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17 Nov. 2017, ITSNT2017
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4. Summary
Background of this work

• Evolution of GNSS High Accuracy Positioning
  – Popular in construction, agriculture, survey
  – Not popular in city area’s positioning
    • Urban canyon environment affects High Accurate Positioning

• We are developing simulator for
  – GNSS users who want to know availability of High Accurate Positioning in urban areas
  – GNSS receiver researchers and developers doing research algorithm for multipath environment
Background of this work

- Example of GNSS positioning error in urban area

Vehicle positioning (Trimble NetR9+RTKLIB single). Maximum horizontal error = 100m

Generally it is caused by multipath errors

Why multipath affects GNSS positioning errors?

*1:Aerial photo: Geographical Survey Institute Map KML
Background of this work

• GNSS multipath error in urban area

To analyze what happens in an urban area, we developed GNSS Raytracing multipath simulator.

Tracking direct signal and reflected signal causes tracking error (depends on algorithm and correlator)

Tracking NLoS reflected signal causes large tracking error (depends on reflected path length)
Raytracing approach

- Raytracing multipath simulation*1 with 3D buildings
  - Satellites position by ephemeris
  - All types of propagation paths done by raytracing.
  - Raytracing used to estimate received level and delay from satellites to GNSS antenna
  - Receiver processing model
  - SNR
  - Multipath error of pseudorange
  - Positioning calculation

Raytracing approach

• Example scenario of Raytracing
  – Vehicle positioning and recorded in Hibiya.
  – simulated signal quality check of urban environment with measurement data

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite System</td>
<td>GPS+QZS L1</td>
</tr>
<tr>
<td>Duration</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Satellite position</td>
<td>Ephemeris</td>
</tr>
<tr>
<td>Receiver Position</td>
<td>Vehicle position (POSLV)</td>
</tr>
<tr>
<td>Multipath</td>
<td>Raytracing with 3D buildings (Hibiya)</td>
</tr>
<tr>
<td>Positioning Method</td>
<td>Single (RTKLIB v2.4.2)</td>
</tr>
<tr>
<td>GNSS Receiver</td>
<td>Trimble Net R9</td>
</tr>
</tbody>
</table>

Measurement course (with POSLV & NetR9)
Raytracing approach

- GNSS SNR simulation in urban area
  - SNR trend of raytracing and actual measurement for G23

Good simulation performance with 3D simple building model*. Signal availability has almost the same trend between simulation and actual measurement. Actual measurement’s trend is more dynamic than simulation result.

*Accuracy of building height is ±1.5m. Material is concrete. Model has no tree and signboard etc.
Raytracing approach

- GNSS SNR simulation in urban area
  - SNR trend of raytracing and actual measurement for G23

Differences between raytracing and measurement occurred due to tree obstruction. Simulating tree effects is our future work in raytracing. Further improvement is expected.

*Accuracy of building height is ±1.5m. Material is concrete. Model has no tree and signboard etc.
Raytracing approach

• GNSS SNR simulation in urban area
  – Simulation accuracy depends on
    • Raytracing engine
    • 3D model’s accuracy
  – many 3D model vendor in Japan
  – SNR simulation in urban area in Japan is possible

How about GNSS positioning accuracy simulation?
Raytracing approach

- GNSS positioning simulation in urban area
  - RTKLIB single positioning with raytracing and actual RINEX obs
  - similar trends by raytracing are obtained

Positioning result depends on receiver processing algorithm.
How to estimate consumer GNSS receiver performance in urban area?
SDR approach

- Algorithm of consumer GNSS receiver is unknown (black box)
  - Difficult to get positioning performance of consumer GNSS receiver through numerical simulation
  - Emulate multipath GNSS signal is a good way

Traditional signal generator is an excellent solution, but it is expensive. We focused on Software Defined Radio.
SDR approach

• Software Defined Radio
  – Wireless system built with software digital signal processing and general purpose RF-frontend (low cost)

SDR signal generator needs only one RF channel for all GPS signal. It is the same for many multipath channels.
Framework of RayTracing Software Defined Radio (RT-SDR) Method

- **Overview**

RayTracing

Software Defined Radio
gps-sdr-sim (customized)*

- support QZSS signal generation
- Troposphere, Ionosphere emulation
- Multipath signal Generation
- GPU: for many multipath calculation

Multipath contained GNSS Signal

RF cable

Now, Our prototype, GPS L1 and QZS L1 are available.

*we named customized gps-sdr-sim “SDR-SAT”
Preliminary Evaluation

- We used two types of scenario for RT-SDR prototype
  - Static Scenario
    - Emulated signal quality check of SDR signal generator with simple scenario
    - Signal quality check with RTK fixing rate
  - Moving Scenario
    - Emulated signal quality check of urban canyon environment
    - Signal quality check with measurement data

Measurement course (with POSLV & NetR9)
# Static Scenario

## Scenario Setup

### Scenario Settings

<table>
<thead>
<tr>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite System</td>
<td>GPS+QZS L1</td>
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<tr>
<td>Duration</td>
<td>1 Hour</td>
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<tr>
<td>Satellite position</td>
<td>Ephemeris</td>
</tr>
<tr>
<td>Receiver Position</td>
<td>Static</td>
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<tr>
<td>Multipath</td>
<td>None(open sky)</td>
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<tr>
<td>Positioning Method</td>
<td>RTK continuous (RTKLIB v2.4.2)</td>
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<tr>
<td>GNSS Receiver</td>
<td>u-blox NEO-M8T</td>
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## SDR Settings

<table>
<thead>
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<th>Setting</th>
<th>Value</th>
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<tbody>
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<td>Frequency</td>
<td>1.575 [GHz]</td>
</tr>
<tr>
<td>RF Frontend</td>
<td>Blade RF x40</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>26 [MHz]</td>
</tr>
<tr>
<td>OS</td>
<td>Windows 10 64bit</td>
</tr>
<tr>
<td>CPU</td>
<td>Core i7 7700</td>
</tr>
<tr>
<td>GPU</td>
<td>NVIDIA GeForce GTX1080</td>
</tr>
</tbody>
</table>
Static Scenario

• Evaluation Result

- Fixing rate = 60%
- Some miss Fix solutions are observed.

We need signal quality improvement in GNSS phase simulation.
Moving Scenario

• **Scenario setup**

**Scenario Settings**

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**SDR Settings**

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</table>

※ used Net R9 for actual measurement
We will use future evaluation.
Moving Scenario

- satellite evaluation result for G23 (NLoS)

Signal attenuation is emulated, and some multipath fadings are emulated.
Moving Scenario

- satellite evaluation result for G23 (NLoS)

Further improvement is expected with raytracing model’s updates.
Moving Scenario

• satellite evaluation result for G09 (LoS)

Differences of SNR between RT-SDR and actual measurements are observed.
Moving Scenario

- Single Positioning Result

Some differences on single positioning result between RT-SDR and actual measurements are observed. We will evaluate again with updated prototype.
Moving Scenario

• DGPS Positioning Result

Many differences on DGPS positioning result between RT-SDR and actual measurement observed. We will evaluate again with updated prototype.
Moving Scenario

• RTK Positioning Result
  – No RTK FIX solution from both method due to insufficient number of satellites
  – Some miss FIX solution observed

For evaluation of urban canyon situation, we need more GNSS system emulation function.
Summary and future work

• Summary
  – We developed RT-SDR framework and prototypes
  – RT-SDR method have many possibilities
    • complex multipath environment emulation
    • build evaluation system with low-cost hardware

• Future work
  – RT-SDR method have many challenges
    • Quality improvement
      – GNSS signal emulation quality of SDR
        » Time synchronization to GPST
      – Multipath signal emulation quality of RT-SDR
    • Functional improvement
      – Multi GNSS : GLONASS/BEIDOU/GALILEO
      – Multi frequency : L2, L5, L6