Cooperative Relative Positioning for Intelligent Transportation System

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Outline

- Research background on ITS
- Related work on dealing with reflected signals in positioning
- Proposed scheme: cooperative relative positioning
- Simulation evaluation
- Initial experiment results
- Conclusion

Research Background

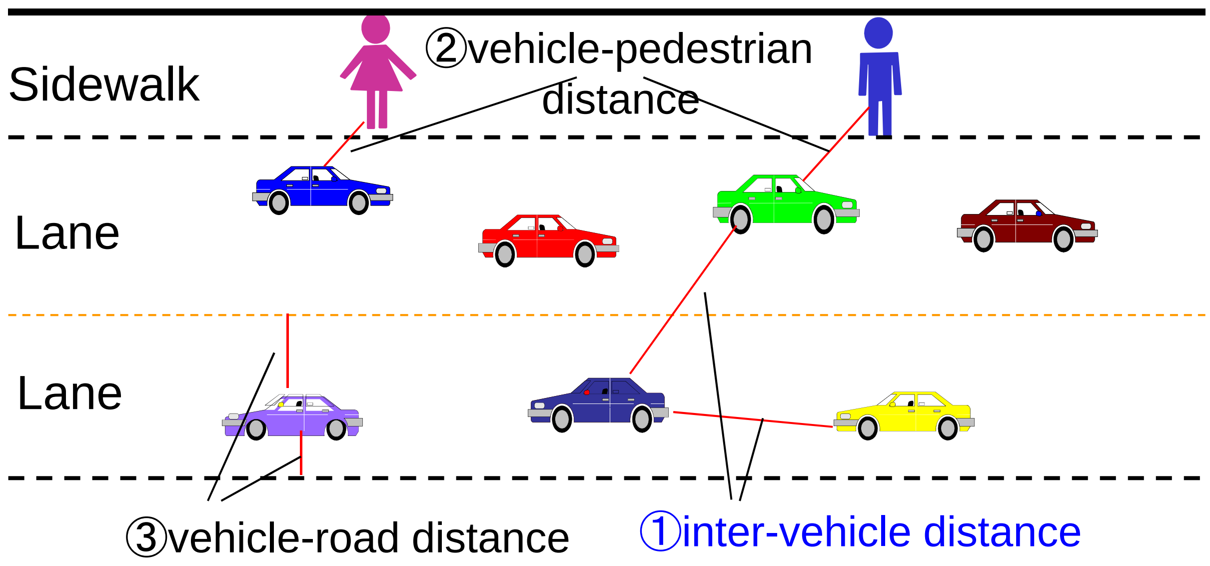
Typical applications of ITS

- Drive-thru data communications

- Car navigation
- ETC
- Support system for safe driving

- Inter-vehicle relative position
  - GPS positioning + inter-vehicle communications
  - Problem: degradation of positioning accuracy in urban areas

Support system for safe driving: Maintain three distances



Related Work

- Propagation of positioning signals in urban area
  - Reflected signal instead of line-of-sight signal due to obstruction and reflection
  - Cannot be well solved by DGPS [1][5]

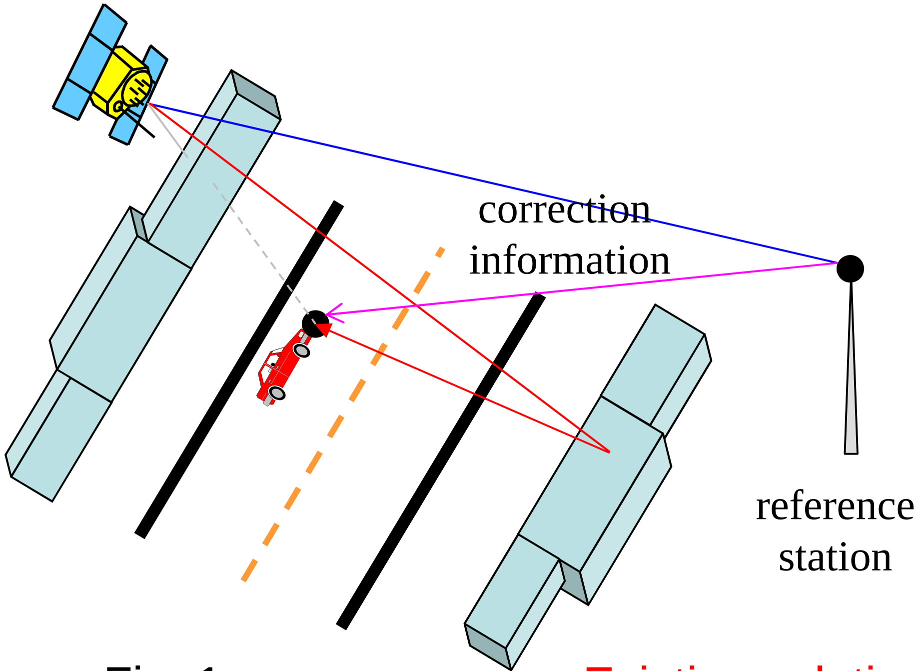


Fig. 1

Existing solutions to reflected signals

(1) Antenna design
(2) Correlator refinement [6-8]
(3) Modulation design [9]
(4) Carrier smoothing [10]
(5) Signal separation
Multipath estimating delay lock loop [11]
Spatial sampling via antenna array [12]
(6) Detection of line-of-sight path
3D GIS database [13]
Infrared camera [14]

Existing solutions: detection and removal of reflected signals

Dilemma in absolute positioning

- Using reflected signal leads to degradation of positioning accuracy
- Removing reflected signals leads a shortage of satellites and increases the outage probability

System Model

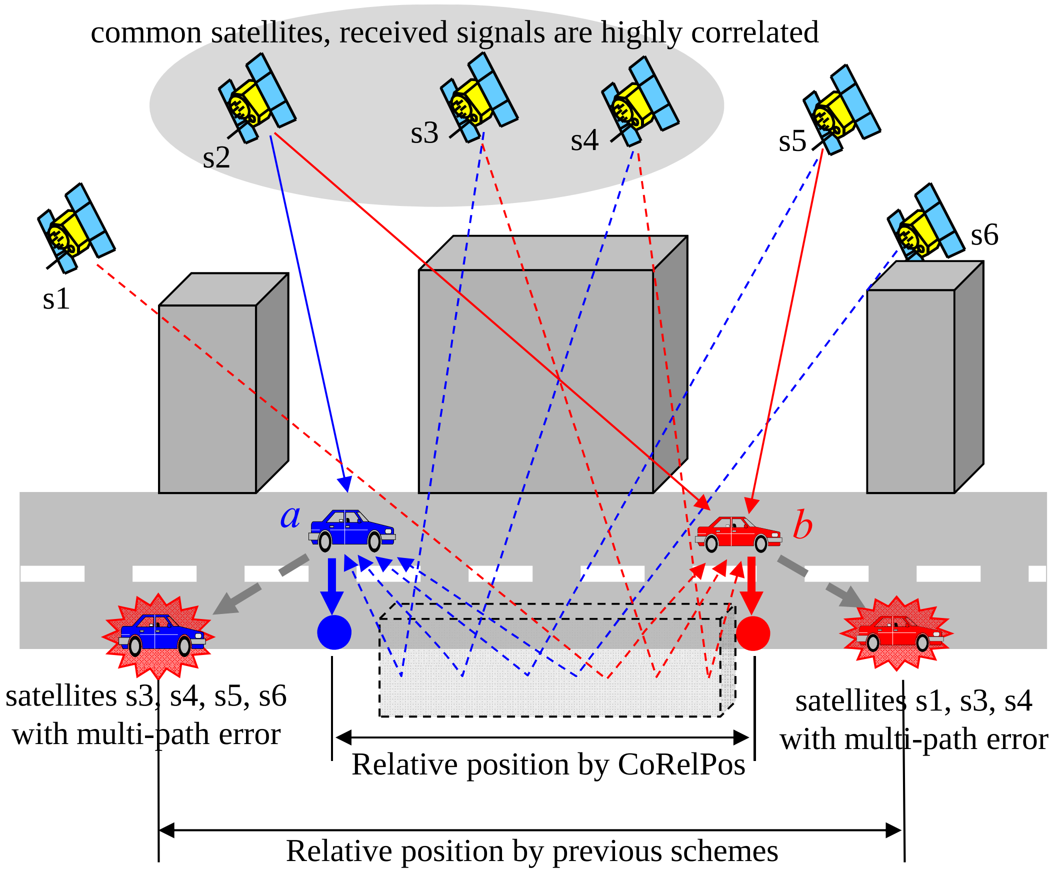


Fig. 2

- Target: improving accuracy of relative position of vehicles in urban area
- Effect of obstruction of buildings
  - Different views of the sky
- Separate selection of satellites
  - Different trends of errors
- Possible correlation of reflected signals
  - Short inter-vehicle distance
  - Reflected by same building
- Using correlated signals
  - Correct relative position

Correlation Detection

Pseudo-range
(vehicles : $n = a, b$
satellites : $s = k, l$)

Errors with spatial correlation

$$p_n^{(s)} = \rho_n^{(s)} + c\cdot(\Delta t_n - \Delta T^{(s)}) + d_{ion,n}^{(s)} + d_{trop,n}^{(s)} + \varepsilon_n^{(s)}$$

Measured pseudo-range | true range | receiver clock error | satellite clock error | ionosphere delay | troposphere delay | noise MP error

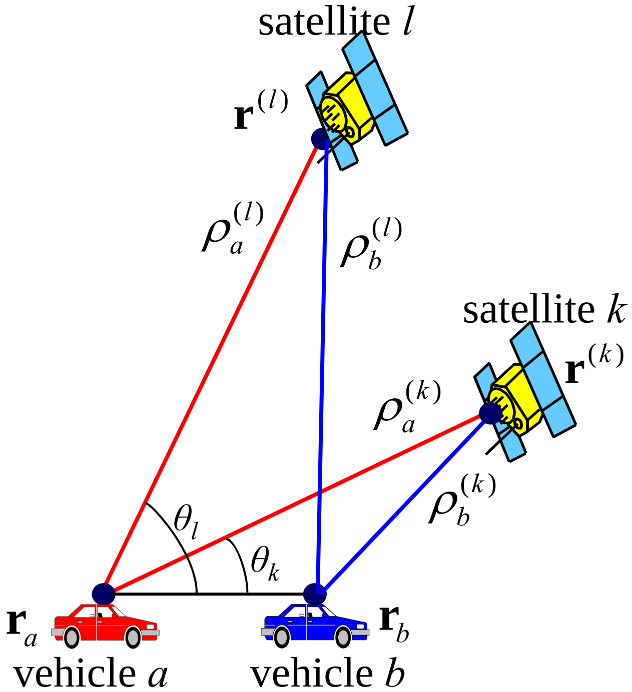


Fig. 4

- Reference satellite l (high elevation angle): both vehicles receive direct signals
- Correlation detection on common satellite k

Double difference of measured pseudo-ranges

$$p_{ab}^{(kl)} = \rho_{ab}^{(kl)} + (\varepsilon_a^{(k)} - \varepsilon_b^{(k)}) - (\varepsilon_a^{(l)} - \varepsilon_b^{(l)})$$

MP errors of satellite k — Approx. 0

DD of true ranges $\rho_{ab}^{(kl)} = (\rho_a^{(k)} - \rho_b^{(k)}) - (\rho_a^{(l)} - \rho_b^{(l)})$

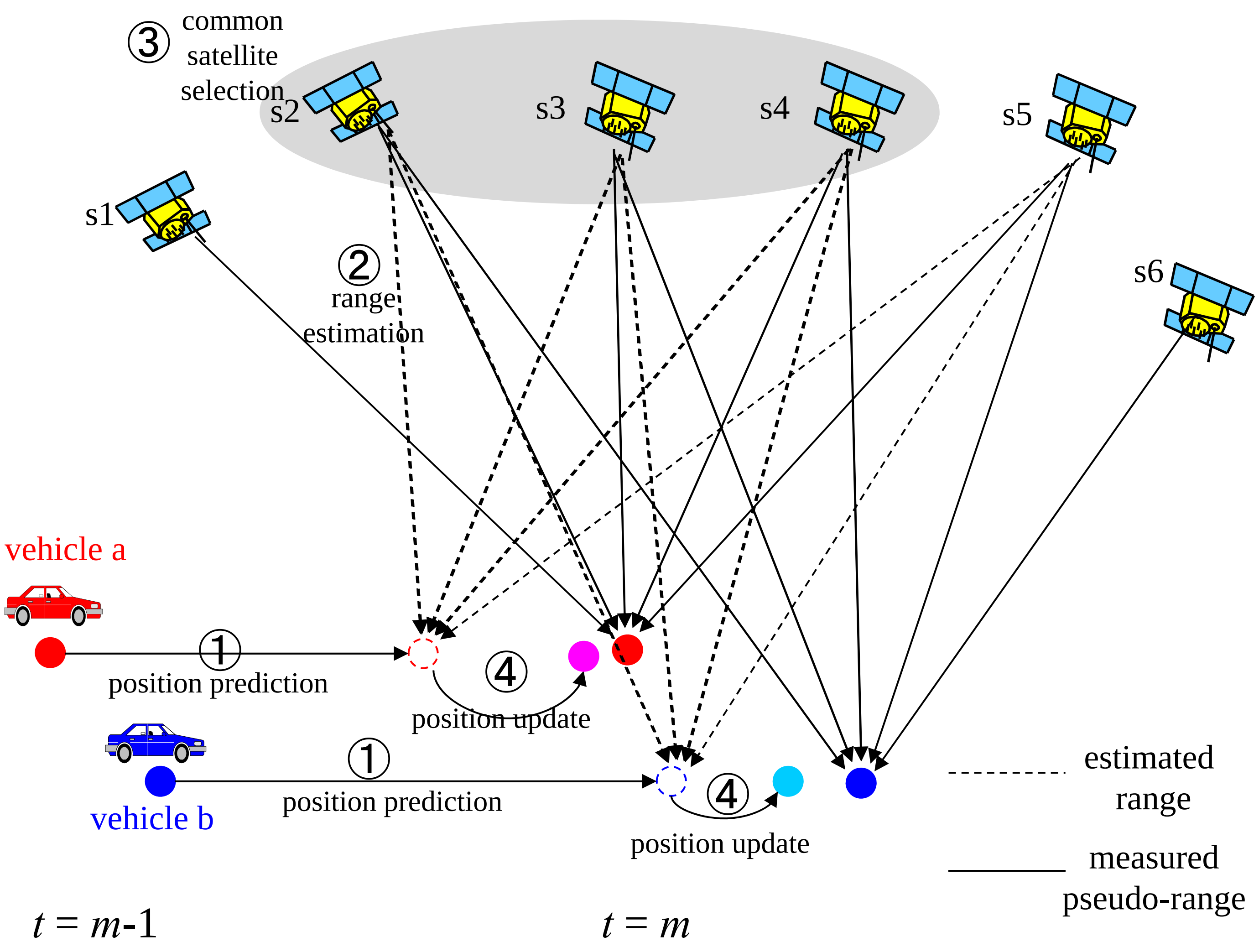
$\rho_n^{(s)} = |\hat{\mathbf{r}}_n - \mathbf{r}^{(s)}|$

$\hat{\mathbf{r}}_n$ Predicted vehicle position

$\mathbf{r}^{(s)}$ Satellite position by ephemeris info

Signals from common satellite k: correlated if $|p_{ab}^{(kl)} - \rho_{ab}^{(kl)}|$ < threshold

Whole Process of Positioning



Simulation Configuration

- Simulating pseudo-range errors by ray tracing: line-of-sight signal and 1 reflection
- Sidewalk, roads and roadside buildings
  - Sidewalk/lane: see Fig.5
  - Building height: uniform distribution in 20-30m, building length: uniform distribution in 0-30m
- Two vehicles: same speed=30km/h, fixed distance=20m
- Compared schemes
  - NoCommSat: 2 vehicles exchange positions, from which relative position is computed.
  - CommSat: 2 vehicles exchange pseudo-ranges, using pseudo-range of common satellites to compute relative position.
  - KF+CommSat: Based on CommSat, obtaining vehicle speed and using Kalman filter to combine GPS positioning and position prediction.
  - CoRelPos (proposed Cooperative Relative Positioning scheme): Based on KF+CommSat, using correlated pseudo-ranges of common satellites to compute relative position.

Simulation Results

- Evaluation under two cases
- Evaluation metric: Complimentary cumulative distribution functions (CCDFs) of horizontal errors.

CCDF(x) = prob(error>x)

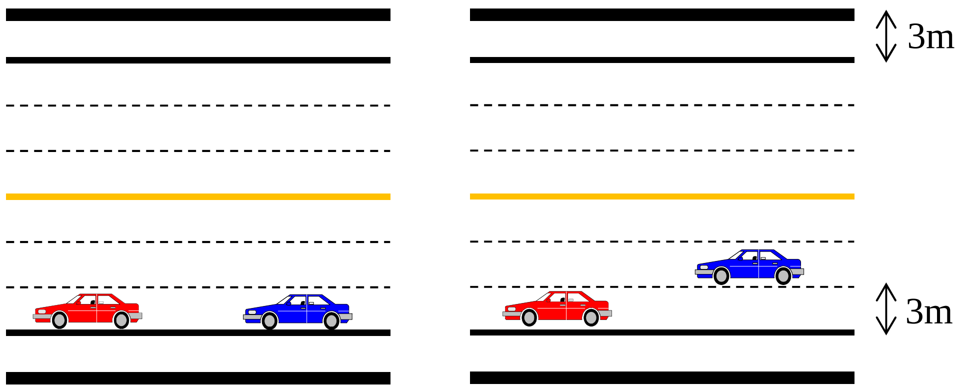


Fig. 5

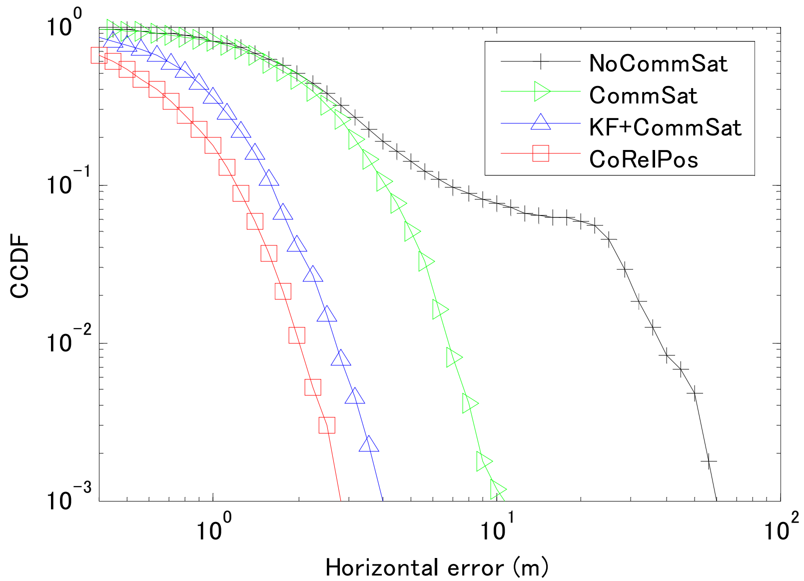


Fig. 6 Distribution of horizontal errors (Same lane)

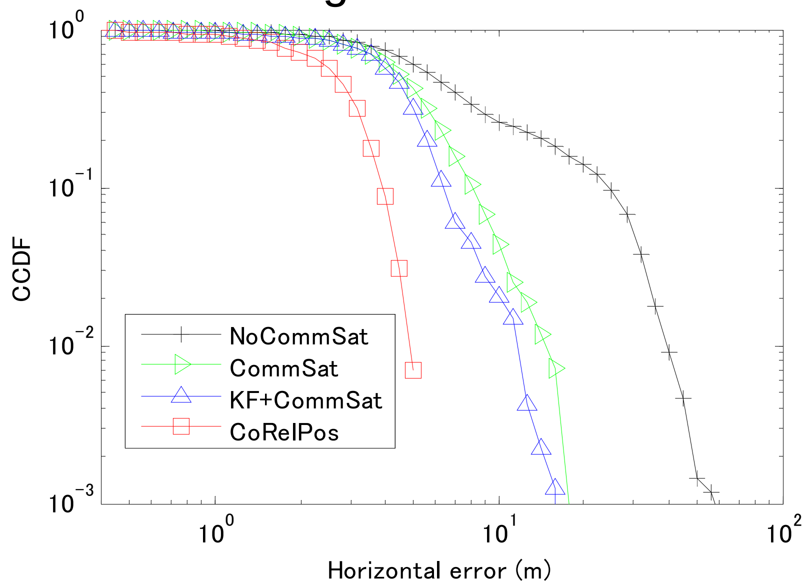


Fig. 7 Distribution of horizontal errors (Different lanes)

Experiment Evaluation

- Configuration
  - Use NovAtel receivers, with raw pseudo-range outputs
  - Two receivers on top of a vehicle: known ground truth of relative position
- Investigating
  - The potential effect of using common satellites: decrease in #satellites, increase in HDOP
  - Correlation of received signals: SNR, correlation detection metric
- Initial experiment results of relative positions

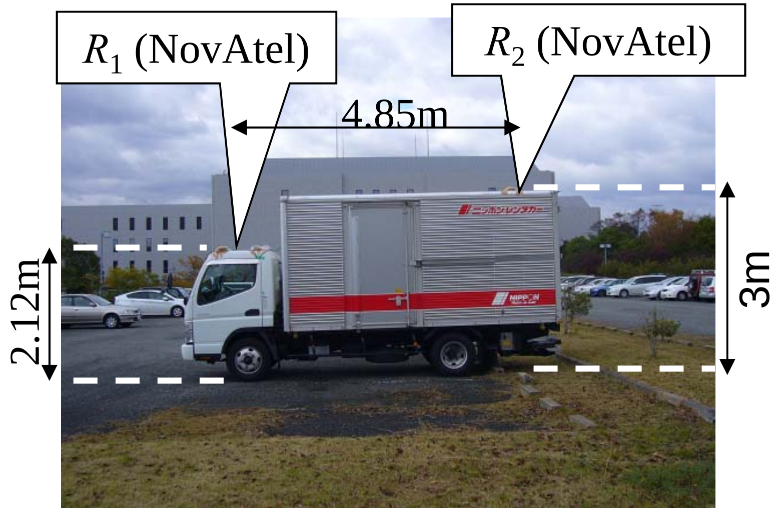
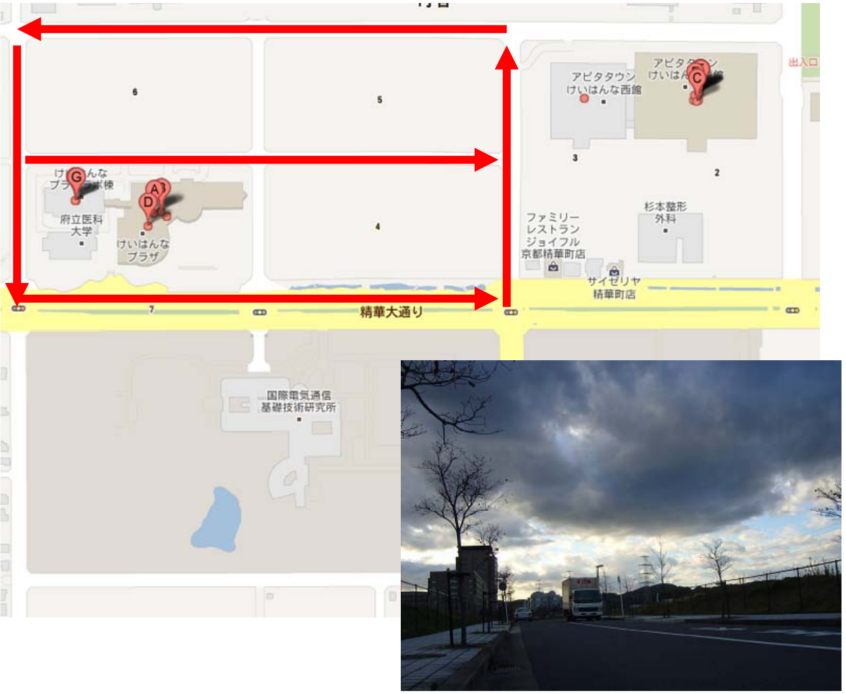


Fig. 8 Experiment setup

Experiment Courses



- ATR course

Approx. open sky

- Kyoto course

Between open-sky and urban canyon

Experiment Result 1

- Investigating the potential effect of using common satellites
- Effect 1: decrease in #satellites, CDF(x) = prob(#sat<x)
- Effect 2: increase in HDOP, CCDF(x) = prob(HDOP>x)

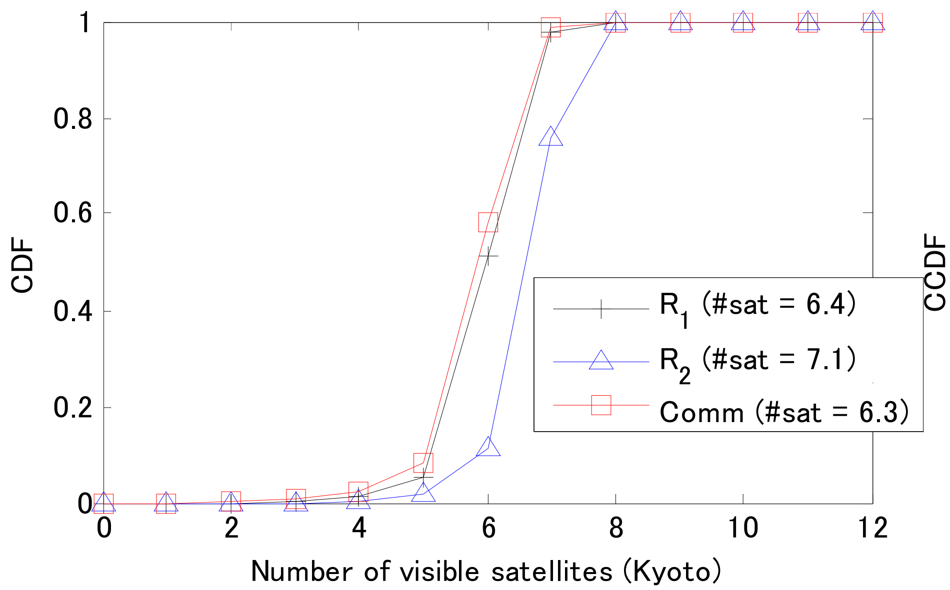


Fig. 9 Distribution of #visible satellites (Kyoto).

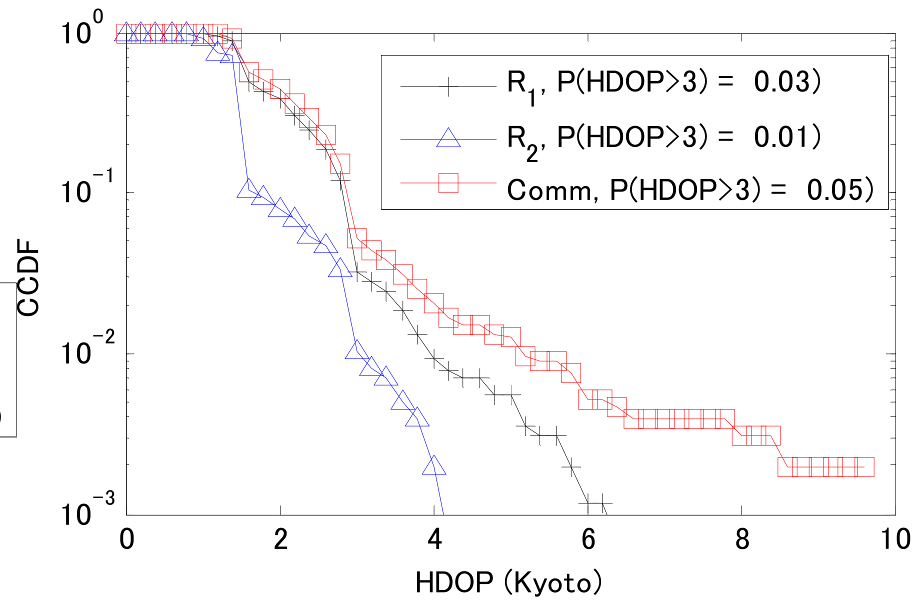


Fig. 10 CCDF of HDOP

Experiment Result 2

- Investigating the correlation in signals received from common satellites
- 1: Correlation in SNR, CDF(x) = prob(|SNR diff| > x)
- 2: Correlation in the pseudo-range

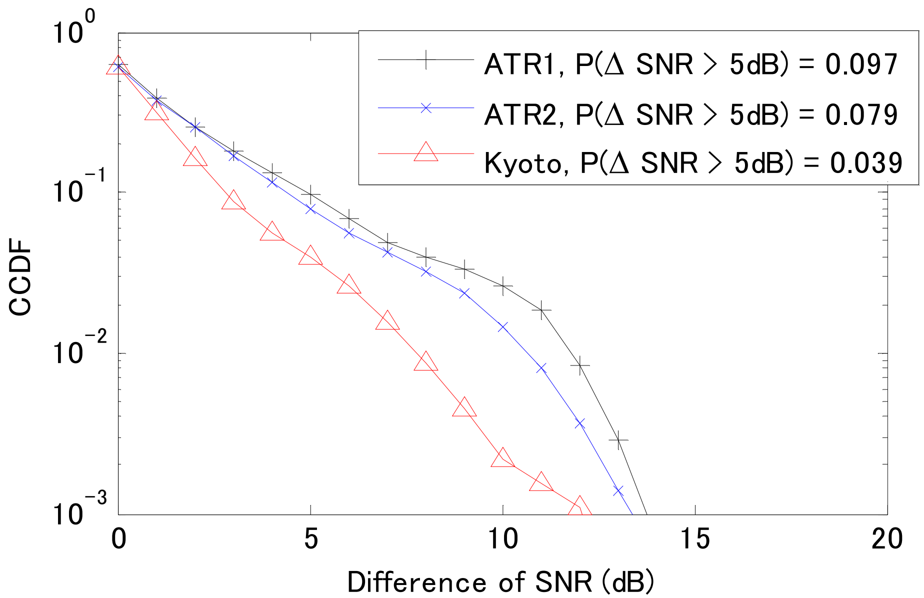


Fig. 11 CCDF of SNR difference

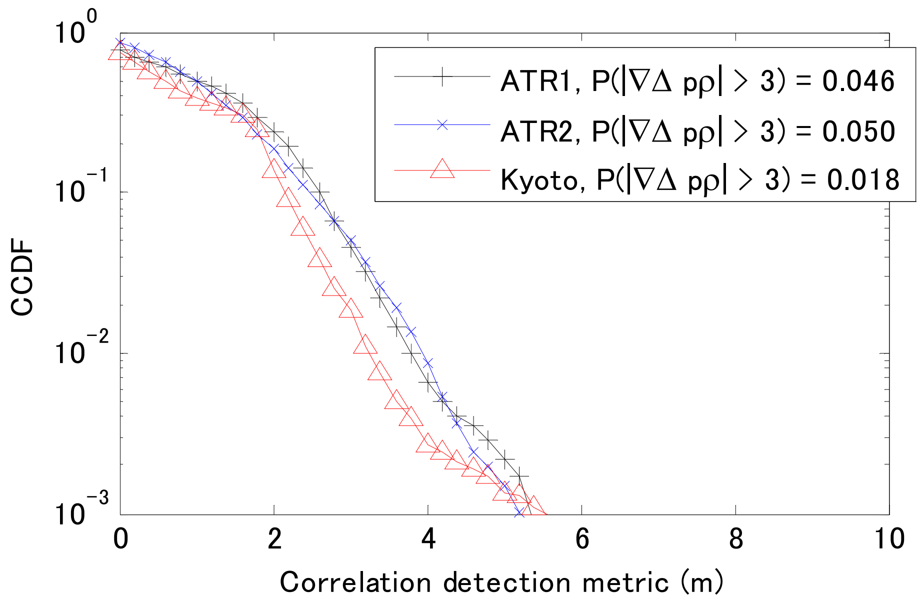
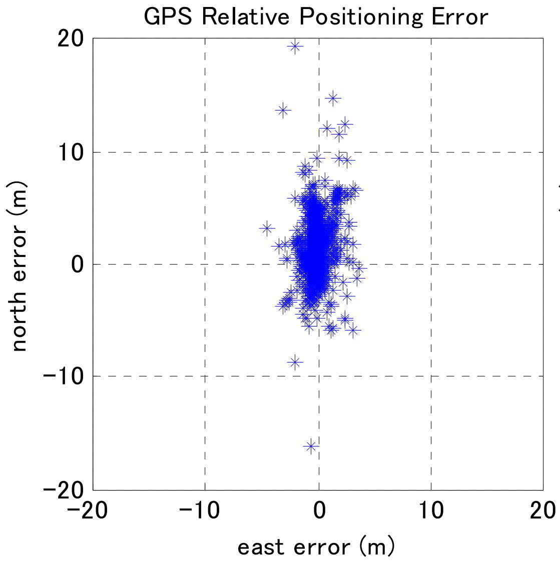


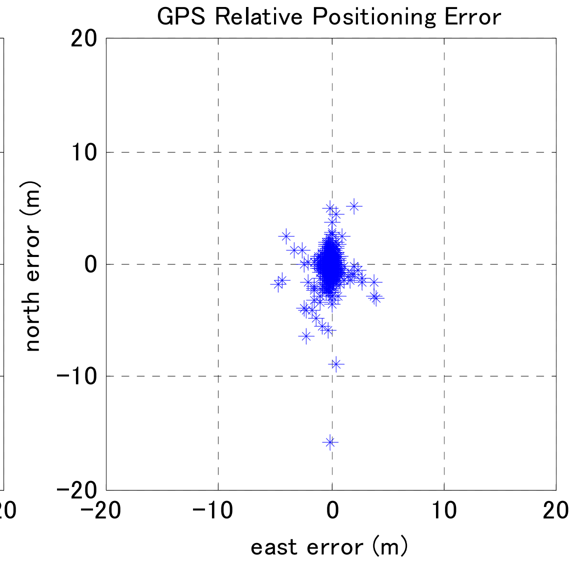
Fig. 12 CCDF of correlation detection metric

Experiment Result 3

- Actual results of relative positioning
  - Currently Kalman filter is not used due to lack of speed info (speed pulse).
  - Correlation detection is not used.
  - We only show the effect of using common satellites
- The proposed scheme can effectively reduce positioning errors.



NovAtel



CoRelPos

Fig. 13 Distribution of error in relative position (Kyoto)

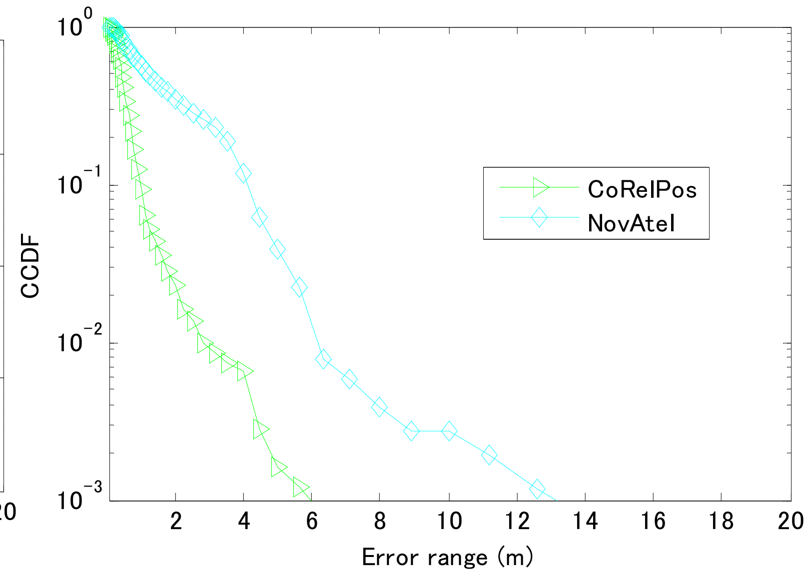


Fig. 14 CCDF of error in relative position (Kyoto)

Conclusion

- We argue that relative position is important in support system for safe driving.
- With a short inter-vehicle distance
  - Positioning signals received from common satellites tend to be correlated.
  - Exploiting all correlated signals, including reflected ones, helps to improve accuracy of relative position.
- Simulation and initial experiments confirmed the effectiveness of the proposed scheme.
- We have a plan to experiment in Osaka with real urban canyons.