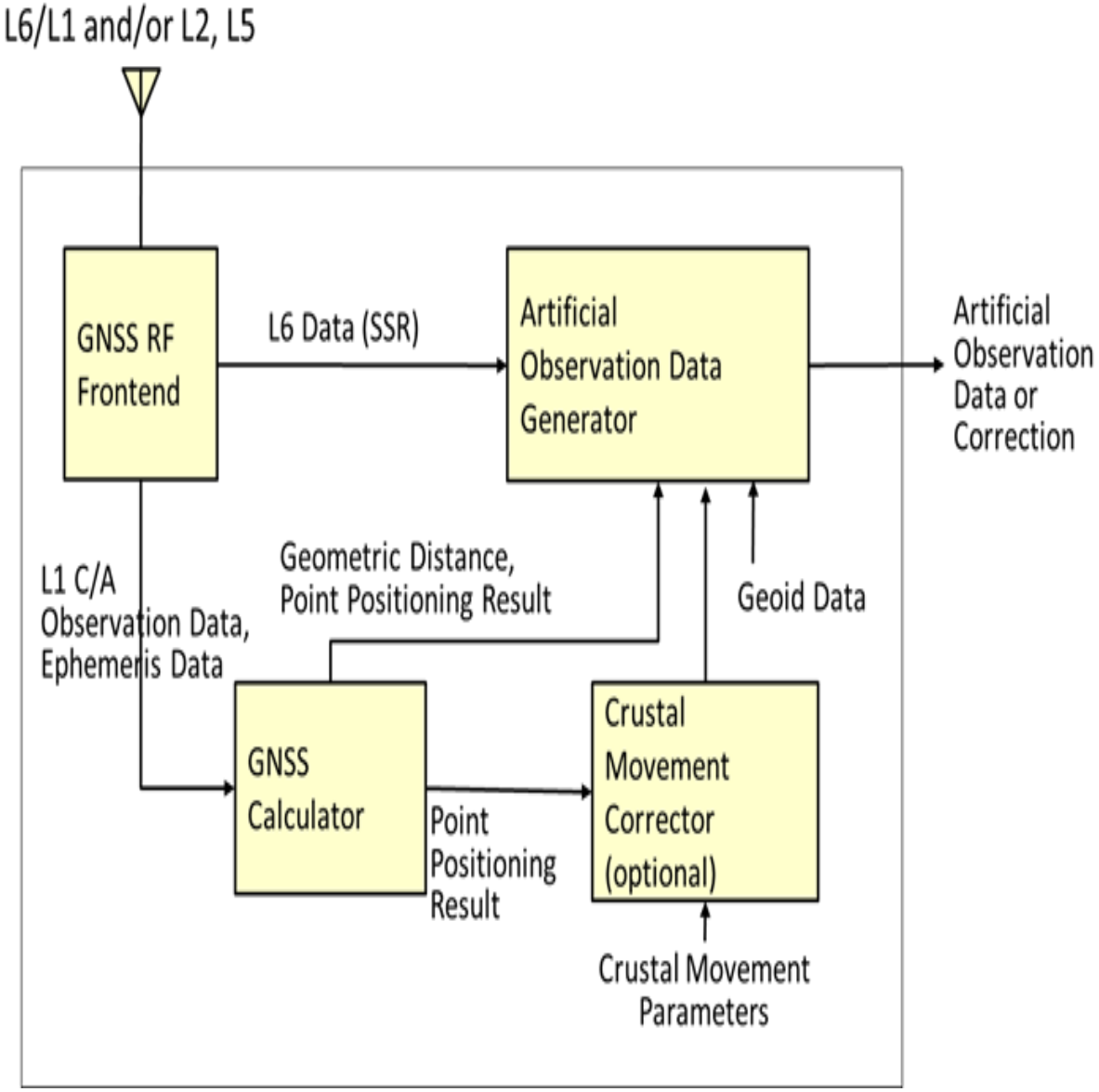
Signal Broadcasted from QZSS	RTK Users	New PPP-RTK Users
Ranging signal (L1/L2/L5) (Compatible with GPS, Galileo)	Receivable	Receivable
L6 Augmentation signal (Augmentation data for PPP-RTK)	Not receivable	Receivable

-Normally understood that Augmentation data are irrelevant to RTK users.

-Can't RTK users enjoy Augmentation data from QZSS ?

If existing RTK receiver can receive SSR augmentation data, a large number of new users would be born, and it can satisfy user voices on RTK driven tractors !?

L6 adaptor concept



1. Conduct GNSS point positioning and use its coordinate as that of NRP.
2. Calculate artificial obs. data at NRP using augmentation data & geometric distance.
3. **Output NRP coordinate and artificial obs. data to RTK receiver to be connected from outside.**
4. **Crustal movement correction (optional) is available for volcanic countries which enables coordinate matching between sat. positioning and mapping.**

Patent application submitted

L6 adaptor product image

L1 range signal from multi GNSS & L6 cm class augmentation from QZSS

Final product image of L6 adaptor for L6 direct service from QZSS

L6 antenna

Existing RTK Receiver

L6 Adaptor for satellite direct utilization

Final product image of L6 adaptor for SSR cm class augmentation from ground network

L1 range signals for multi-GNSS

Cm class augmentation from cell phone network

Existing RTK Receiver

Compact PC or Smartphone with L6 adaptor processing software

Prototype model for SSR from cell phone network

L1 Rx Antenna

GNSS RF Front-end

Artificial observation data and NRP coordinate

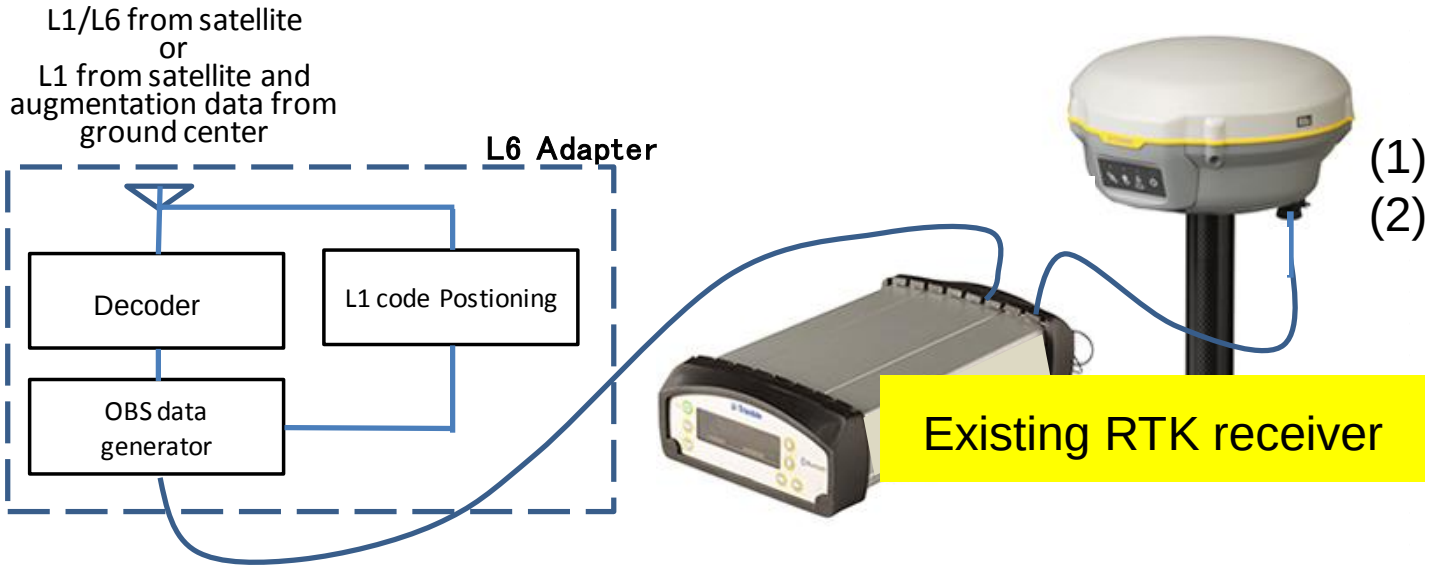
Bluetooth
(Normal positioning result & Ephemeris)

SSR from cell phone net

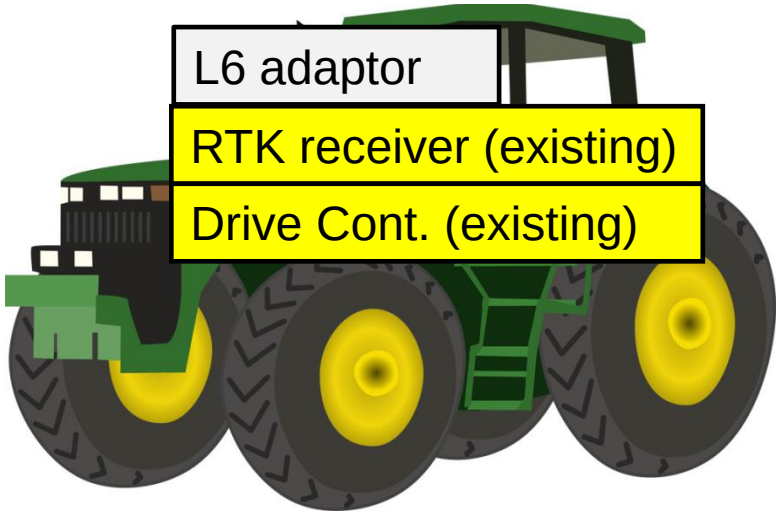
Existing RTK Receiver

Compact PC (Windows) with L6 processing software

L6 adaptor use case for professional market



(1) No BS is needed.
(2) Predetermination of BS coordinate is unnecessary.



(1) No reference station is needed.
(2) Communication problems between Ref. station and RTK receiver no longer occurs.
(3) Centimeter class point positioning performance is kept unchanged.

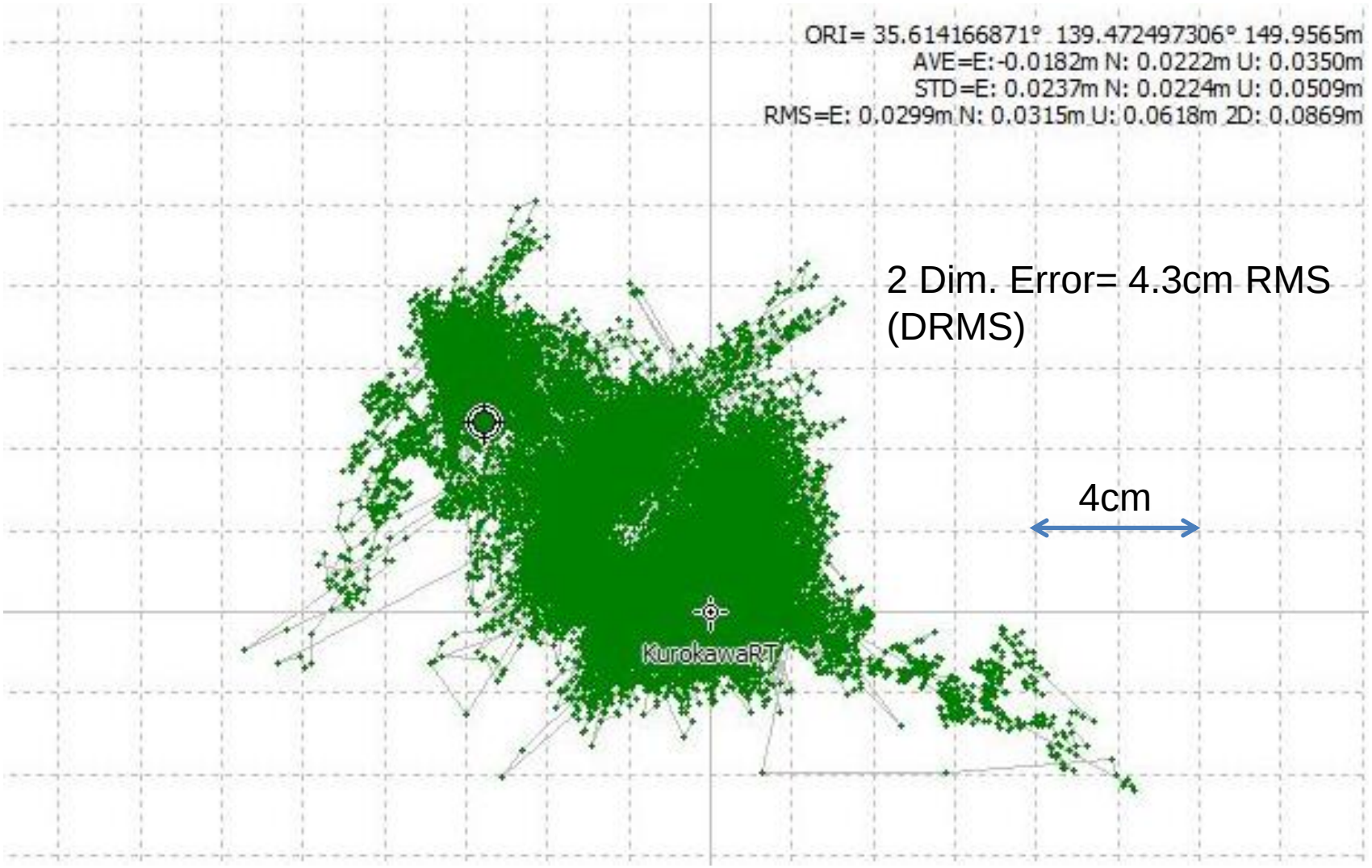
Demonstration test of prototype model performance

Antenna with survey grade

Prototype GNSS front-end

Existing JAVAD-α

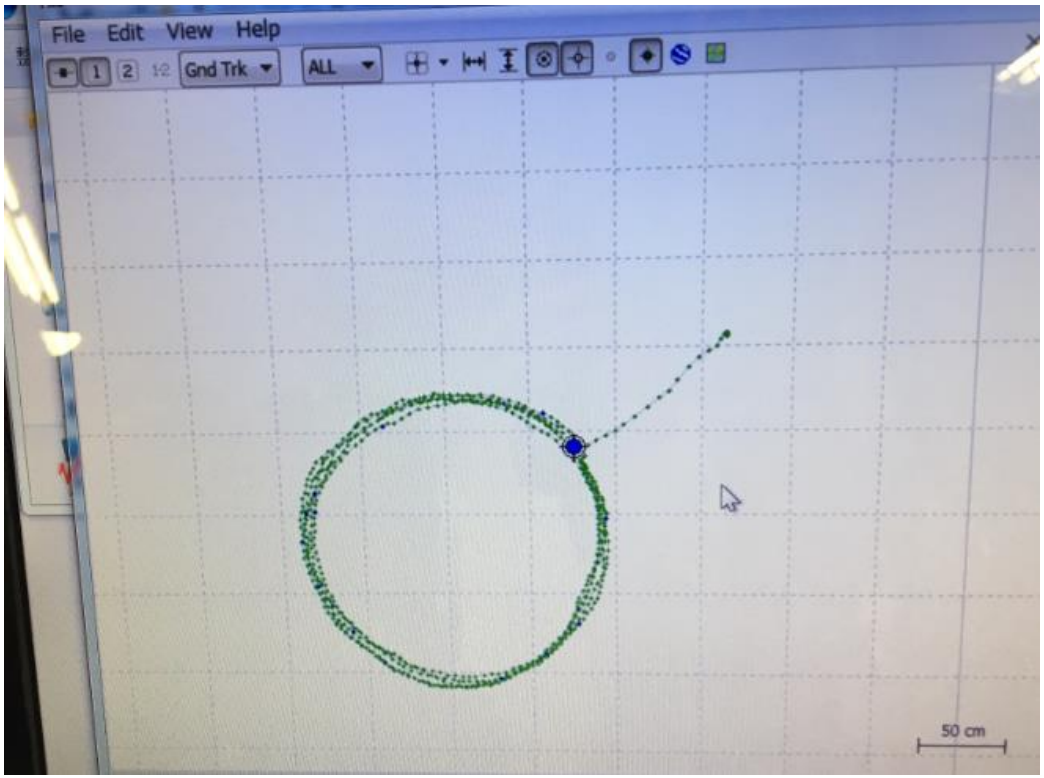
Result of 24 hours continuous measurement



Result of kinematic measurement

This test was conducted by courtesy of CORE Corporation LTD. Japan, on May 26, 2017 at his premises.

Antenna was moved by hand 4 times roughly around a 1.8 meter-dia. circle printed on the roof floor. L6 adaptor prototype received cm class SSR augmentation continuously and its kinematic performance was verified at a walking velocity.



L6 adaptor/smartphone equivalent test setup

	Antenna	Receiver	Augmentation	Processor
Smartphone (target)	Smartphone-grade with range error of $\sigma \cong 11.4$ mm *	Smartphone-grade L1 code/carrier	Cm-class/level augmentation (MADOCA-AR, CLAS, SSR, PPP-AR, etc.)	Real-time L6 adaptor & RTK processing with carrier smoothing @ smartphone
Test setup (equivalent)	Survey-grade antenna with range error of $\sigma \cong 3.4$ mm *	Survey-grade L1 code/carrier	CMAS cm-class augmentation with intentional range noise of $\sigma = 12$ mm	Post PPR-RTK processing with carrier smoothing @ center PC

Survey-grade antenna for range SG

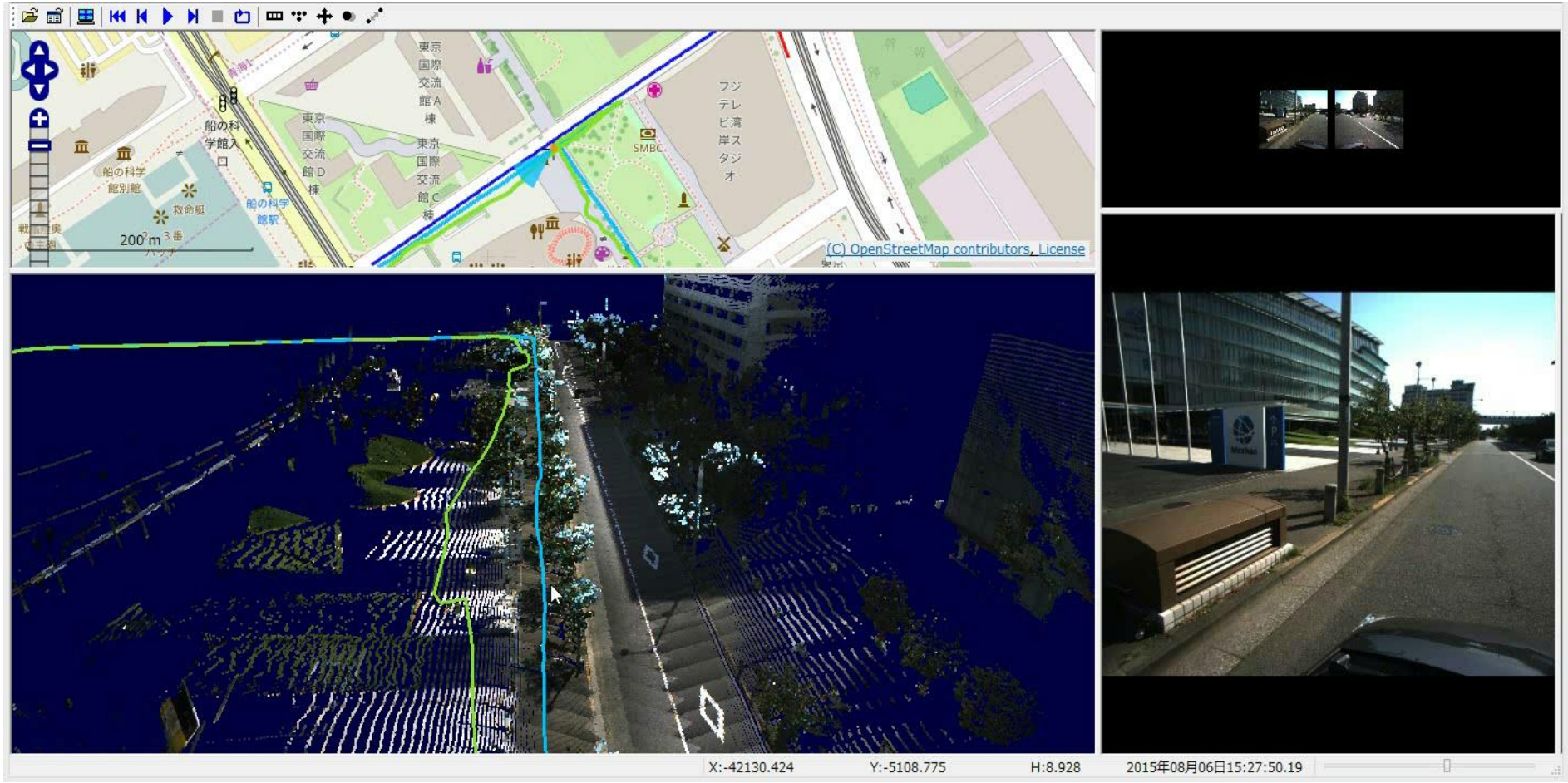
L1 code/carrier receiver With Obs.

* Values are referenced from papers written by Dr. K. P. Pesyna, Jr, et. al., “Centimeter Positioning with a Smartphone-Quality GNSS Antenna”

L6 adaptor/smartphone equivalent test result

Reference Point	Positioning error	x:Latitude [cm]	y:Longitude [cm]	$\sqrt{(x^2+y^2)}$ [cm]	height [cm]
A	bias	-2.43	-6.36	6.81	11.17
	σ	15.662	13.46	20.65	32.85
	RMS	15.85	14.86	21.74	34.70
B	bias	12.75	2.30	12.96	-19.01
	σ	15.98	13.55	20.95	33.06
	RMS	20.44	13.74	24.63	38.14
C	bias	-0.38	1.65	1.69	-19.51
	σ	12.80	11.79	17.40	31.26
	RMS	12.80	11.91	17.49	36.85
d	bias	5.00	4.27	6.57	-17.03
	σ	12.53	11.25	16.88	28.85
	RMS	12.58	12.03	18.11	33.50

L6 adaptor/smartphone simulated test



Blue: test setup test with augmentation
Green: test setup test without augmentation
Right picture: MMS vehicle movement when generating laser point cloud.
(This test was conducted by SPAC with cooperation of Aisan Technology Corp.)

Summary and conclusions

1. **We clarified physical meaning of RTK and PPR-RTK, and concluded PPP-RTK generates artificial observation data at non-physical reference point to drive RTK processor inside of PPR-RTK receiver.**
2. **We developed L6 adopter concept which functions as non-physical reference point to drive RTK processor from outside. This can act as attachment to existing RTK receiver so that they can enjoy QZSS L6 augmentation service.**
3. **L6 adopter prototype which receives cm class SSR augmentation data sent from ground network has been completed. Combining this prototype with existing RTK receiver, 4.3 cm DRMS accuracy in 24 hrs continuous operation and sufficient kinematic performance are confirmed.**
4. **If existing smartphones are loaded with L6 adaptor software and serviced with cm class SSR augmentation from ground network, new users/applications in consumer market should be borne easily.**
5. **Equivalent test to simulate existing smartphone's point positioning accuracy verified about decimeter DRMS positioning accuracy without multi path effect.**
6. **The ground augmentation service for L6 adaptor/smartphones should be a good approach for South East Asian countries to enjoy QZSS originated service in a quickest manner, before receiving official & direct service from QZSS.**

We hope this "bridging method" lowers technical/business barriers of PPP-RTK for all users/manufacturers, and enhances QZSS technology utilization.

If any questions and inquiry, please visit
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at exhibition hall,
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