Instantaneous RTK Positioning with Altitude-aiding for ITS Application

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Background

- Future ITS services will include autonomous ground vehicle navigation and dynamic prevention of traffic accidents.
- The key technology is real-time high accuracy positioning within ~10cm.
- One of the candidates is "**Instantaneous RTK positioning**".

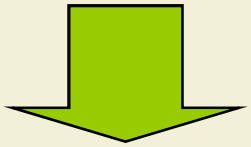
Motivation

- Early studies

Number of papers by Delft, NSW and Calgary
Instantaneous AR (1990, Hatch)
Single-Epoch AR for Highway and Racetrack Applications (2001, Shinko etc.)
Fast AR for Marine Navigation (2003, Falin wu etc.)
Epoch-by-Epoch^{TM} (2003, Bock etc.)

- New viewpoints in this study

Instantaneous AR in the relatively open sky have been already discussed.
However, **Instantaneous AR in urban areas is rarely discussed because the performance is too poor to discuss.**



The objective of this paper is to improve availability of Instantaneous AR in urban areas.

Present RTK Condition in Urban Areas

- Good line-of-sight signal reception is absolutely necessary for RTK. (as a top priority)
- Two main reasons why the RTK service is not good in urban areas.

1. The number of visible satellites (NVS) decreases due to the number of high buildings and the cycle slips take place frequently. →**NVS vs. RTK**
2. Signals from the satellites can be easily affected by multipath. →**Multipath vs. RTK**

The reasons behind these factors were investigated.

Number of Visible Satellites vs. RTK

- A **FIX rate** in **single-epoch** RTK was investigated using the observation data of Geographical Survey Institute (GSI) in Japan. (open sky, L1+L2)
- Outline of Analysis

- Period is 1 week in 2007 (every 30 sec.)
- Baseline is 0.3km and 13.3km
- LAMBDA and Modified Hatch
- **Single-epoch AR for the number of visible satellites was calculated**

Single-epoch means AR is resolved using only single-epoch observation
FIX rate means the percentage of correct fixing times

Results

LAMBDA: FIX rate every number of satellites

	Mask	5	6	7	8	9	10	11
0.3km	15 °	100	99.2	99.9	100	100	100	100
13.3km	20 °	75.6	88.6	94.7	97.7	99.2	100	

Modified Hatch: FIX rate every number of satellites

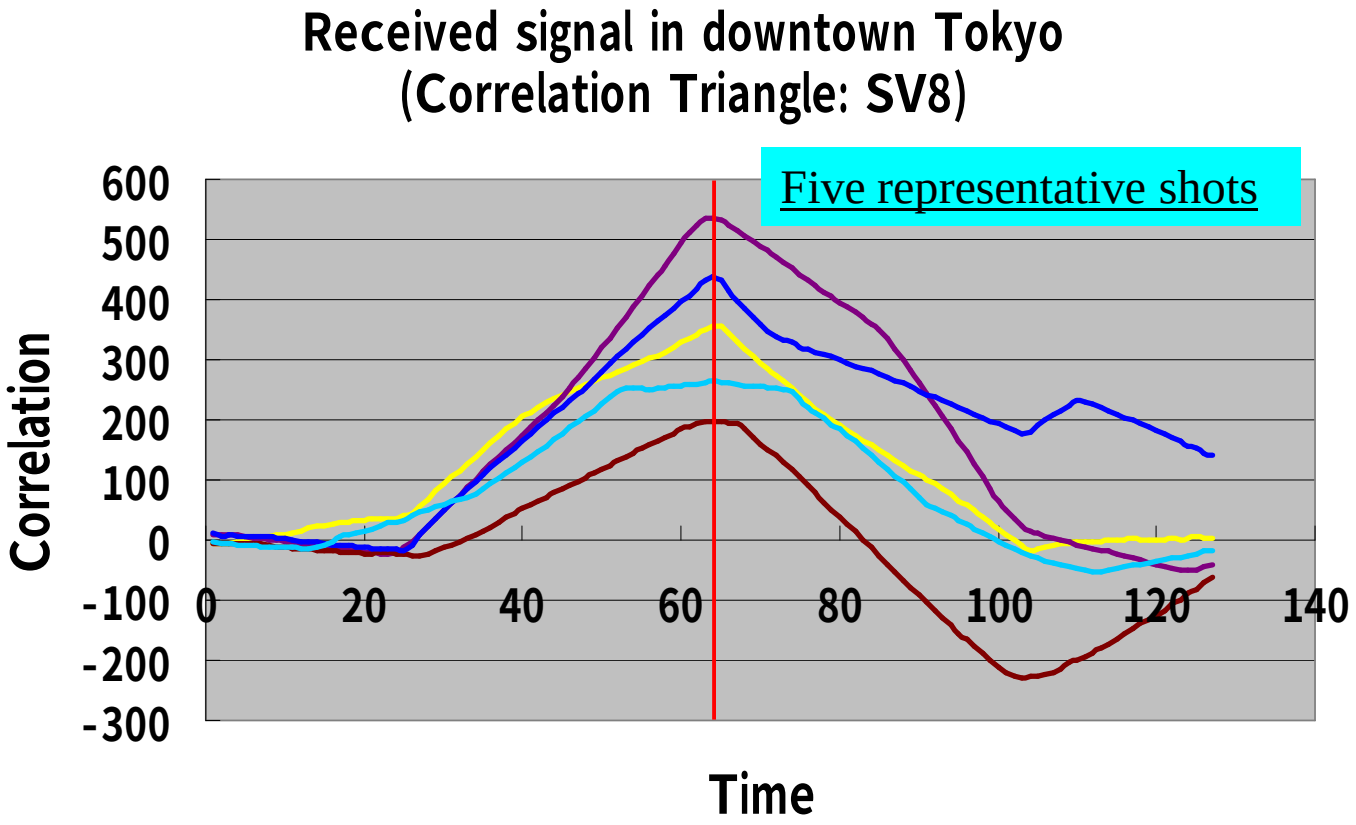
	Mask	5	6	7	8	9	10	11
0.3km	10 °	47.6	81.7	93.6	98.5	99.1	99.8	99.9
13.3km	10 °	19.7	63.7	92.0	97.0	98.6	98.7	99.6

FIX rate in all epochs ⟶

	0.3km / 13.3km
LAMBDA:	99.9% / 90.5%
Modified Hatch:	96.0% / 94.1%

In difficult situations, it would be difficult to maintain a high FIX rate due to the type of bias errors.

Multipath vs. RTK



SQM receiver
by ENRI,Furuno

Bandwidth :20MHz
Sampling :40MHz

Useful to grasp
multipath condition

The AR performance strongly depends on code and carrier multipath errors.

Improving RTK Performance

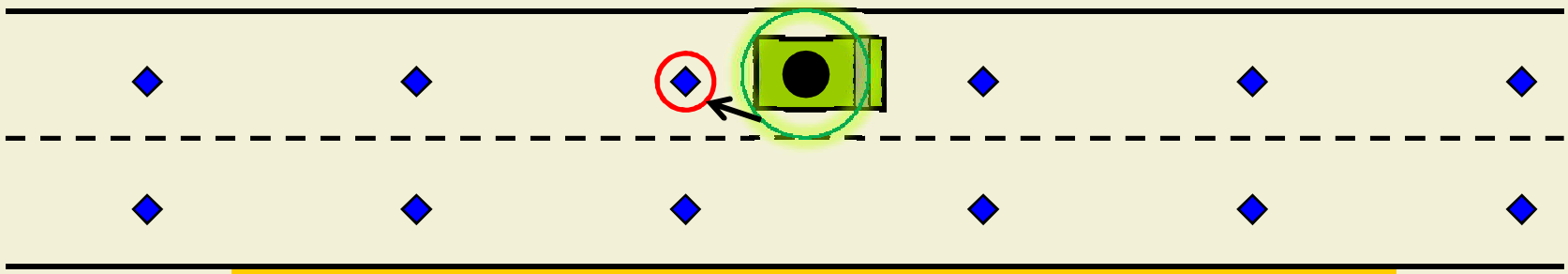
- High quality service in RTK positioning requires the accurate pseudorange, carrier phase and the good geometry of many visible satellites.

1. The advent of Galileo and QZS
2. The modernization of GNSS
3. Reduction of multipath errors
4. Fault detection and exclusion of satellites from the positioning
5. Combining RTK with INS or other sensors

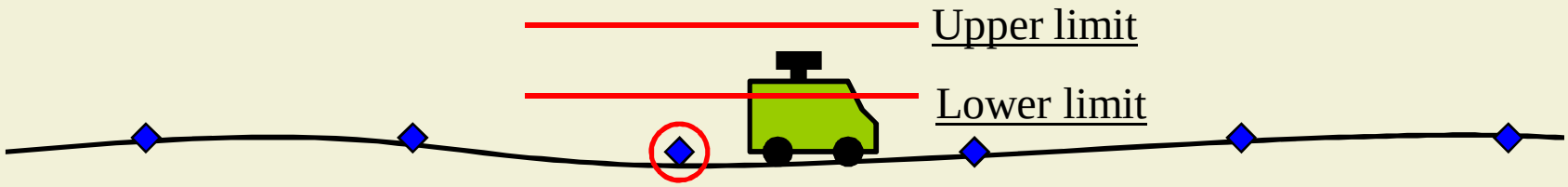
In this paper, the precise map information (altitude-aiding) was used to improve RTK performance.

Ambiguity Resolution with Altitude-aiding

- **Precise map table has accurate height profiles corresponding to the horizontal positions in the course. Beforehand, it has to be prepared.**

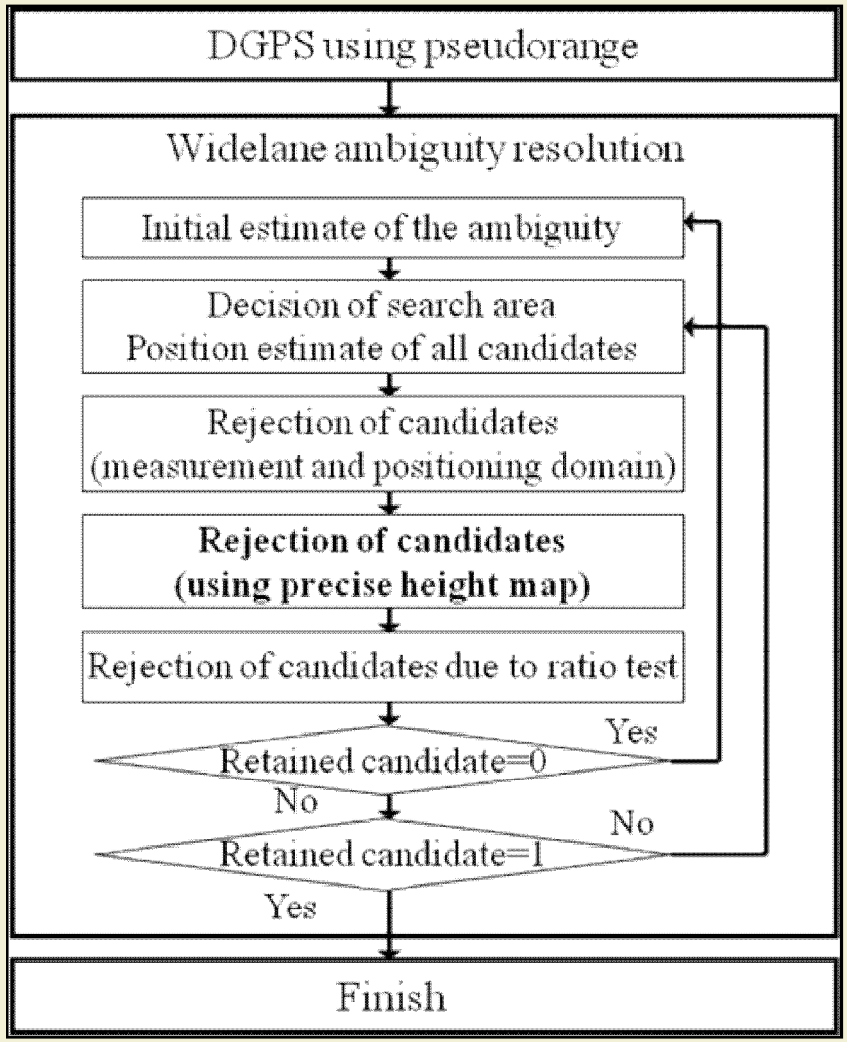


Step1: From the DGPS horizontal positions, the closest point in precise map is determined.



Step2: From the height profile in this point, the upper and lower limit is determined (±50cm).

Flowchart of the Ambiguity Resolution

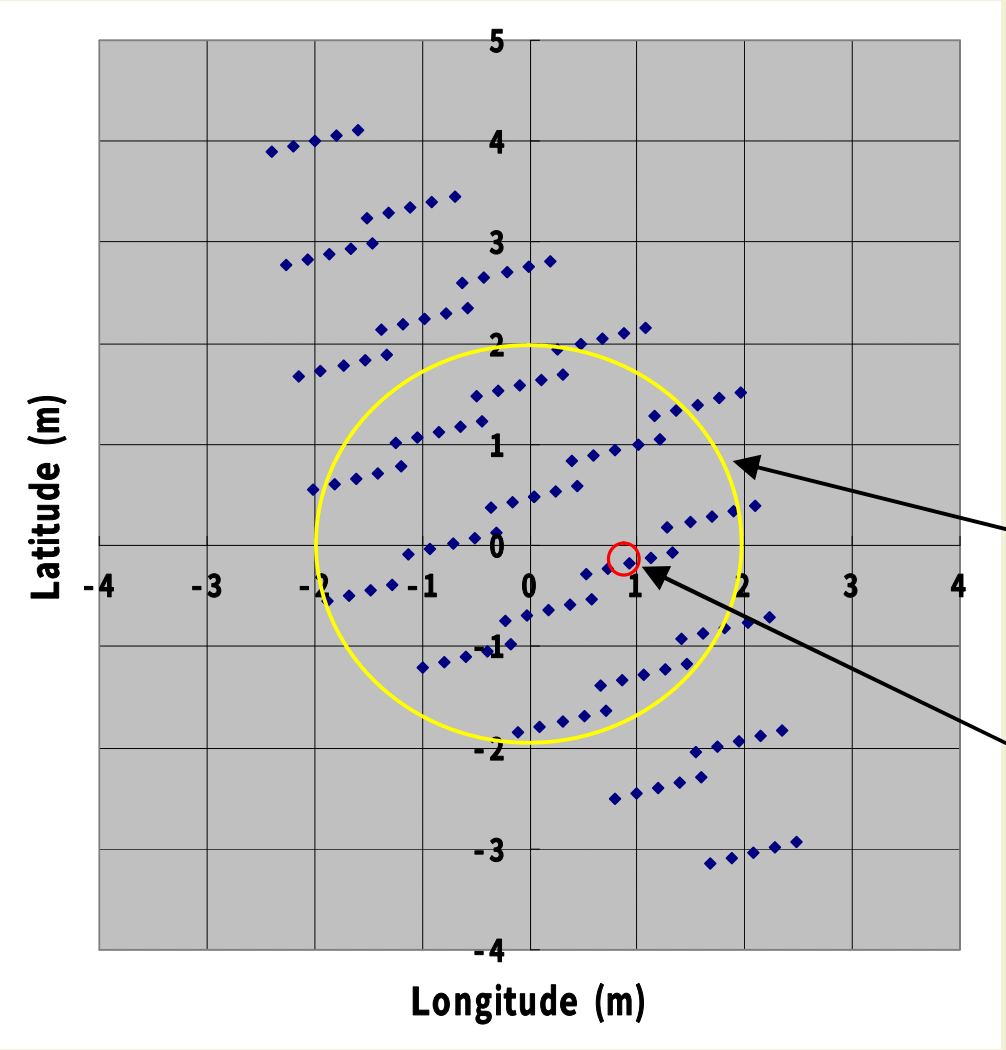


- The AR algorithm is based on Hatch method.
- Wide-lane
- Atmospheric errors were not considered.
- Primary and Secondary

(Primary group includes 4 satellites. If we search ±2 DD wide-lane ambiguities, 5*5*5=125 candidates

The following 3 slides show the good examples of rejection of candidates in the actual car data.

Test in the Positioning Domain

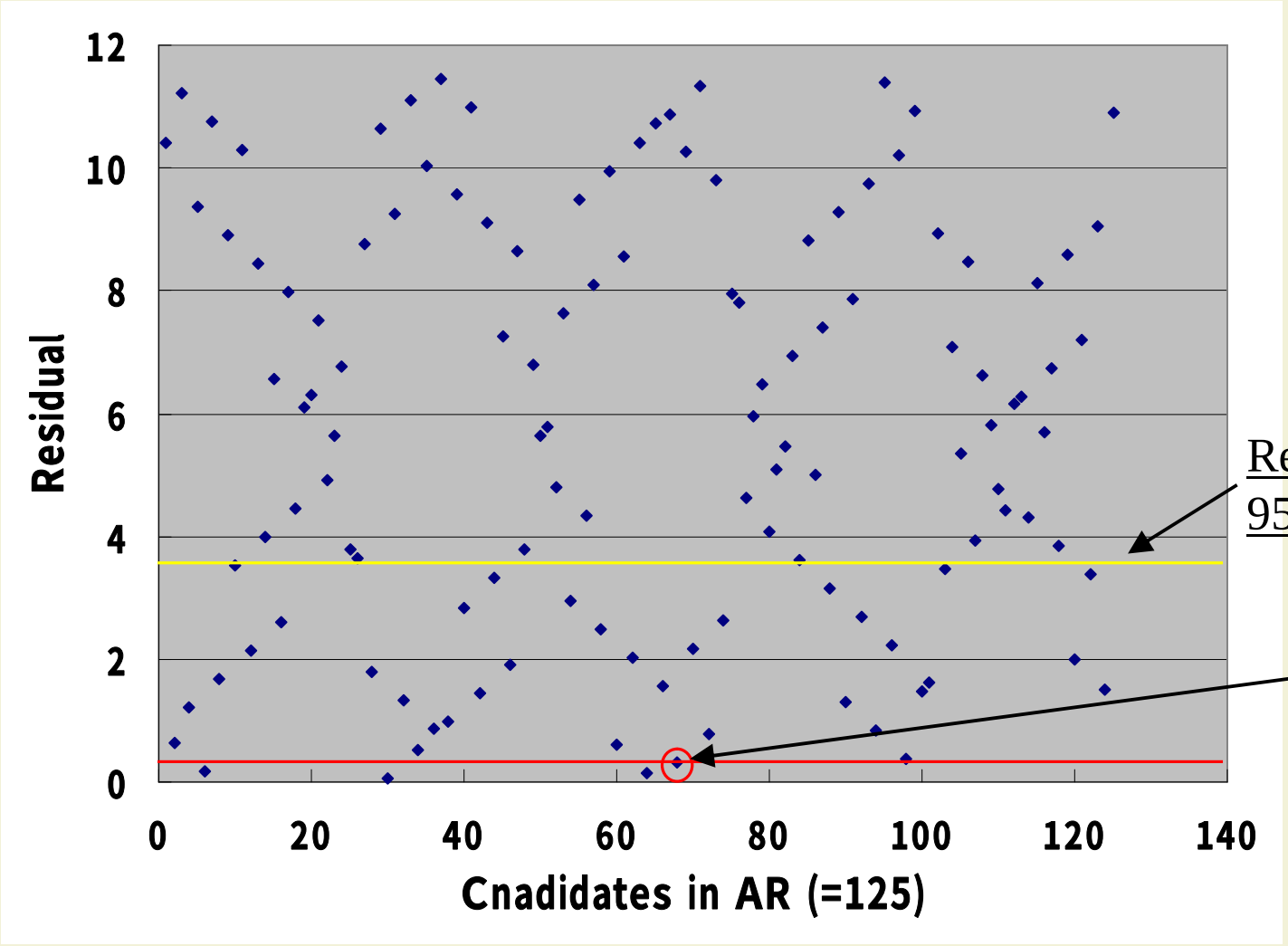


Car in the urban area
125 candidates
GPSTIME=197079
NVS=5
(0,0)→DGPS position

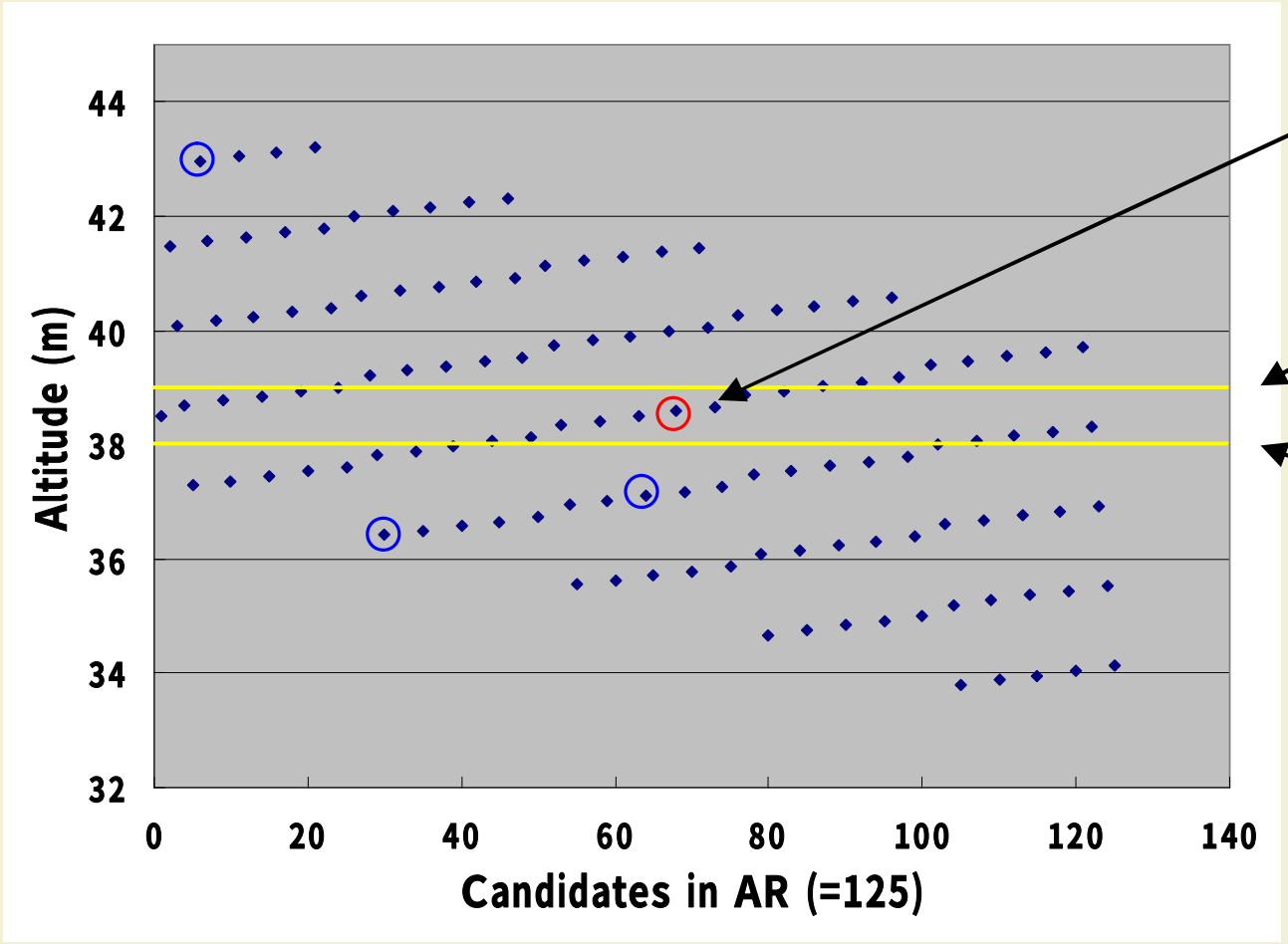
The horizontal search area of 95% confidence level

Correct candidate

Test in the Measurement Domain



Rejection of Candidates by Altitude-Aiding



Correct candidate

Upper limit by precise map info.

Lower limit by precise map info.

By using altitude-aiding before the measurement domain test shown in this figure, the wrong candidates can be rejected. As a result, the correct candidate is retained.

Street Test

Photograph of the test course

The precise map of this course has been prepared in advance by means of our post-processing software.

The raw GPS data were obtained by car in downtown Tokyo on March, 2007.

The distance of this course : 550m
Car went back and forth 3 times.

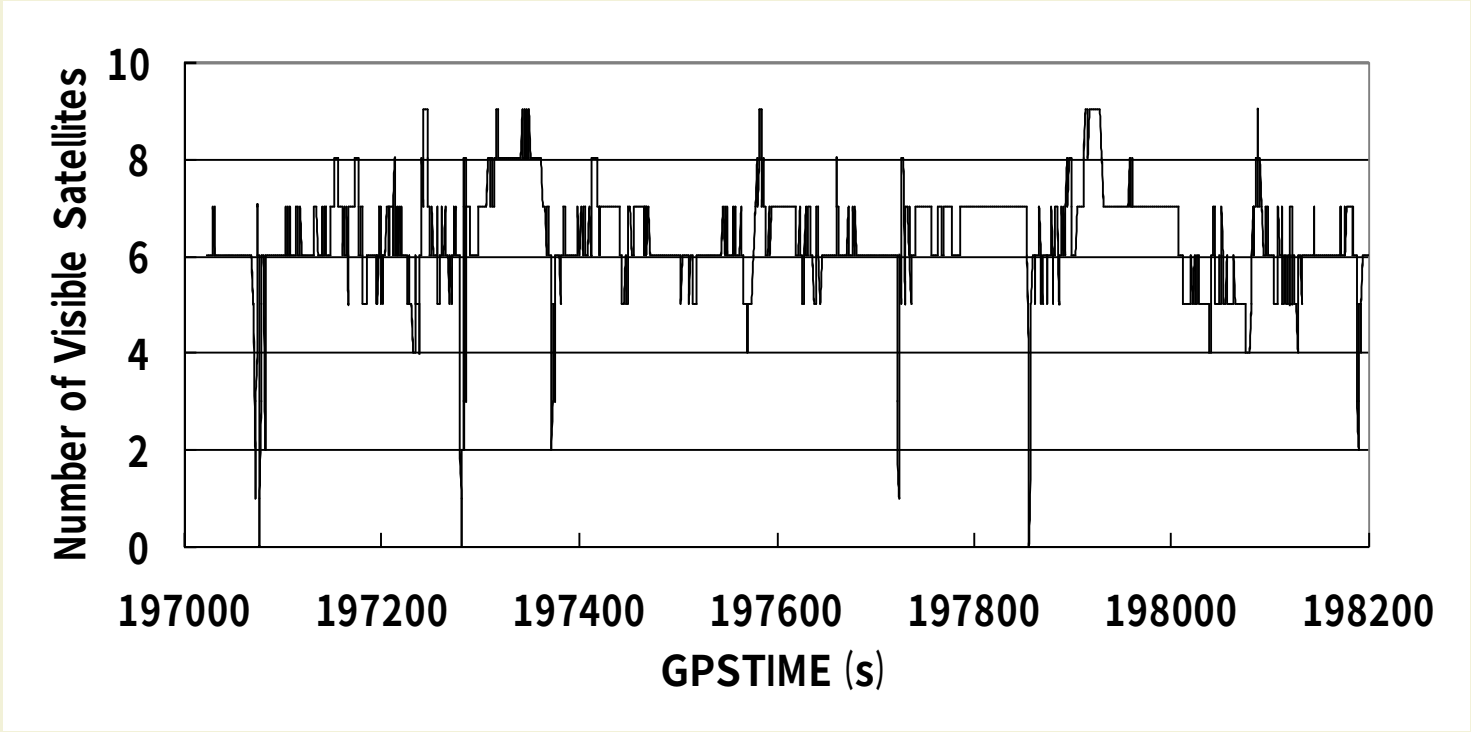
It was surrounded by some medium-rise buildings and a pedestrian bridge.

The maximum speed was 40km/h and the entire time was 20 min.

GPS receiver : NovAtel OEM4
GPS antenna : NovAtel GPS702
Baseline : within 1 km.

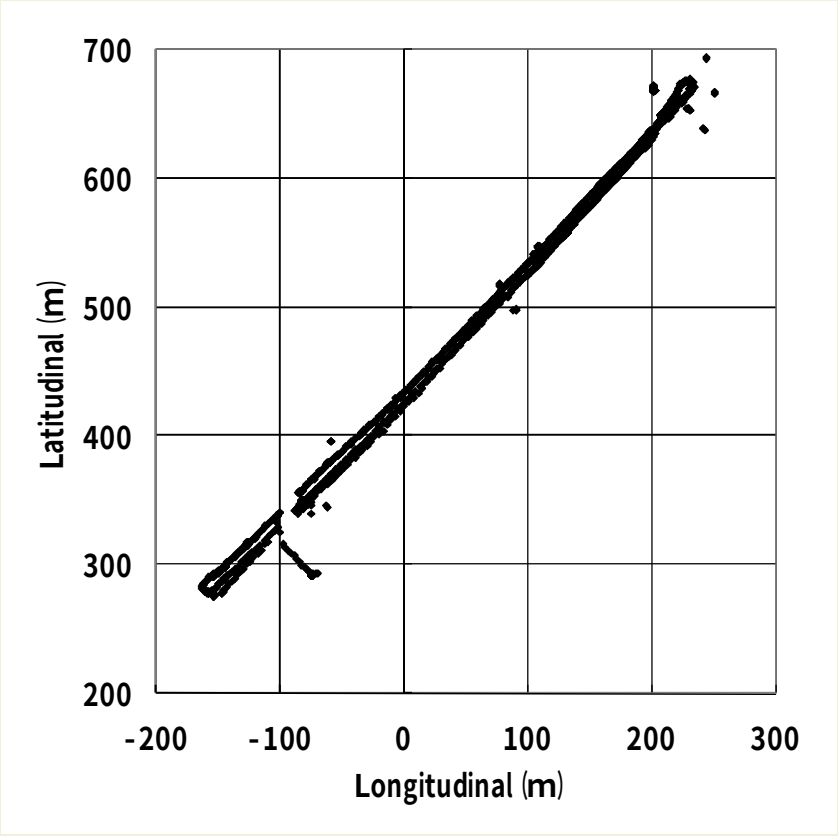
The rover antenna was installed on the rooftop in the car.

Temporal Variation of the Number of Visible Satellites in the Car



- Since the road width was relatively wide, the average number of visible satellites was 6.3. The percentage of the period with 5 or more visible satellites was around 97%

Horizontal Positions in DGPS



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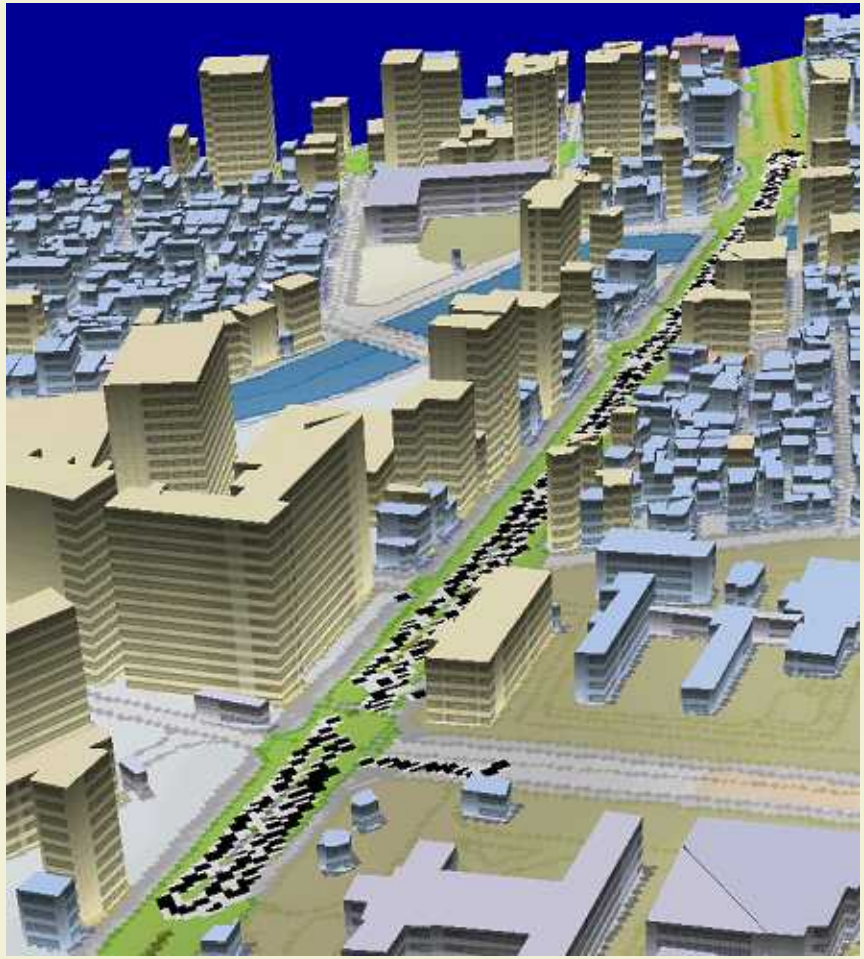
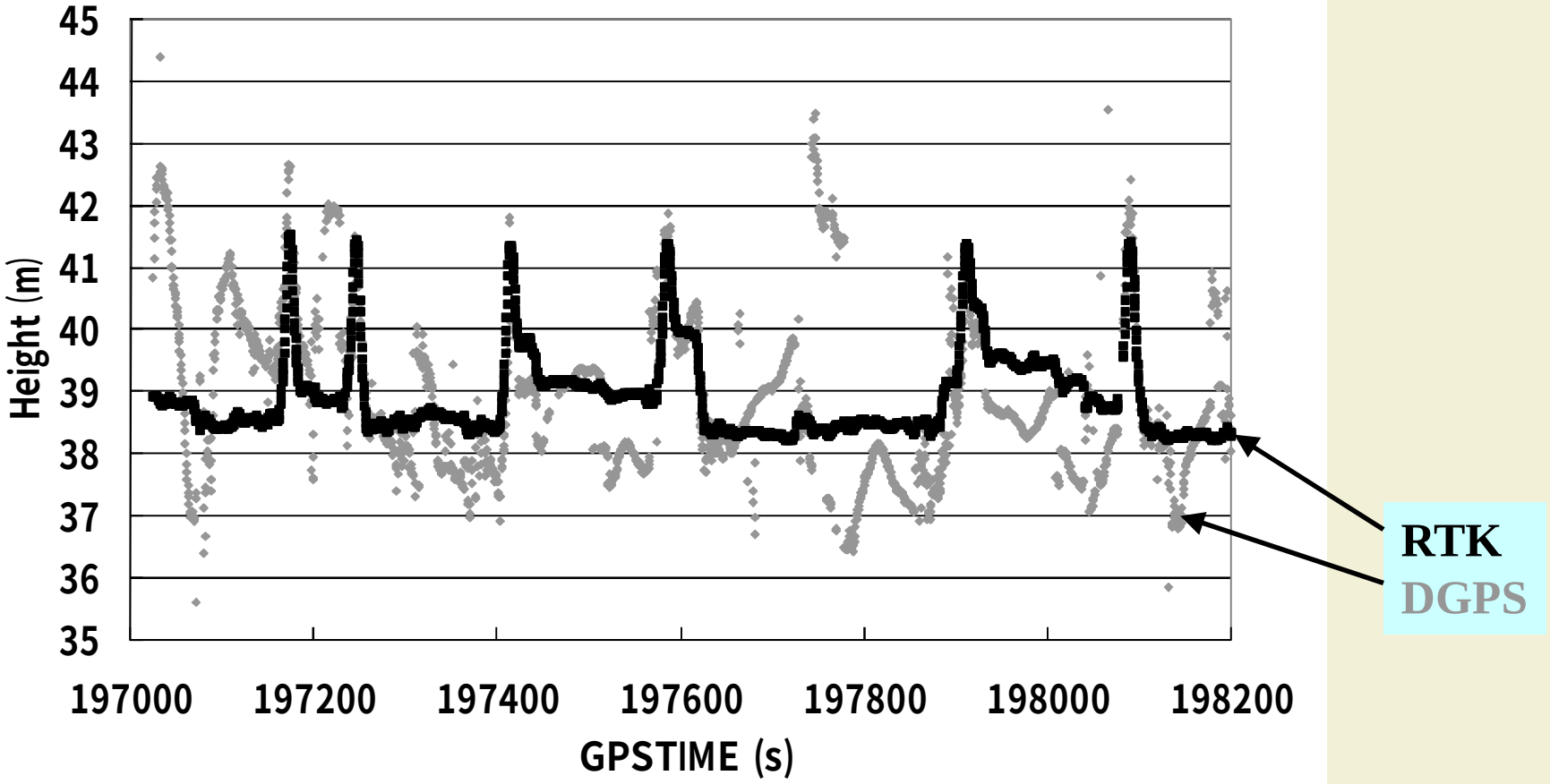


Horizontal Positions in 3D map

Height in both RTK and DGPS



Ambiguity Fix Percentage

	Proposed	Conventional
FIX rate	**90.0%**	**47.5%**
Single-epoch FIX rate	**100.0%**	**63.2%**

- The single-epoch FIX rate is equal to the correct fixing times in single-epoch when divided by the number of correct fixing times.
- In this experiment, when the ambiguities were correctly determined, it turned out that every time to fix was single-epoch in all the cases.

Impressions of Our Proposed Method

- A few tests have been performed in the different environments in 2007.
- In the **open sky area**, the candidate with minimum residual is almost correct.
- In the **urban area**, a few candidates sometimes left. In these cases, the candidate that is closest to DGPS result tends to be correct.
- In the **dense urban area**, it has same tendency. But availability is considerably low due to insufficient NVS.

Summary and Future Plans

- **The ambiguity resolution with altitude-aiding has been demonstrated.**
- **In this test, FIX rate was improved more than 40% by using our proposed method. Further, single-epoch FIX rate was dramatically improved.**
- **This proposed method can improve RTK performance as long as the precise map is prepared.**

- **The AR algorithm will have to be modified .**
- **Another test will be performed.**
- **Our proposed method with other sensors will be considered.**