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]

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

- **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

Fig. 2
Correlation Detection

Pseudo-range
vehicles: \( n = a, b \)
satellites: \( s = k, l \)
\[
\rho_n^{(s)} = \rho_n^{(s)} + c \cdot (\Delta t_n - \Delta T^{(s)}) + d_{ion,n}^{(s)} + d_{trop,n}^{(s)} + \varepsilon_n^{(s)}
\]

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

Double difference of measured pseudo-ranges
\[
\rho_{ab}^{(kl)} = \rho_{ab}^{(kl)} + (\varepsilon_a^{(k)} - \varepsilon_b^{(k)}) - (\varepsilon_a^{(l)} - \varepsilon_b^{(l)})
\]

MP errors of satellite \( k \)
Approx. 0

\[
\rho_n^{(s)} = |\hat{r}_n - r_n^{(s)}|
\]

Signals from common satellite \( k \): correlated if \( |p_{ab}^{(kl)} - \rho_{ab}^{(kl)}| < \text{threshold} \)
Whole Process of Positioning

1. Position prediction
2. Range estimation
3. Common satellite selection
4. Position update

$t = m - 1$
$t = m$

Vehicle a
Vehicle b

Common satellite selection
Estimated range
Measured pseudo-range
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.
  \[ CCDF(x) = \text{prob}(\text{error}>x) \]

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, $\text{CDF}(x) = \text{prob}(\Delta \text{SNR} > x)$
- 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.

![Graphs showing distribution and CCDF of error in relative position](image-url)
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.