Position Matching Estimation for GNSS Positioning in Multipath/Non-Line-Of-Sight Environments

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Context and Objectives of this Study:

- Context: GNSS Challenges in Urban Environments
- Problematic and Objectives
- Related works

3D GNSS Simulation using SPRING

Contribution: Position Matching Estimation (PM-3D)

- Principal
- Practical Implementation

Experimental Results

- General Experimental Setup
- Comparison Algorithm
- Positioning Performance

Conclusion
Position Estimation:

- Trilateration method: find out the user position by knowing ranging to three known satellites.
- Additional measurement to solve synchronization between GNSS receiver and satellite clocks.

In GNSS systems, four ranges (surface of sphere) of four satellites: three for calculating the position in 3D and the fourth one for time synchronization.

Estimation accuracy depends on:

1. The geometry between each satellite and the receiver (DOP)
2. The satellite signal state and health (Presence or not of MP and NLOS)
Context of the Study

- Poor Positioning Accuracy:
  1. Masking Effect
  2. Limited satellite visibility ➔ High DOP
  3. Signal Degradation ➔ MP and NLOS bias

- Masked satellites across the street
- Degraded DOP in this direction
- Poor accuracy across the street

➔ To improve Accuracy: Aided Information are needed!

From: Suzuki-ION GNSS+2015
GNSS in urban Environment: Case Study

1. Blue: Reference
2. Red: Conventional GNSS solution

Typical conventional GNSS positioning (Urban environment in Toulouse)

→ ~ 20m horizontal Positioning errors in this example
→ Non Gaussian Error Distribution
Related Works

NLOS Constructive Use

NLOS Down-weighting

NLOS Identification & Elimination

3D City Model
3D GNSS Simulator

Robust Estimation (Low Breakpoint)

MP Modeling

GNSS + Additional Hardware (Antenna Array, Camera...)

GNSS + Distinction criteria (C/N0, Elev), RAIM

GNSS + INS, GNSS+ Cameras ...

Positioning Approaches in Harsh Environments
Related Works based on 3D maps

3D-Mapping Aided GNSS

Taxonomy based on Considered points in 3D maps
- Pattern-Matching Approaches
  - Shadow Matching
  - Skyline Matching
  - Photo Matching
  - HDOP/PR Matching
- Priori-Position Based Approaches
  - Select Position among an array of candidates positions
  - Predict PR errors using GNSS simulations on a a-priori input point

Taxonomy based on the used 3D information
- 3D City Model Approaches
  - Input Point = Previous estimated Point: A. Bourdeau & Sahmoudi (ISAE)
  - Simplified 3D Model (Urban Trench) + probabilistic method (IFFSTAR)
- 3D Simulator Approaches
  - Pure Geometrical infos from 3D Maps
  - 3D models + Ray-tracing algorithms (simulate GNSS)

- SM
- Urban Trench
- GNSS PR Correction (Suzuki + Miura)
- Bias prediction + Particle filtering (Hsu)
- Pattern Matching based on bias prediction (Kumar)
Our Previous Works

I. Stand-Alone GNSS Receiver without Aided Information:

Robust Estimation: based on PR measurements innovation: ENC’15
⇒ Adapted to suburban areas

Regularized Estimation: Joint Estimation of user position and MP/NLOS bias: ENC’17

II. 3D GNSS Simulator Integration with GNSS

SPRING Simulator: (3D City Model + Ray-Tracing+ Rx Model)

Simulated 3D PR Bias

Measurements Domain

PR MP/NLOS Bias Bounds

PR bias Correction using Bias Bounds: ION’15

Position Domain

Scoring of Different Candidate Positions

Approximate Maximum Likelihood (AML-3D): ION’17

Position Matching (PM-3D): ITSNT’17
**SPRING:** a **GNSS simulator** developed by the French Space Agency (CNES) that has the capability of simulating, via ray-tracing techniques, all received paths in a certain input position and time.
Example of 3D GNSS Simulation using SPRING
**Position Matching Estimation (PM-3D)**

**Proposed Matching Metric:**
Position Similarity Between Computed LS solution (from true PR) and predicted LS solutions (using simulated PR) across different candidate positions

→ Distance between Computed LS solution and Predicted LS solution

1. Simulated PR: problem of receiver clock bias simulation ➔ **Elimination of Rx clock bias by differentiation of PR across all satellites using a reference satellite**
2. Final PM-3D Estimation: **weighted average of candidate position with the highest matching**
Algorithm: PM-3D

**Inputs:** Received PR Measurements

1. Define 2D search area and an array of outdoor candidate positions
2. Apply 3D GNSS simulation (SPRING) on each candidate position → Simulated PR measurements at each candidate point → Simulated LS solution for each candidate position
3. Compute Position matching (Distance) between Computed LS solution and Simulated LS solutions at each candidate position
4. PM-3D: Weighted average based on Position Matching

**Output:** Estimated Position (PM-3D)
**General Experimental Setup**

**Environment:** Toulouse, France  
**Date:** 18/03/2015  
**Mode:** Dynamic

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**GNSS Receiver:** UBLOX6T  
**Recording Frequency:** 10 Hz

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**Reference:** SPAN NOVATEL (IMU+DGPS)

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### Skyplot View GPS+GLONASS

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<th>GPS 12</th>
<th>GPS 28</th>
<th>GPS 24</th>
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<td>27.7</td>
<td>46.2</td>
<td>42</td>
<td>47.7</td>
<td>35.2</td>
<td>34</td>
<td>24</td>
<td>28</td>
</tr>
</tbody>
</table>
General Experimental Setup: 3D Map

1. 2D area selection using Q-GIS Software

2. Height extrusion → 3D Model

3. Selection of a grid of point and elimination of indoor points

Many thanks to Prof P. Groves/UCL, UK for his invitation and scientific exchange
General Experimental Setup: 3D Map

1. White: Candidate positions (1600 Points)
2. Red: Reference

1. 3D Simulation (using SPRING) on each point of this 2D grid
2. Scoring function at each point (Based on Position matching)
3. Final position estimation based on points with highest scores
Comparison Algorithm

**Algorithm: SM-3D**

**Inputs:** Received PR Measurements

1. Define search area and an array of outdoor candidate positions
2. Predict Satellite Visibility using building boundaries information at each candidate position
   - **Predicted Satellite Visibility** at each candidate point
3. Observe Satellite Visibility
4. Compute matching between predicted and observed satellite visibility at each candidate position
5. Determine final position based on satellite visibility matching

**Output:** Estimated Position (SM-3D)

**SM-3D Block Diagram**

**SM-3D Pseudocode**
Positioning Performance

Note 1: Better Positioning performance using 3D-Mapping approaches compared to conventional algorithm

Note 2: PM-3D gives better Pos. accuracy in this case:

i. Mean: 3,41m
ii. HPE at 95%: 6,36m
iii. HPE at 97%: 6,5m
iv. HPE at 99%: 8,64m

SM-3D: Mean: 4,22m,
HPE at 95%: 7,95m,
HPE at 97%: 9,15m
Conclusions

✓ Context & Problematic:

- Use of Additional information is mandatory: 3D GNSS Simulator for example

✓ Solution (Contribution):

- Position Matching between simulation and computed LS solutions over an array of candidate positions ➔ Distance between computed and simulated LS positions
  - Derivation of sub-optimal efficiency (Paper)
  - Practical implementation of the proposed estimator

✓ Results:

- 3D-Mapping methods give good Pos. performance in harsh environments
- Good positioning accuracy obtained using the proposed PM-3D

✓ Limitations:

- Computational loads (if using a large grid)
- Depends on 3D simulator precision
Thank You!

Questions?