Real-Time Geophysical Applications with Android GNSS Raw Measurements

**Marco Fortunato**, Michela Ravanelli, Augusto Mazzoni

*Geodesy and Geomatics Division, DICEA, “Sapienza” University of Rome*

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Outline

1 Introduction
   - Android Location API
   - Smartphones and Geoscience

2 GNSS tools
   - rinex ON
   - VADASE

3 Data Analysis
   - Static Scenario
   - Fast Movements
   - Ionospheric conditions

4 Conclusions and future developments
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Android GNSS Raw Measurements API

Innovations

Running on Android 7.0 or higher, Android GNSS Raw Measurements API allows to access:

- **GNSS Clock:**
  - Receiver clock (pseudorange computation)
  - Clock bias
- **GNSS Navigation Message:**
  - Nav message bits
  - Nav message status
- **GNSS Measurements:**
  - Received satellite time (pseudorange computation)
  - Code
  - Phase

Benefits for GNSS Mass-Market Community

The availability of GNSS observables from Android smartphones enables:

- **improved location accuracy** with high-end positioning algorithm (RTK and PPP)
- **Geoscience applications** of such mass-market devices

Input from GNSS community

**GSA Raw Measurements Task Force:**

- aims to share knowledge on Android raw measurements (Discussion forum and Measurements Database)
- encourages researches and innovative application

How Can Smartphones Contribute to Geosciences?

- Geosciences generally require **dense information**
- Smartphones are the **most common GNSS mass-market device**
- The release of **multi frequency and multi constellation** Android smartphones enhances GNSS solutions
- **Multi sensor devices**, as smartphones, increase the number of **independent measures** related to Geoscience applications

**Earth’s fast movement**

**Ionospheric monitoring**

**Tropospheric monitoring**

- [www.altimetry.info](http://www.altimetry.info)
Purpose of the work

This work is a **feasibility study** aiming at evaluate the **real-time capabilities** of Android smartphones:

- to detect **fast movements**, with frequency shaking and oscillation amplitude comparable to **seismic waveforms**
- to monitor **ionospheric conditions**
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RINEX Logger and Monitoring App

- **Rinex ON** has been developed by NSL as part of **FLAMINGO** initiative ([www.flamingognss.com](http://www.flamingognss.com)) - an HORIZON 2020 project.
VADASE (Variometric Approach for Displacements Analysis Stand-Alone Engine)

How does VADASE work?

- **real-time estimation of epoch by epoch velocity**
- multi-constellation and multi-frequency compatibility
- **no ambiguity term** is contained in the observation equation

**Observation equation [Colosimo et al., 2011]**

\[
L^S_R(t + 1) - L^S_R(t) = \Delta L^S_R = \Delta \rho^S_R|_{OR} - c \Delta \delta t^S + \Delta T^S_R - \Delta I^S_R + e^S_R \Delta \varepsilon_R + c \Delta \delta t_R + \varepsilon^S_R
\]

- time difference of phase observations
- known terms
- unknowns
- noise
VADASE: a Consolidated Tool for GNSS Seismology

VADASE allows the estimation of:

- real-time 3D velocities with accuracy of few mm/s on high-end receivers
- real-time 3D fast movements displacements with accuracy of 1-2 cm on high-end receivers
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Xiaomi Mi 8 vs M0SE (EUREF/IGS Station)

Test description

- Xiaomi Mi 8 in **open sky environment** near M0SE station
- **1Hz observations** collected for **15 minutes**
- **GPS and Galileo L1/E1** VADASE processing with *cycle slip detectors* and recursive **Leave-One-Out (LOO)** algorithm

<table>
<thead>
<tr>
<th></th>
<th>RMSE [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
</tr>
<tr>
<td>Mi 8</td>
<td>0.003</td>
</tr>
<tr>
<td>M0SE</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Experiment with a Vibrating Table

Test description

- **Xiaomi Mi 8** and **STONEX S900A** in *open sky environment*
- Acquisition rate **1Hz** for the smartphone and **10 Hz** for the GNSS receiver
- 1D Oscillation **frequency** ≈ **1 Hz**
- 1D Oscillation **amplitude** ≈ **0.08 m**
- Two phases of the movement with **different velocities**
- Oscillatory and static periods
- **GPS and Galileo L1/E1** processing
Velocity from STONEXS900A

- VADASE allows to detect fast movements of the vibrating table
Characterisation of the Movement with STONEX S900A

1D Velocities

1D Displacements

- Zero-crossing method outcomes:
  - Displacement **Amplitude** = 0.081 m ± 0.002 m
  - Maximum **Velocity** = 0.26 m/s ± 0.022 m/s

VADASE with 10 Hz observations is able to describe the oscillations
Aliased Solutions from 1Hz Observations

- **ALIASING**: acquisition rate (1Hz) prevents the possibility to reconstruct a phenomenon with similar frequency (slightly lower than 1Hz)
**Modified Vibrating Table**

**Test description**

- **Xiaomi Mi 8** and **STONEX S900A** in open sky environment
- Acquisition rate 1 Hz for the smartphone and 10 Hz for the GNSS receiver
- 1D Oscillation with fluctuating frequency ≈ 0.1 Hz
- 1D Oscillation **amplitude** ≈ 0.125 m
- The movement improved is not regular
- **GPS** and Galileo L1/E1 processing

Acquisition rate of 1 Hz allows to retrieve the vibrations induced by the table.
Comparison between Xiaomi Mi 8 and STONEX S900A

1D Velocities

- RMSE = 0.011 m/s
- Spikes are observed near the velocities peaks

1D Displacements

- RMSE = 0.021 m
- Spikes are observed near the velocities peaks
Ionospheric conditions

Results from VARION

- Originated from VADASE, VARION allows the real-time estimation of time variation of the total electron content (TEC).
- The computation starts from the time variation of geometry free combination on phase measurements.

RMSE = 0.072 TECU/s

RMSE = 0.082 TECU/s
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Conclusions

- **Android GNSS raw measurements** analysed with VADASE are able to retrieve real-time fast movement velocities and displacements.

- RMS of 1 cm/s for the velocity and 2 cm for the displacements with respect a geodetic class receiver were obtained in this work.

- Acquisition rate of 1 Hz prevents the detection of the majority of fast movements happening on the Earth (e.g. earthquakes).

- Among the noisier measurements, the possibility to densify ionospheric information with Android smartphones was proven.

Future Developments

- Test the methodology with **high frequency GNSS raw measurements** (if provided by future Android versions).

- Test the methodology **without static-start conditions** to replicate the typical user behaviour.

- Analysis of ionospheric conditions with Android measurements during **high ionospheric activity periods**.
Thanks for your kind attention