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Centimeter-class Positioning Augmentation Utilizing Quasi-Zenith Satellite System

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1. Overview of Quasi-Zenith Satellite System

Quasi-Zenith Satellite System

The **Quasi-Zenith Satellite System (QZSS)** developed by **Japan Aerospace Exploration Agency (JAXA)** is a regional navigation satellite system, which uses multiple satellites located on the quasi-zenith orbit, so that one of the satellites is always visible near the zenith at anywhere in Japan, including many extensive urban zones and mountains difficult to receive the existing GNSS signals.

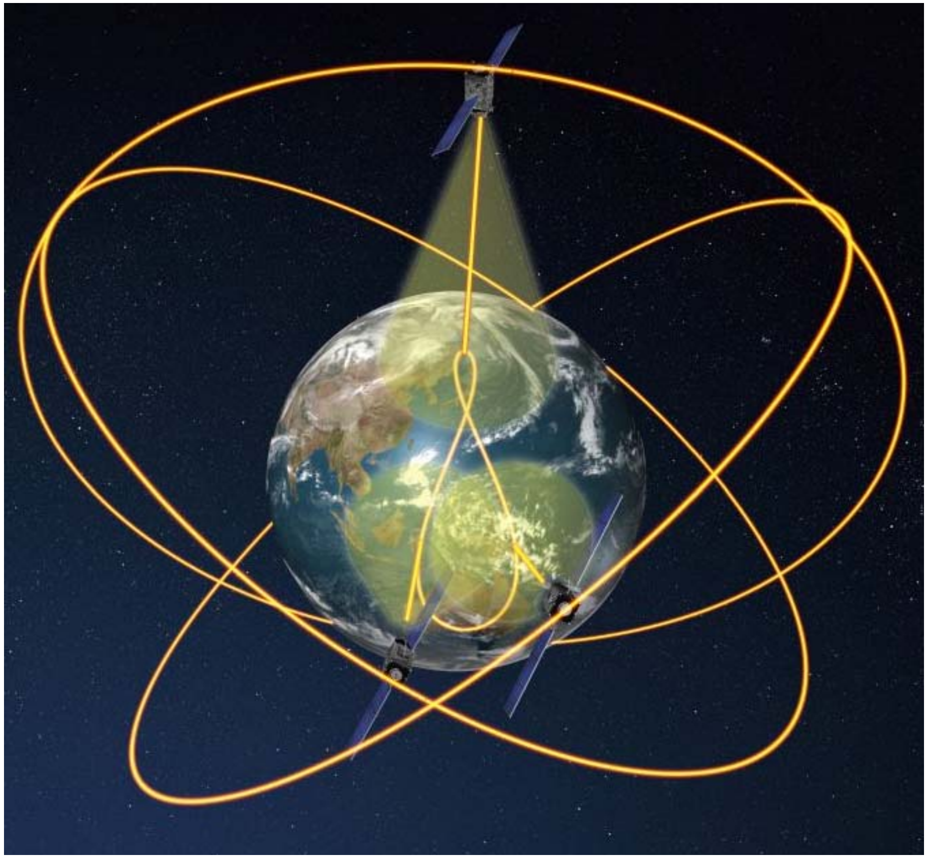


Fig. 1. Multiple satellites on the quasi-zenith orbit ©JAXA

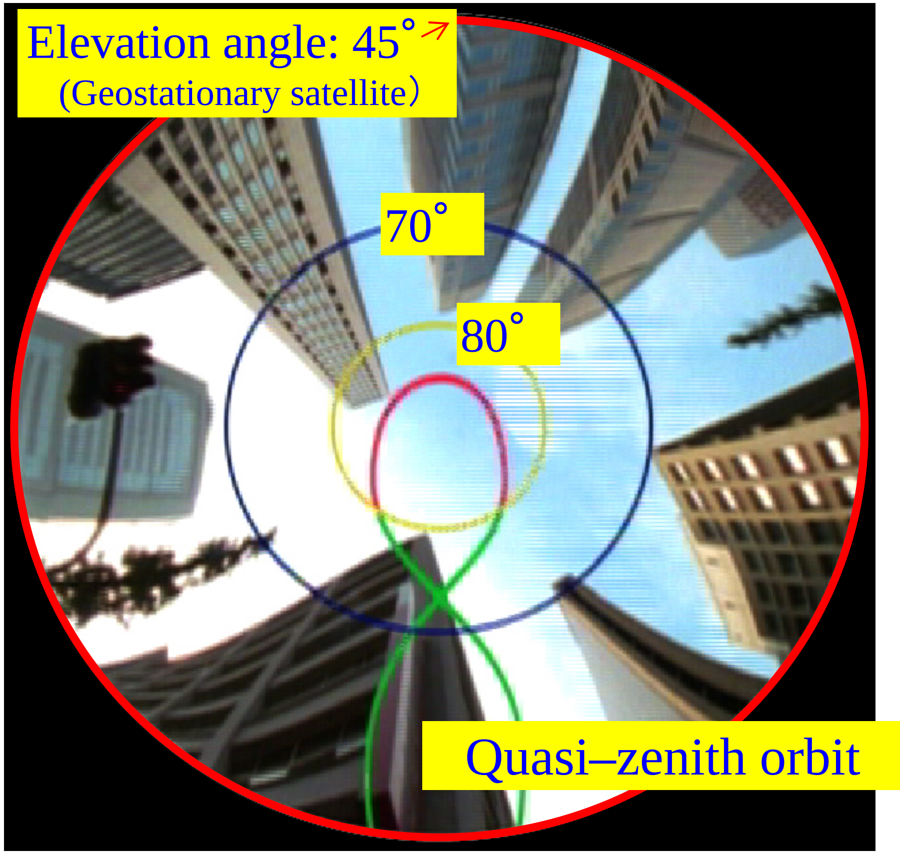


Fig.2. Quasi-zenith orbit visible from the ground at Tokyo

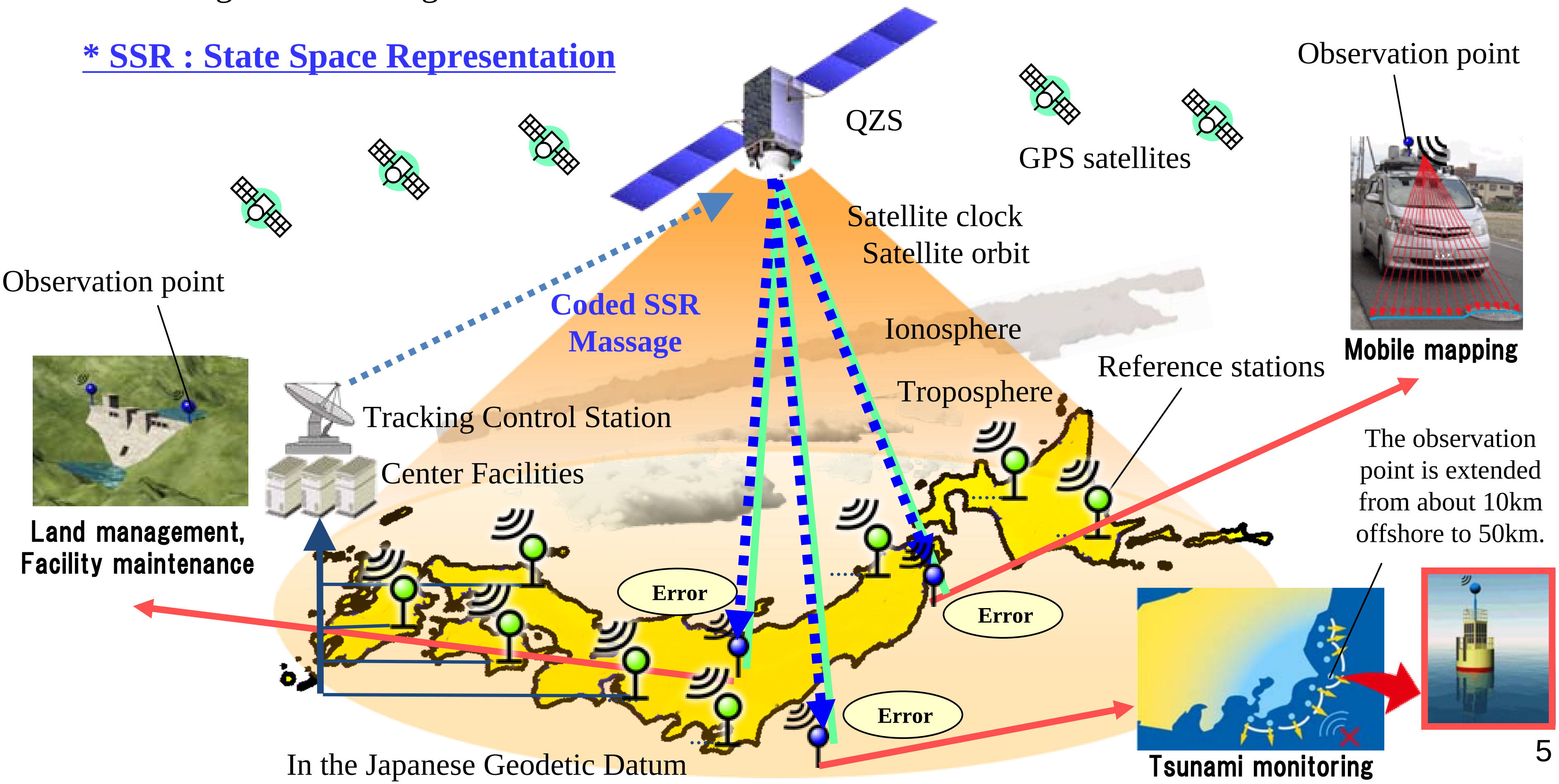
2. The Method of Centimeter-class Positioning Augmentation

Centimeter-class Augmentation

Augmentation uses **Coded SSR* Message** which is available in nation-wide area of Japan, and is broadcast via QZS to achieve centimeter-class positioning accuracy.

- Error corrections for each area and each satellite are calculated in real time.
- The total message amount is reduced to 1/1000 of the existing ground-based service.
- Integrity information is broadcast with the corrections in the message.
- The augmentation targets GPS satellites at the moment.

*** SSR : State Space Representation**



Correction Generation Engine

State Space Representation (SSR) module is utilized as a correction generation engine.

Tab.2. Comparison of centimeter-class satellite positioning

Positioning method		Positioning Accuracy [rms]	Transmission to nation-wide of Japan	Transmission volume for the nation-wide	TTFF	Real-time	Availability for mobile object
Network RTK	SSR	3cm	Possible	1695bps	Within 1min	Yes	Available
	FKP	3cm	Possible	1.5Mbps	Within 30s	Yes	Available
	VRS	3cm	Not possible	—	Within 30s	Yes	Available only near virtual reference points

FKP: Flaechen Korrektur Parameter
VRS: Virtual Reference Station

1. SSR method provides each error component separately; satellite clock, satellite orbit, signal bias, ionosphere and troposphere.
2. We are able to choose transmitting period and spatial grid span of each component based on its physical characteristics.
3. We optimized these parameter so that the total message amount is dramatically reduced and the required accuracy is still achieved concurrently.

Structure of "Coded SSR Message"

The Coded SSR Message consists of a 49 bit header, **<u>1695 bits of data</u>** and 256 bits for error correction using Reed Solomon Coding. The total size of one message is 2000 bits. The actual transfer volume for augmentation data is 1695bps

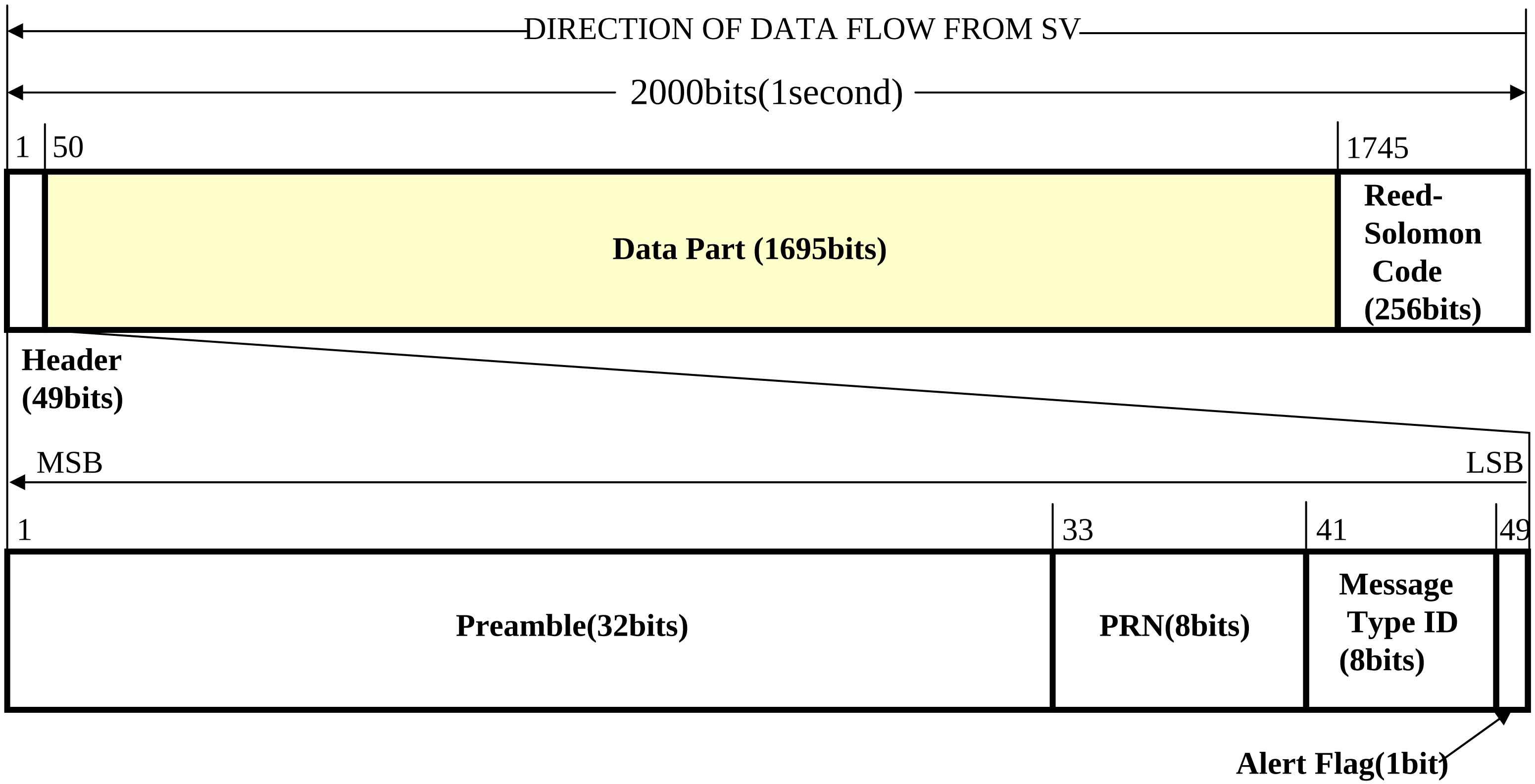


Fig.4. Structure of "Coded SSR Message"

Contents of "Coded SSR Message"

Error corrections and integrity information are broadcast.

The user can convert each error component to total correction at the user position.

Tab.3. Contents of "Coded SSR Message"

Transmission Item	Components	Update period [s]
High-speed correction items	Satellite Clock Correction	5
Low-speed correction items	Satellite Orbit Correction	30
	Ionosphere Correction	30
	Troposphere Correction	30
	Signal Bias Correction	30
Integrity information		30
Others (Preamble, GPS week/second, IODE, PRN)		30

Augmentation Network

The whole of Japan and surrounding ocean area are divided into 12 networks.
In each network, error corrections are generated and combined.

No	Network
1	West Hokkaido
2	East Hokkaido
3	North Tohoku
4	South Tohoku
5	Kanto
6	Hokuriku
7	Chubu
8	Kansai
9	Chugoku
10	Shikoku
11	North Kyushu
12	South Kyushu & Okinawa

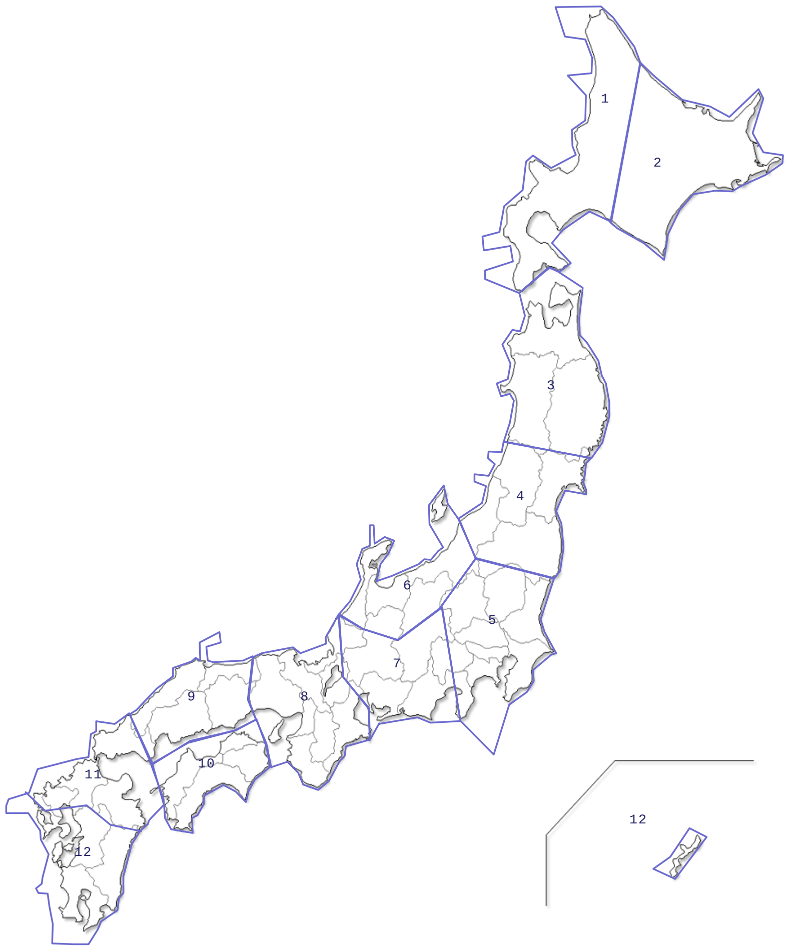


Fig.5. Augmentation Network covering the nation-wide of Japan

3. QZS Application Demonstration of Centimeter-class Positioning Augmentation

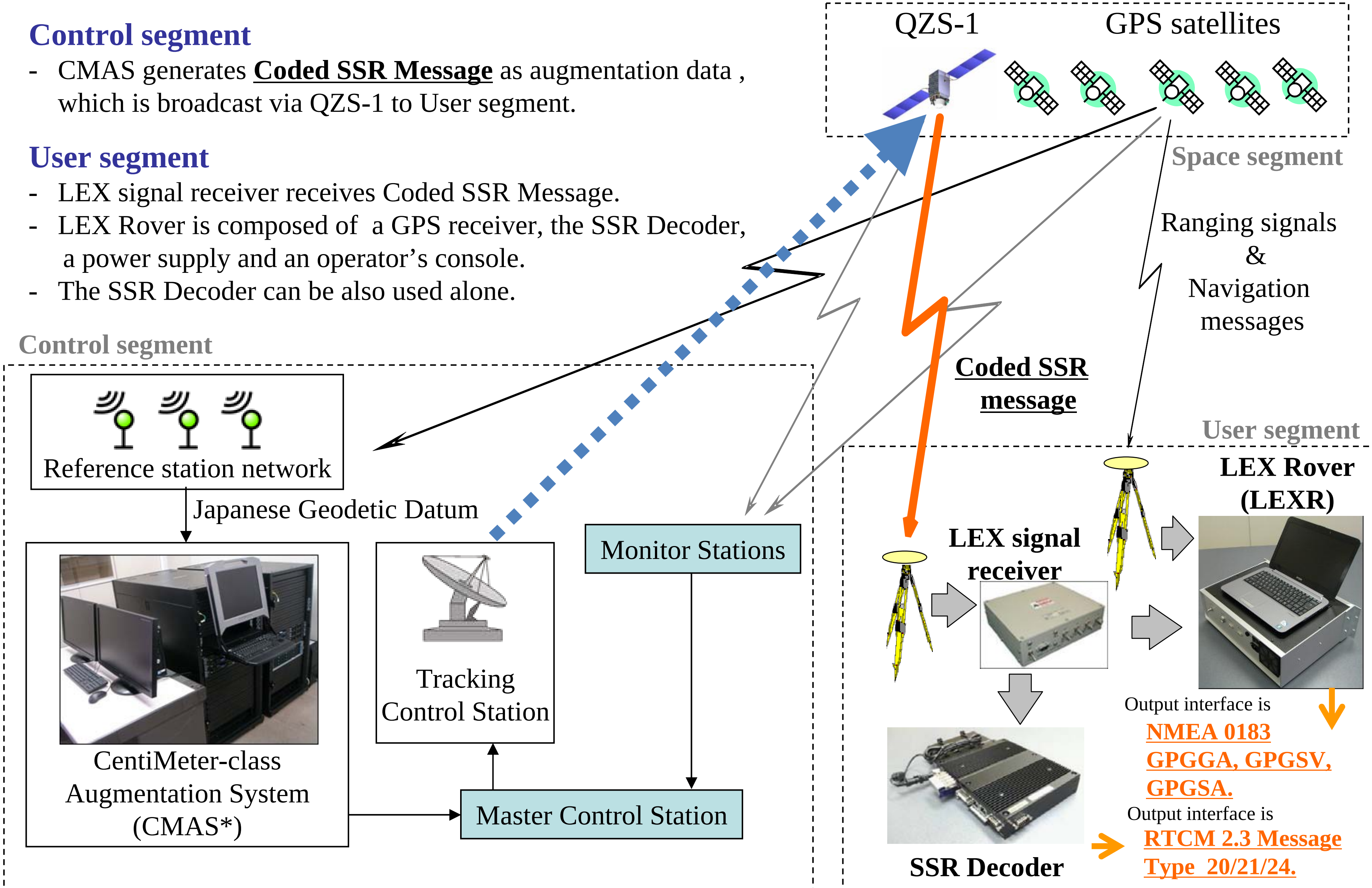
System Configuration

Control segment

- CMAS generates **Coded SSR Message** as augmentation data , which is broadcast via QZS-1 to User segment.

User segment

- LEX signal receiver receives Coded SSR Message.
- LEX Rover is composed of a GPS receiver, the SSR Decoder, a power supply and an operator's console.
- The SSR Decoder can be also used alone.



*CMAS was developed by SPAC, and funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan.

Result of Real Time Positioning (static)

Real time accuracy is 1.0 cm (drms) in horizontal and 1.9 cm (rms) in vertical direction.

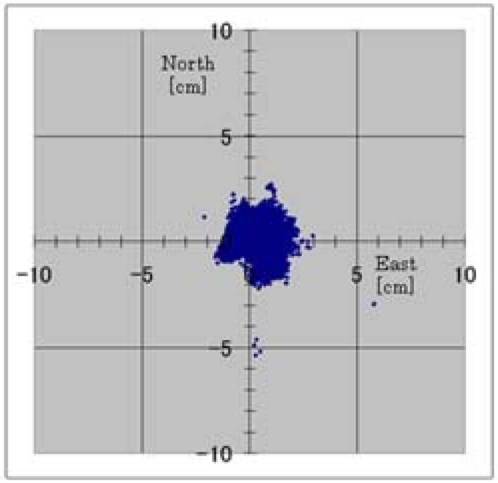


Fig.6. Error Distribution in the horizontal direction

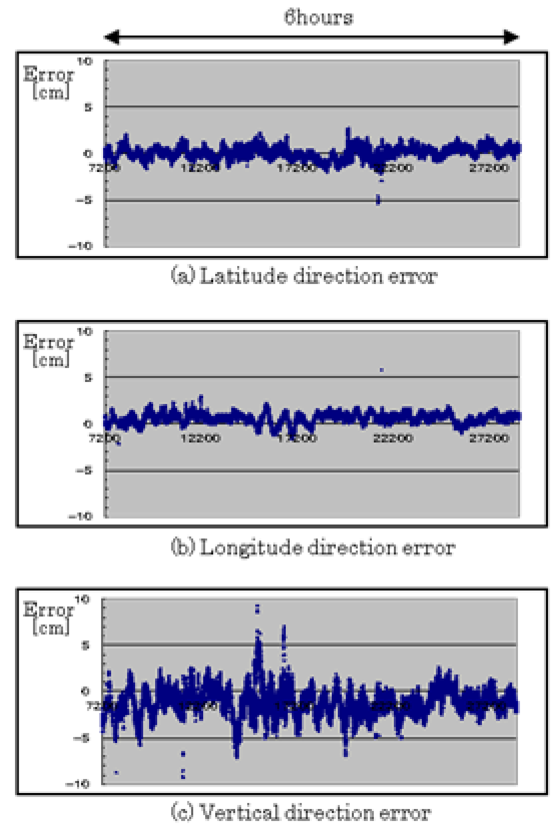


Fig.7. Time variations of error

Tab.4. Real time fixed point positioning result

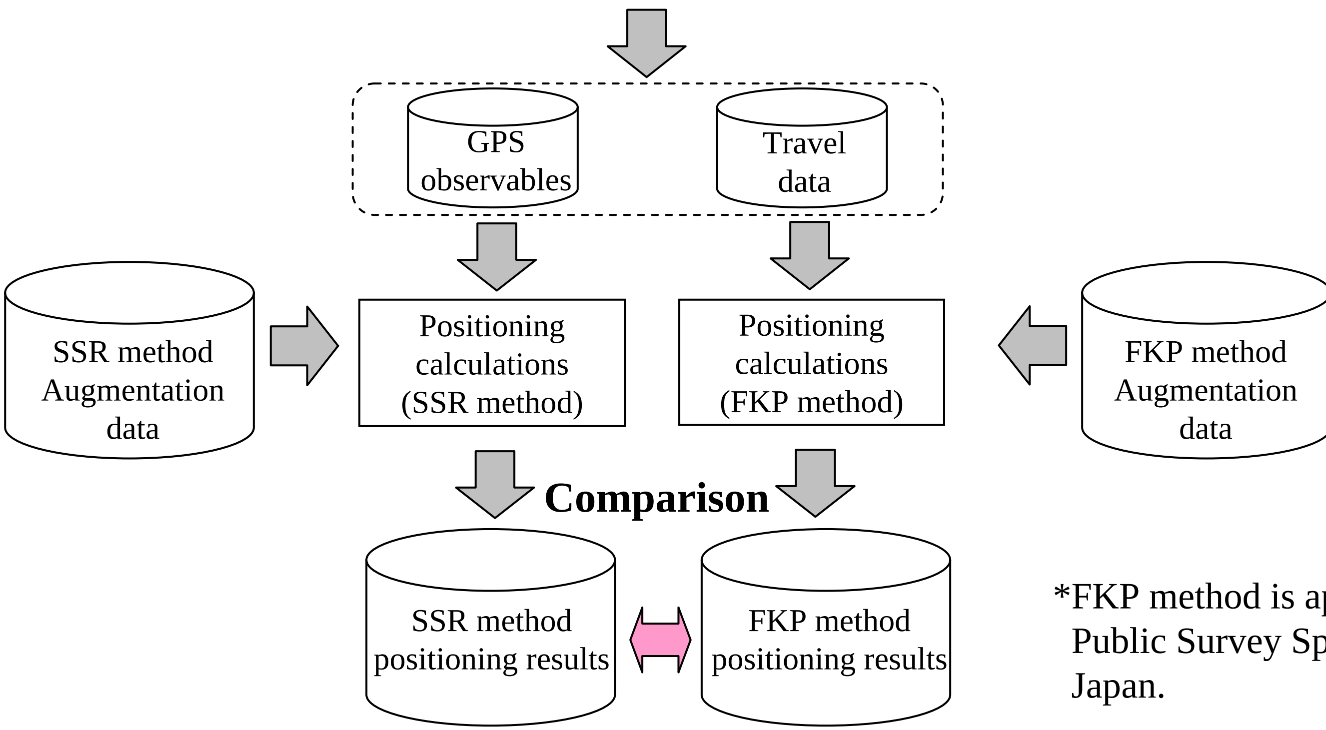
Evaluation items		Accuracy
Horizontal direction	Average error	0.9cm
	Standard deviation (σ)	0.4cm
	Positioning accuracy (drms)	1.0cm
Vertical direction	Average error	-1.2cm
	Standard deviation (σ)	1.4cm
	Positioning accuracy (rms)	1.9cm
3D direction	Positioning accuracy (drms)	2.1cm

Observation: 11 a.m. to 5 p.m. (JST) on 1st January 2011: a total of 6 continuous hours

Experiment for Mobile Positioning

Experiment for mobile Positioning is carried out with MMS equipped with LEX Rover (LEXR), antennas and a LEX signal receiver.

Mobile Mapping System (MMS)



*FKP method is approved in the Public Survey Specification of Japan.

Fig.8. Configuration of the experiment

Result of Real Time Positioning (kinematic)

The same level of positioning accuracy as FKP method which is officially approved as a standard method for public survey in Japan, can be obtained.

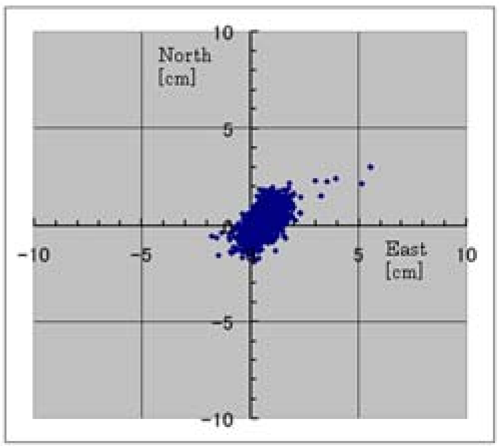


Fig.9. Distribution of difference in the horizontal direction

Tab.5. Real-time positioning result of mobile object

Evaluation items		Difference
Horizontal direction	Average	0.6cm
	Standard deviation	1.2cm
Vertical direction	Average	1.4cm
	Standard deviation	1.9cm

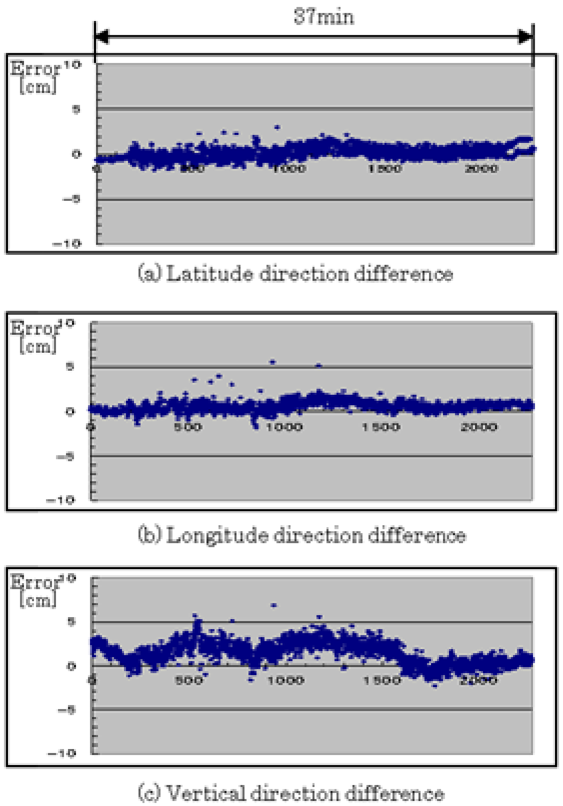


Fig.10. Time variations of difference

Observation: 37 minutes from 10 a.m. (JST) on 23rd December 2010.

Variation in Accuracy for Areas

Tab.6. Variation in accuracy for areas

Network	Accuracy		Fix rate
	Horizontal (drms)	Vertical (rms)	
Hokkaido West	1.2cm	3.0cm	96%
South Tohoku	1.1cm	2.8cm	98%
Kanto	1.3cm	2.7cm	98%
Kansai	1.2cm	3.0cm	97%
Chugoku	1.3cm	2.8cm	97%
Shikoku	1.4cm	2.9cm	98%
South Kyushu	1.2cm	3.2cm	97%
Average	1.2cm	2.9cm	97%

Observation : at West Hokkaido, South Tohoku, Kanto, Kansai, Chugoku, Shikoku, and South Kyushu for 2 days out of February, April, June, August and October in a period of 1 hour from 9 a.m., 12 p.m. and 3 p.m. (JST)

Time to First Fix (TTFF)

We evaluated the fix time of hot start by using some reference stations which were not used for the generation of augmentation data. The cumulated frequency of the fix time achieved 100% at **2.8 sec**. Because another 30 sec is necessary to receive one cycle of Coded SSR message, TTFF in this evaluation was **32.8 sec**.

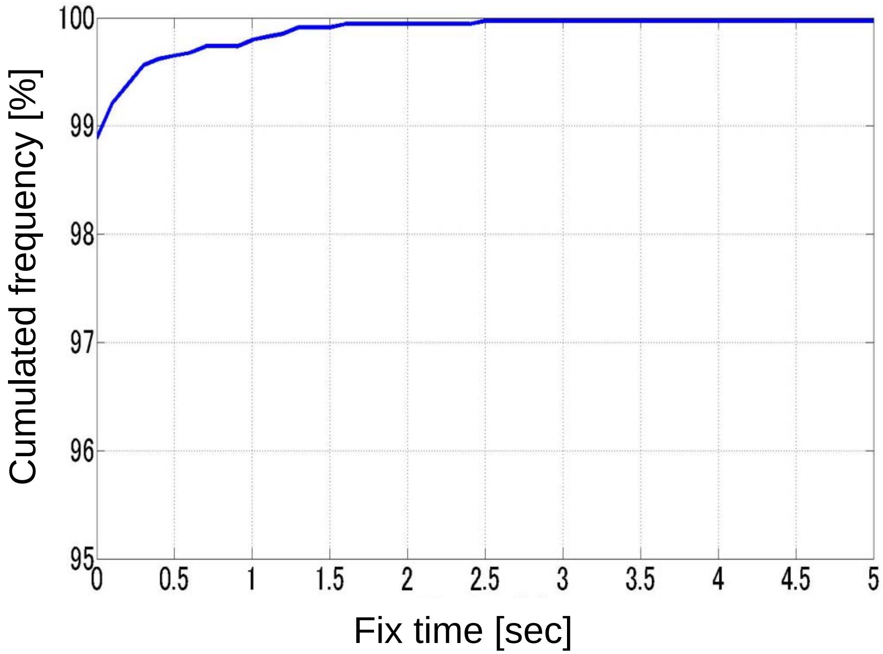


Fig.11. Cumulative frequency distribution of fix time

Observation: 12 p.m. and 1 p.m. (JST) on 4th February 2010
from 7 ERPs in the Kanto network.

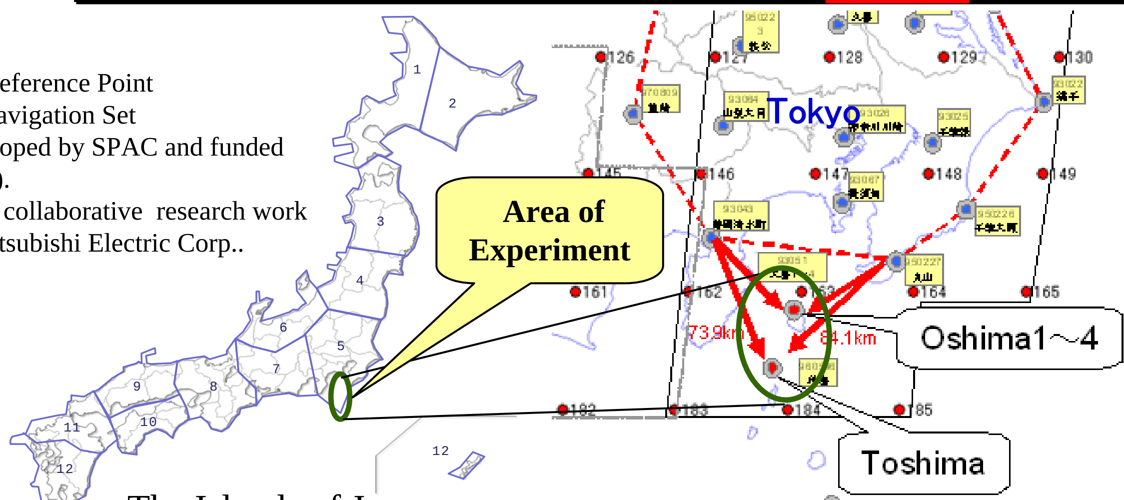
4. Further Examples of the QZS Application

“GPS ocean wave meter” Utilizing QZSS

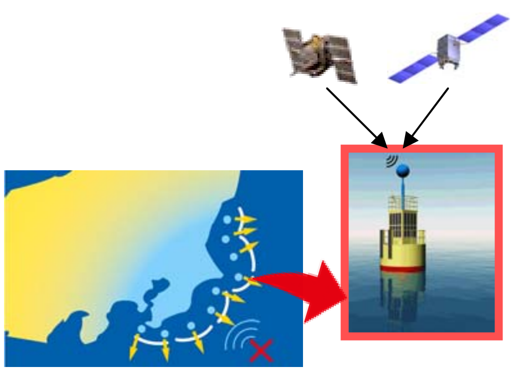
Tsunami is observable with cm-class accuracy on the sea within 50km from the nearest ERP*1.
With QZSS reinforcement and INS*2 integration, continuous 100% positioning can be realized.
CMAS’s cm-class positioning contributes to **Ocean Civil Engineering**, **Maritime Security Operation** and **Maritime Charting**.

ERP		Distance from nearest ERP		Distance from CMAS network border	Positioning Results		
		Shimizu (93043)	Maruyama (950227)		Horizontal	Upward	Fix rate
93051	Oshima1	56.9km	59.4km	31km	2.02cm	2.33cm	100%
960594	Oshima3	62.2km	56.4km	33km	2.14cm	3.29cm	96%
960595	Oshima4	58.8km	63.6km	36km	1.93cm	3.73cm	89%
93055	Oshima2	67.9km	61.2km	41km	2.27cm	5.96cm	83%
960596	Toshima	73.9km	84.1km	53km	1.64cm	2.22cm	90%

*1 ERP: Electric Reference Point
*2 INS : Inertial Navigation Set
- CMAS was developed by SPAC and funded by MEXT (Japan).
- This is a result of collaborative research work by SPAC and Mitsubishi Electric Corp..



The Islands of Japan



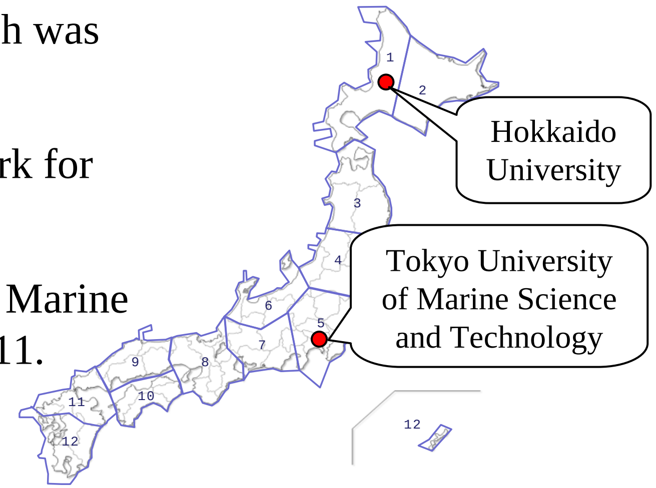
Detection of Tsunami

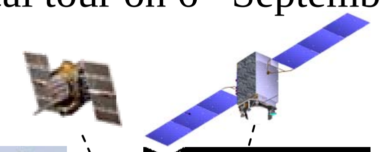
"Automatic Driving of Tractor" Utilizing QZSS

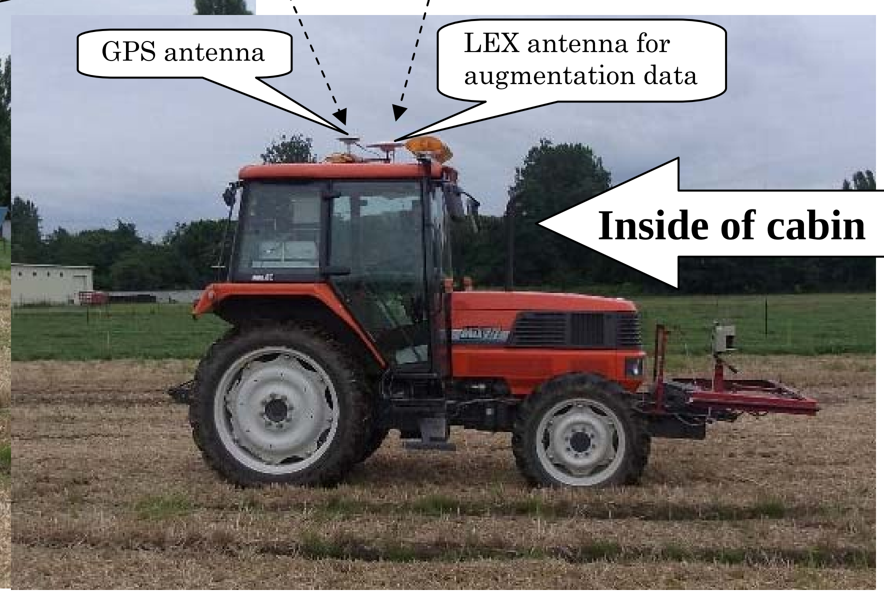
An unmanned tractor with LEX Rover and a LEX signal receiver was driven autonomously with centimeter-class accuracy at the experiment, which was carried out by Hokkaido University on 23rd August 2011.

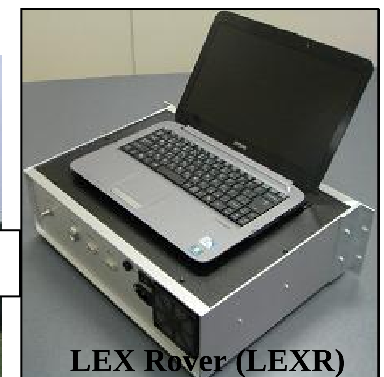
The autonomous vehicle control using LEX signal will efficiently work for valuable applications, such as Farming, Construction and Logistics.

This unmanned tractor was also demonstrated at Tokyo University of Marine Science and Technology in ICG-6 technical tour on 6th September 2011.









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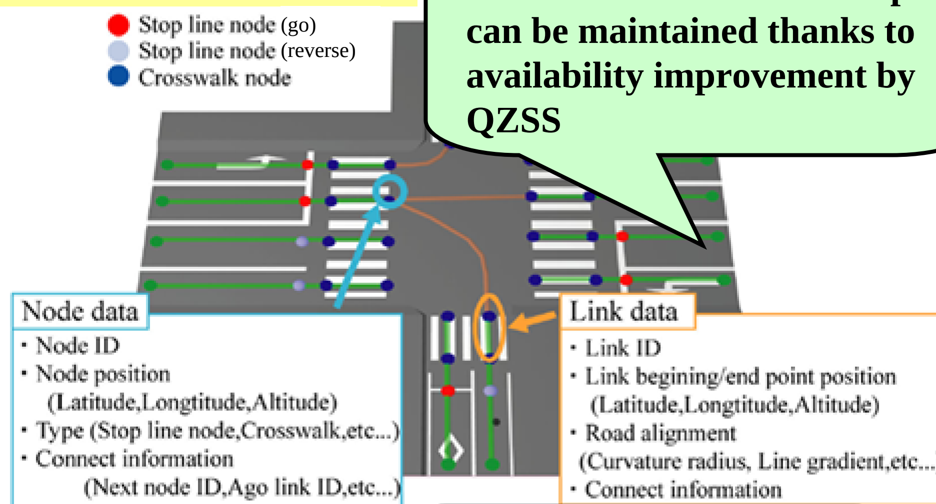
Potential QZSS Application Utilizing "MMS"

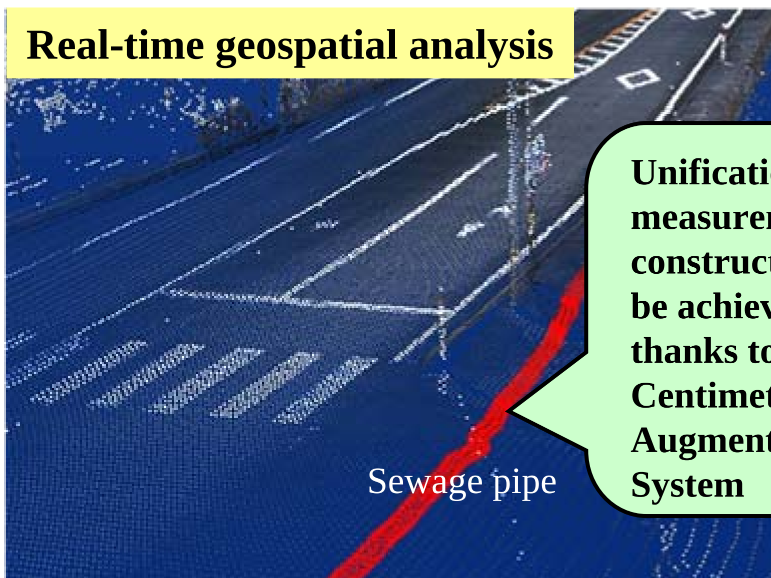
Mobile Mapping System(MMS)

3D digital lane map



Precise 3D intersection map can be maintained thanks to availability improvement by QZSS

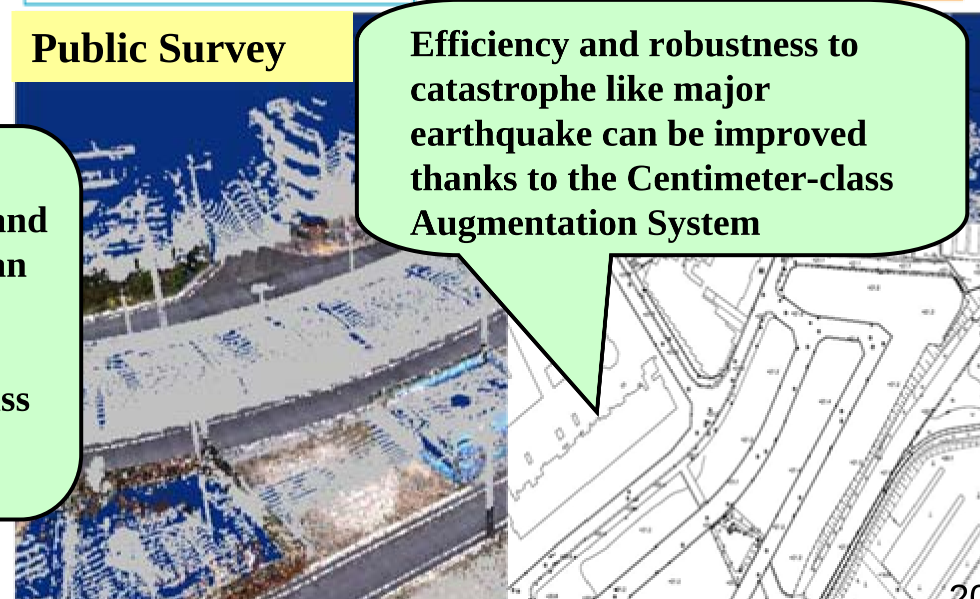
Real-time geospatial analysis



Unification of measurement and construction can be achieved thanks to the Centimeter-class Augmentation System

References:" Image Lab 2011.1 Vol22", p.79

Public Survey



Efficiency and robustness to catastrophe like major earthquake can be improved thanks to the Centimeter-class Augmentation System

References:" Image Lab 2011.1 Vol22", p78-79

5. Conclusion

Conclusion

☆ We developed a pre-practical system for centimeter-class positioning augmentation utilizing the Quasi-Zenith Satellite System.

☆ SSR method is utilized as a correction generation engine.

☆ We performed real-time positioning experiments both for static and kinematic in the field with QZS-1 ‘MICHIBIKI’.

Experimental Result

Same level of accuracy and TTFF as the conventional centimeter-class positioning systems which are publicly approved and used for public survey has been achieved.

Future Plan

The practical realization of the Centimeter-class Augmentation System.
Generation of wide variety of new applications with centimeter-class positioning accuracy.

Thank you for your attention

The development of CMAS by SPAC was made in commission of the “Development and preparation of positioning terminals and a simulator towards the promotion of utilization of QZSS” as a part of the 2009 Earth Observation Technology Survey Research, funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan.