Performance Evaluation of GPS Augmentation Using Quasi-Zenith Satellite System

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Current GPS

- Provides limited availability and capability
- Japan
  - Mountainous terrain
  - Urban canyons

Japan

- Leads the world in the various applications of GPS equipment and services
  - Civil use
- 5.7 million GPS-equipped cellular phones
- 2 million GPS-equipped car navigation units
  - Annually sold

Proposed QZSS

- Japanese Quasi-Zenith Satellite System (QZSS)
- Augments GPS
- Highly elliptic orbit (HEO) satellites orbiting
- GEO-synchronous
- Zenith direction (high elevation angle)
  - Receive signal from at least one of the satellites

Satellite Constellation

- 5 types of satellite constellations
  - Considered with QZSS
- 3 favored types
  - Discussed

QZSS Options

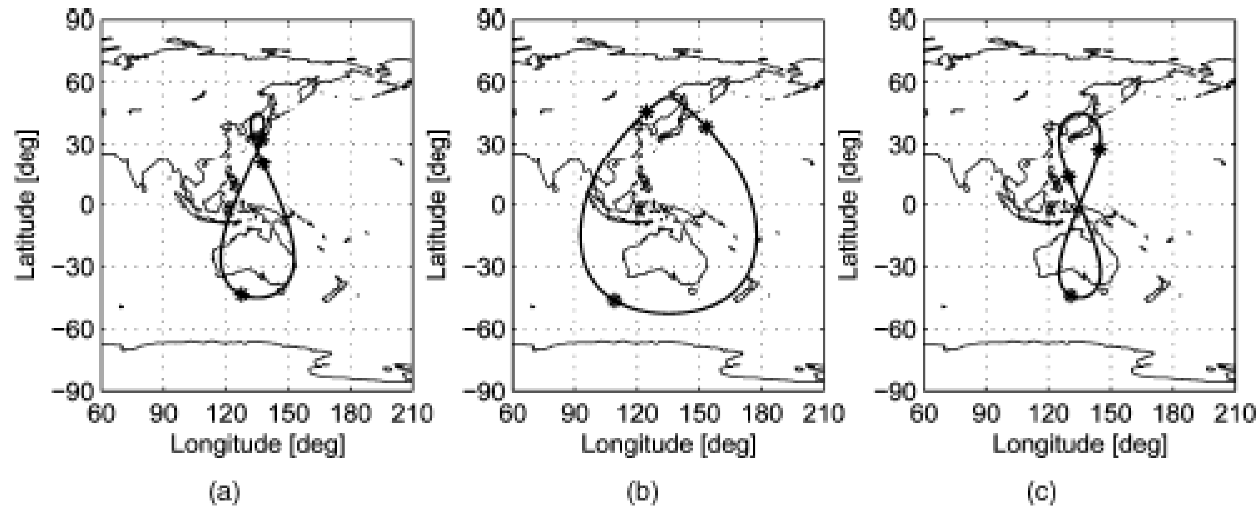


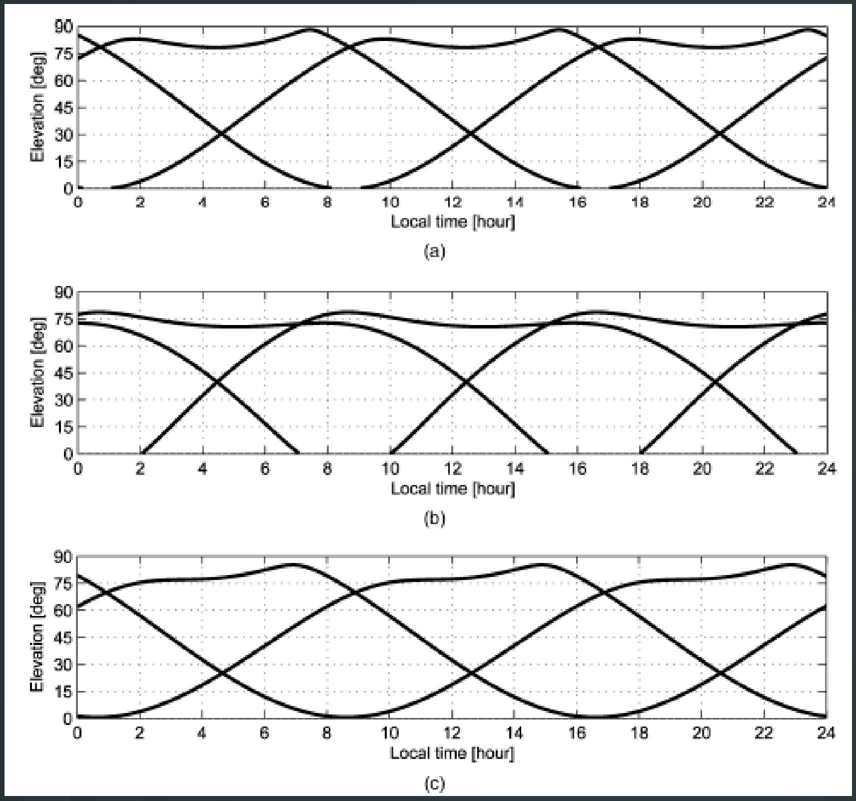
Fig. 1. Ground tracks of three QZSS satellite constellation options. (a) Option 1. (b) Option 2. (c) Option 3.

TABLE I

Parameters of the Three QZSS Satellite Constellation Options

QZSS Option	Ground Track	Number of Satellites	Eccentricity	Inclination	Semi-major Axis
1	Asymmetrical 8 shape	3 + 1	0.099	45.0°	42,164 km
2	Egg-shape	3 + 1	0.360	52.6°	42,164 km
3	Symmetrical 8 shape	3 + 1	0.000	45.0°	42,164 km

- User located in Tokyo
- Track
  - at least 1 QZSS satellite with 70 degree mask elevation
  - 2 QZSS satellites with a 30 degree mask elevation



Signal Structure

- QZSS uses
  - Same signal structure as GPS and Wide Area Augmentation System (WAAS)
  - Pseudorandom noise (PRN) code

TABLE II
Possible Signals of GPS and QZSS, with Corresponding Frequencies, Wavelengths, and Typical Code Measurement Accuracies

Signal	Frequency [MHz]	Wavelength [m]	Typical Code Measurement Accuracy σ_p [m]
L1	1575.42	0.1903	0.30
L2	1227.60	0.2442	0.30
L5	1176.45	0.2548	0.10

DOP

- Dilution of precision
  - Measure for geometrical strength
- Lower the DOP is, higher the quality of the position estimate
- GDOP is applied to evaluate the performance of positioning with code

Ambiguity Success Rate

- Obtained once all these are known
  - Functional model
  - Stochastic model
  - Integer ambiguity estimator
- Used to elevate the capability of carrier-phase-based positioning
- Higher
  - Better the performance

Software Simulations

TABLE III
Configuration of all Scenarios Considered in the Simulations

	System	GPS, GPS+QZSS (three options)
Functional model	Baseline model	Single medium length baseline (20 km), roving-receiver geometry-based model
	Mask elevation	30°
	Number of epochs used for each solution	1
	Number of frequencies	2 (L1 and L2)
Stochastic model	Code standard deviation	$\sigma_P = 0.300$ m
	Phase standard deviation	$\sigma_\phi = 0.003$ m
	Ionospheric model	Ionosphere-weighted model, $\sigma_I = 0.020$ m
	Tropospheric delay	$\sigma_T = 0.010$ m
	Integer Ambiguity Estimation	Bootstrapped Estimator
Spatial simulation	Date and time	May 15, 2003, 12:00
	Location	Asian-Pacific and Australian area (Latitude: 90° S–90° N, Longitude: 60°–210°)
Temporal simulation	Date and time	May 15, 2003, 00:00–May 15, 2003, 24:00
	Location	Tokyo ($35^\circ39'59''$ N, $139^\circ47'32''$ E)
Output	Spatial variation Temporal variation	Number of visible satellites, GDOP, and ambiguity success rate

Spatial Variations

TABLE IV
Spatial Variations of the Number of Visible Satellites, GDOP, and Ambiguity Success Rate for Different Constellations

System			GPS Only	GPS+QZSS 1	GPS+QZSS 2	GPS+QZSS 3
Whole Area	Number of Visible Satellites ≥ 4		85.51%	95.67%	92.21%	95.40%
Positioning available area (GPS only)	Number of visible satellites	MIN	4	4	4	4
		MAX	8	11	11	11
		MEAN	5.20	6.40	6.17	6.46
	GDOP	MIN	2.98	2.48	2.63	2.46
		MAX	607.30	52.52	75.13	53.25
		MEAN	14.45	7.10	10.01	6.90
	Ambiguity success rate	MIN	28.93%	28.93%	28.93%	28.93%
		MAX	98.78%	99.81%	99.81%	99.82%
		MEAN	64.53%	84.27%	78.05%	84.02%

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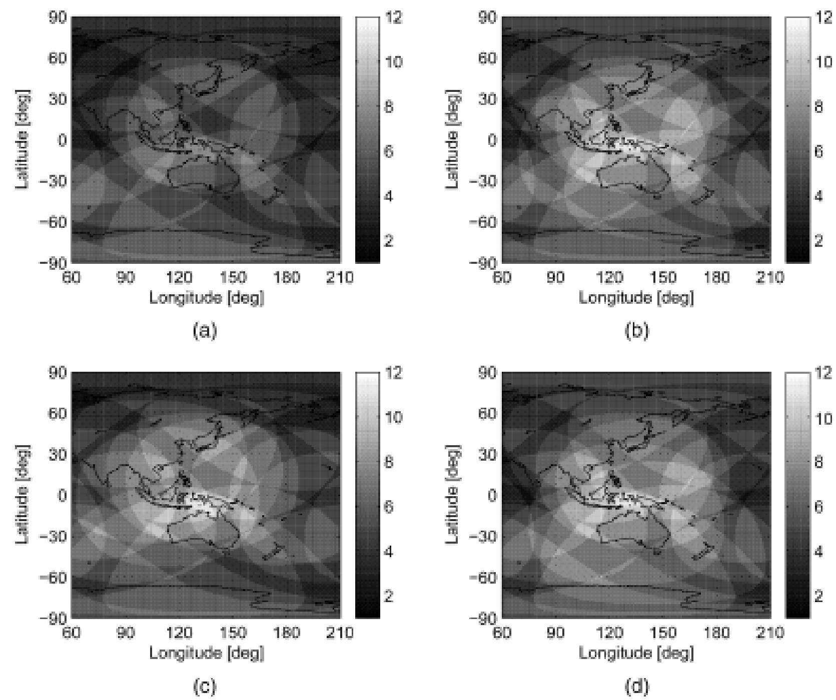

Fig. 3. Spatial variations of number of visible satellites for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

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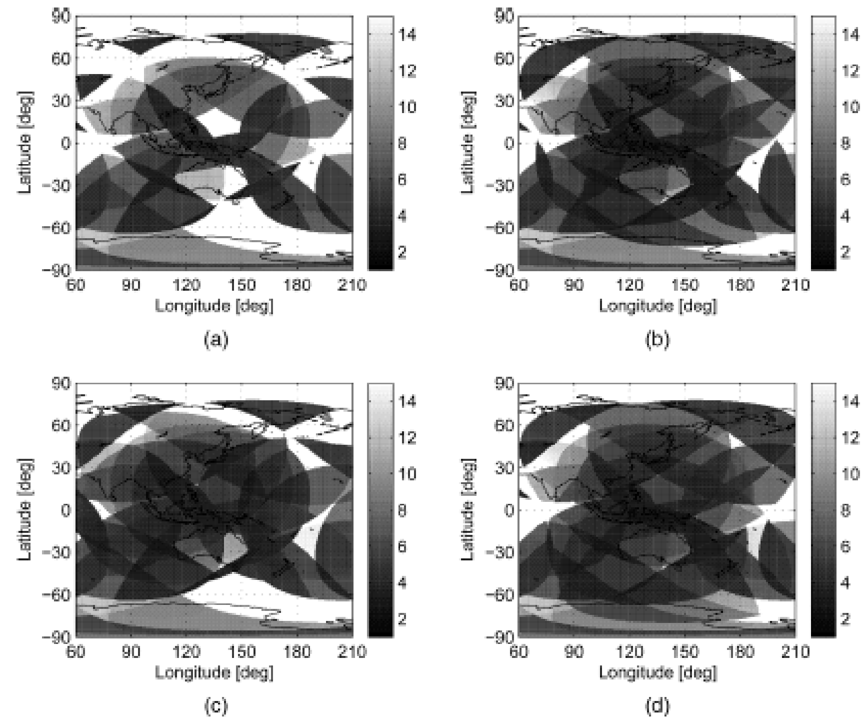

Fig. 4. Spatial variations of GDOP for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

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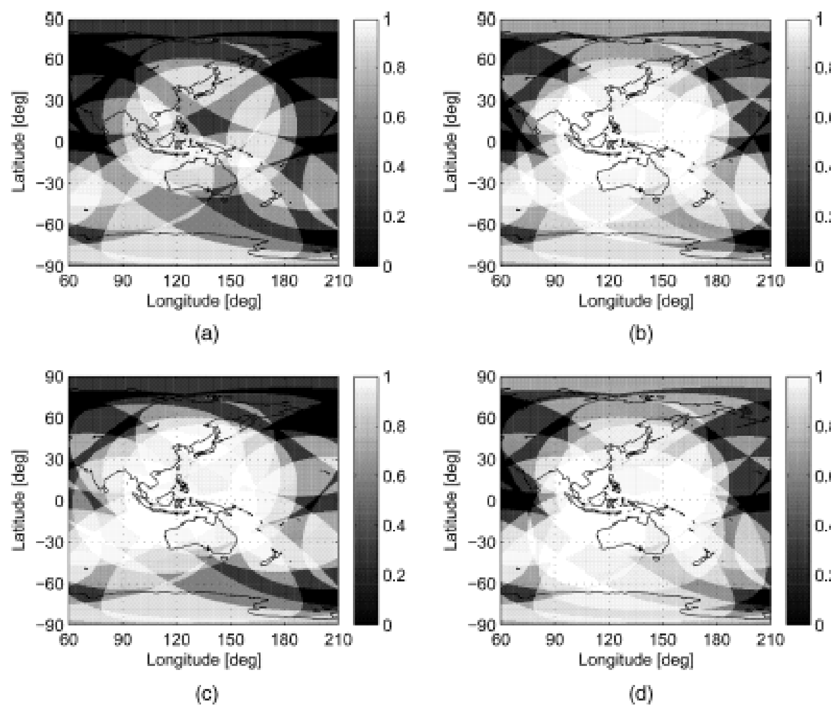

Fig. 5. Spatial variations of ambiguity success rate for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

Spatial Variations

- Improve the satellite visibility
- Extend the positioning available area
- Offer better GDOP
- Improve the capability of carrier phase positioning
  - Japan and neighboring regions
- 1st option
  - More favorable availability, accuracy, and capability of carrier-phase-based positioning

Temporal Variations

TABLE V
Temporal Variations of the Number of Visible Satellites, GDOP and Ambiguity Success Rate for Different Constellations in Tokyo

	System		GPS Only	GPS+QZSS 1	GPS+QZSS 2	GPS+QZSS 3
Whole Time	Number of Visible Satellites ≥ 4		91.40%	100.00%	100.00%	100.00%
Positioning available time (GPS only)	Number of visible satellites	MIN	4	6	5	5
		MAX	8	10	10	10
		MEAN	4.93	6.94	7.07	6.81
	GDOP	MIN	2.88	2.37	2.43	2.44
		MAX	1672.75	12.81	38.51	12.65
		MEAN	11.78	4.78	5.44	4.85
	Ambiguity success rate	MIN	28.93%	72.40%	40.79%	49.23%
		MAX	98.27%	99.47%	99.43%	99.55%
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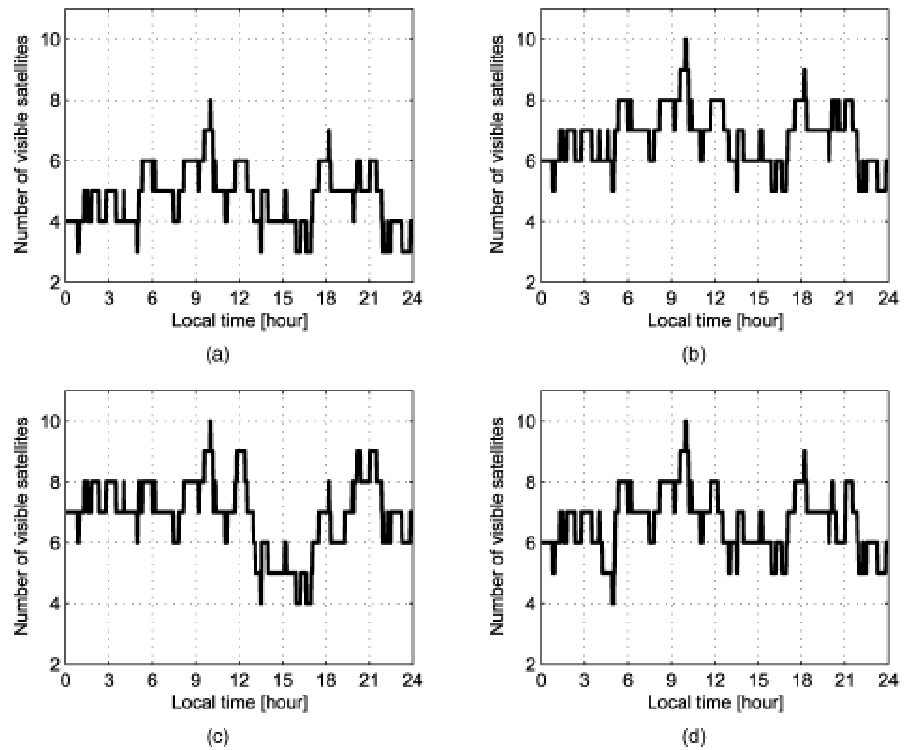

Fig. 6. Temporal variations of number of visible satellites for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

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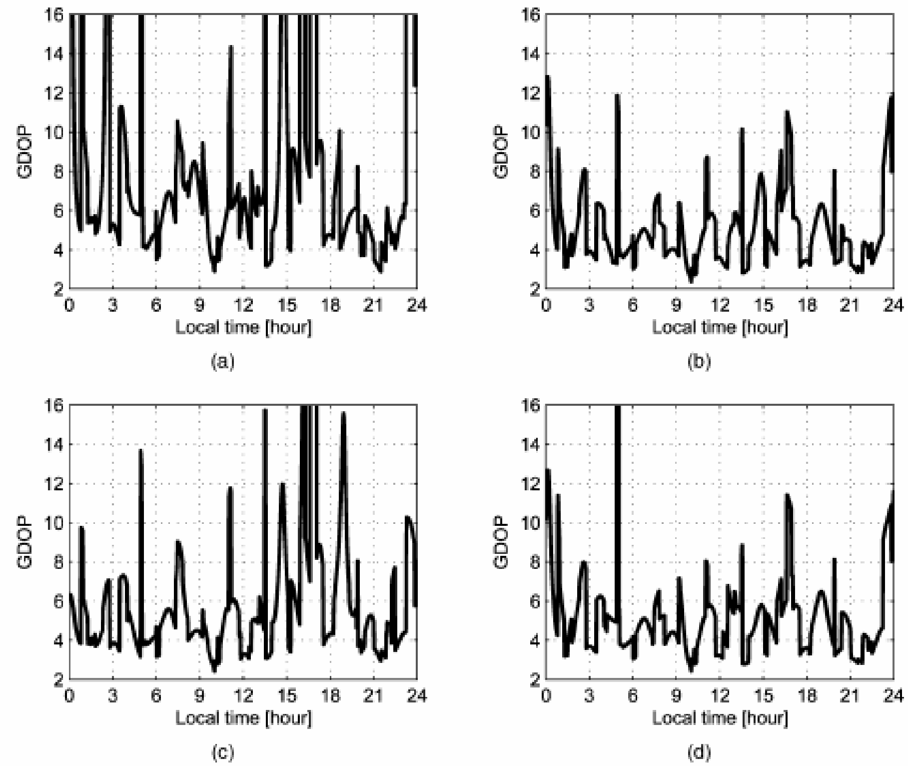

Fig. 7. Temporal variations of GDOP for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

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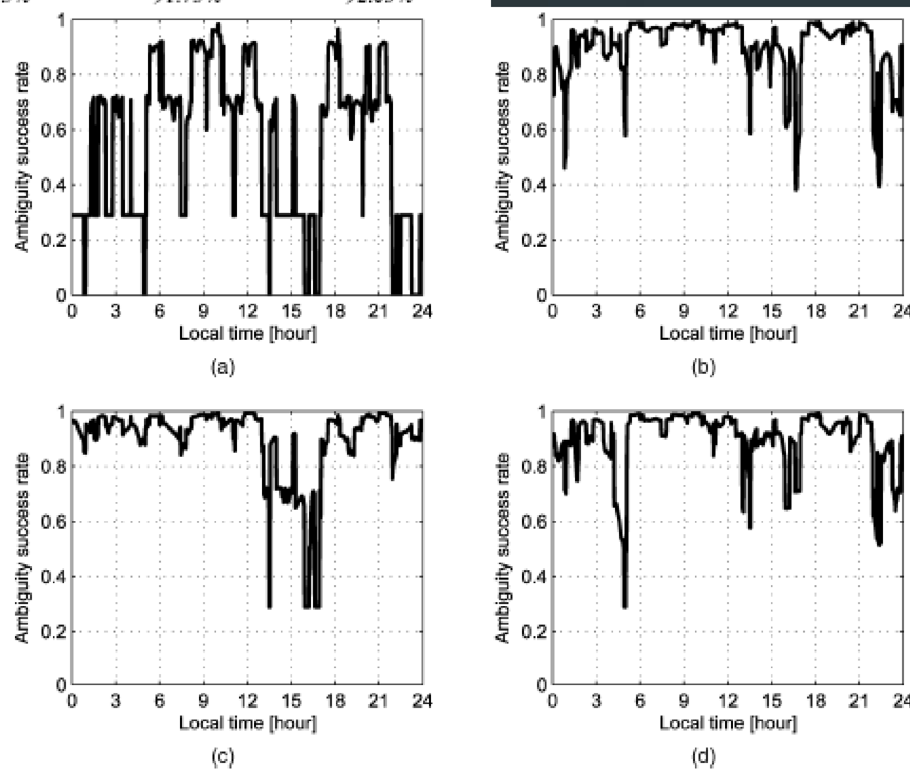

Fig. 8. Temporal variations of ambiguity success rate for different constellations. (a) GPS only. (b) GPS and QZSS option 1. (c) GPS and QZSS option 2. (d) GPS and QZSS option 3.

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- Extend the positioning available area
- Offer better GDOP
- Improve the capability of carrier phase positioning
  - Japan
- 1st option
  - More favorable accuracy and capability of carrier-phase-based positioning

Conclusion

- Improve the satellite visibility
- Extend the positioning available area
- Offer better GDOP
- Enhance the capability of carrier phase positioning
- 1st QZSS option
  - Best for Japan
- 3rd QZSS option
  - Best for the whole Asian-Pacific and Australia area