GNSS Data Processing for High-Accuracy Positioning using Low-Cost Receiver Systems

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Quiz

• What is the Price of a GNSS Receiver?
  • $10? / $100? / $500 / $1,000 / $3,000 / $10,000 or more?

• What is the Accuracy that you can get from a GNSS receiver?
  • mm, cm, dm, few meters or 10 – 30m

• But, what are your requirements?
  • Types of Applications
  • Accuracy Requirements
  • Data Logging Methods
    • Static Mode on a Tripod
    • Dynamic Mode on a Car, Tractor or Machine?
  • Real-Time or Post-Processing
Low-Cost Receiver Systems
High-End Survey Grade Receivers

- Multi-frequency
  - GPS: L1/L2/L5
  - GLONASS: L1/L2/L3
  - GALILEO: E1/E5/E6
  - BDS: B1/B2/B3
  - QZSS: L1/L2/L5/L6
  - NAVIC: L5/S

- Multi-system
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc

- Price varies from $3,000 to $30,000 or more
Low-Cost Receivers

• Multi-System
  • GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc

• Basically Single Frequency
  • L1/E1/B1-Band
  • Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
    • Future trend for Mass Market System will be L1/L5
  • Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market

• Low Cost:
  • Less than $300 (Multi-GNSS, L1 Only) including Antenna and all necessary Hardware, Software
    • Our target is within $100 or less including everything

*Note: Only one signal type from each system is processed
e.g. GPS has L1C/A and L1C in L1, but only L1C/A is used in Low-Cost Receiver
Our Definition of Low-Cost Receiver

- Price: $100 or less
- Accuracy: Better than 100cm
- Weight: 100g or less

\[100^3\]
\[\$100 \times 100\text{cm} \times 100\text{g}\]

Will it be possible?
Many Applications require Low-Cost, Small-Size & Low-Power Receiver System

But, is it possible to get High-Accuracy with Low-Cost Receivers?
Question?

Although the **Normal Accuracy of GPS is about 10m**, why can we get **Centimeter Level Accuracy**?
GPS Position Accuracy
How to achieve accuracy from few meters to few centimeters?

- **SPP (Single Point Position)**
  - 50 cm grid

- **DGPS (Differential GPS)**
  - Code-phase observation
  - 50 cm grid

- **RTK (Real Time Kinematic)**
  - Carrier-phase observation
  - 5 cm grid
Errors in GPS Observation (L1C/A Signal)

<table>
<thead>
<tr>
<th>Error Sources</th>
<th>One-Sigma Error , m</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>DGPS</td>
</tr>
<tr>
<td>Satellite Orbit</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Satellite Clock</td>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ionosphere Error</td>
<td>4.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Troposphere Error</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Multipath</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Receiver Circuits</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

If we can remove common errors, position accuracy can be increased.
Common errors are: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath
How to Remove or Minimize Common Errors?

Use Differential Correction

Base-Station
Antenna is installed at a known-position

For RTK, both rover and base receivers need to use the same satellites

Rover
User in the Field (Either fixed or moving)

RINEX data for post-processing

Base-length < 40Km

Send Correction Data to Rover For Real-Time Position

RTCM

[X]_{error} = [X]_{known} - [X]_{measured}
How to Remove or Minimize Common Errors?

Principle of QZSS MADOCA and CLAS Services

Correction Data:
- Satellite Orbit Error of GPS and Other Satellites
- Satellite Clock Error of GPS and Other Satellites

Correction data for other satellites will also be provided

Base-Station not required
Low-Cost RTK Receiver System

**TYPE R1** Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode

![Diagram showing connections between GNSS Antenna Rover, Raspberry Pi 3B, Tablet, GNSS Receiver, and NTRIP Caster.]

**TYPE R2** Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only

![Diagram showing connections between GNSS Antenna Rover, Raspberry Pi Zero w/WiFi&BT, GNSS Receiver, and Raspberry Pi 3B.]

**TYPE A1** Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only

![Diagram showing connections between GNSS Antenna Rover, GNSS Receiver, Android Device, and NTRIP Caster.]

**TYPE MA** Type D: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only

![Diagram showing connections between GNSS Antenna Rover, GNSS Receiver, Android Device, and MADOCA Correction Server.]

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## Low-Cost RTK Receiver System

<table>
<thead>
<tr>
<th>Type</th>
<th>Receiver System</th>
<th>Usage</th>
<th>RTK Processing Engine</th>
<th>Mode</th>
<th>User Interface</th>
<th>Base-Station Data</th>
<th>Correction Data Format</th>
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</thead>
<tbody>
<tr>
<td><strong>Type R1</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Beta Version</td>
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<tr>
<td><strong>Type R2</strong></td>
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<tr>
<td>Beta Version</td>
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<tr>
<td><strong>Type A1</strong></td>
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<td>Release 1.0</td>
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<td>Release 1.0</td>
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</tbody>
</table>

### Details:

- **Type R1** Beta Version:
  - Receiver System: Real-time RTK Base and Rover Setting
  - RTK Processing Engine: Raspberry Pi 3B
  - Mode: Base or Rover
  - User Interface: Android Device
  - Base-Station Data: NTRIP Server
  - Correction Data Format: RTCM 3

- **Type R2** Beta Version:
  - Receiver System: Log Raw Data for Post-processing RTK
  - RTK Processing Engine: Raspberry Pi Zero/WiFi&BT Option: RaspberryPi Camera
  - Mode: Rover Only
  - User Interface: None
  - Base-Station Data: Post-processing
  - Correction Data Format: User Defined

- **Type A1** Release 1.0:
  - Receiver System: Real-time RTK Simultaneous Log of Raw Data
  - RTK Processing Engine: Android Device
  - Mode: Rover Only
  - User Interface: Android Device
  - Base-Station Data: NTRIP Server or VRS
  - Correction Data Format: RTCM 3

- **Type MA** Release 1.0:
  - Receiver System: Real-time PPP Based on MADOCA Correction Data from Internet
  - RTK Processing Engine: Android Device
  - Mode: Rover Only
  - User Interface: APP: MADROID
  - Base-Station Data: MADOCA Correction Data Server
  - Correction Data Format: MADOCA Format

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Slide: 14
Screen Shots of RTKDROID and MADROID

Connect GNSS receiver to Android device

(1) RTKDROID:
   For RTK or PPK

(2) MADROID:
   for MADOCA-PPP,
   MADOCA-PPP/AR (future)
### Low-Cost MADOCA PPP Receiver Systems

<table>
<thead>
<tr>
<th>Type A: MAD-π</th>
<th>Type B: MAD-WIN</th>
<th>Type C: MADROID</th>
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<tbody>
<tr>
<td>Receiver: Dual Frequency Receiver</td>
<td>Receiver: Dual Frequency Receiver</td>
<td>Receiver: Dual Frequency Receiver</td>
</tr>
<tr>
<td>Data Format: UBX, SBF or RTCM 3</td>
<td>Data Format: UBX, SBF or RTCM 3</td>
<td>Data Format: UBX or RTCM 3</td>
</tr>
<tr>
<td>Correction Data: UBX, RTCM3 or JAXA online</td>
<td>Correction Data: UBX, RTCM3 or JAXA online</td>
<td>Correction Data: JAXA online</td>
</tr>
</tbody>
</table>
MADOCA Low-Cost Receiver Systems

Type – A : MAD-π

- GNSS Antenna
- GNSS Receiver
- L1/L2 GNSS Receiver + MADOCA Decoder
- Raspberry Pi 3B or 4B
- WiFi
- MADOCA Correction Data Server
- Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

Type – B : MAD-WIN

- GNSS Antenna
- GNSS Receiver
- L1/L2 GNSS Receiver + MADOCA Decoder
- PC
- WiFi
- MADOCA Correction Data Server
- Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

Type – C : MADROID

- GNSS Antenna
- GNSS Receiver
- L1/L2 GNSS Receiver Only
- Android Device
- WiFi
- MADOCA Correction Data Server
- Use MADOCA correction data from server
GNSS MADOCA Receiver and Antenna

Size: W: 55 x B: 55 x D: 15

GNSS and MADOCA Receiver
L1, L2, E5b, L6
GPS, GLONASS,
GALILEO, BEIDOU,
QZSS
Receiver System Architecture

- GNSS Antenna
  - L1, L2, L5, L6

- L1/L2 Antenna

- F9P Receiver
- GNSS Receiver
- L1/L2/E5B

- MADOCA DECODER
  - (QZSS, L6)

- Micro-USB
  - COM Port: 1
    - Baud Rate: 115,200
    - (GNSS Data)
  - COM Port: 2
    - Baud Rate: 57,600
    - (MADOCA Data)

- Splitter
GNSS Raw Data, F9P Receiver Output
### GNSS Navigation Data Bits, F9P Receiver Output

<table>
<thead>
<tr>
<th>SV</th>
<th>MSG</th>
<th>DATA (* denotes invalid words)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDS 7 E1D1 0</td>
<td>1</td>
<td>36901595 02960070 05E08162 2285100A 00D70A96 3D 450F44 1D D66E1 10C072A5 14E0A8F2 27F0E156</td>
</tr>
<tr>
<td>BDS 7 E2D1 0</td>
<td>??</td>
<td>36901595 02960070 05E08162 2285100A 00D70A96 3D 450F44 1D D66E1 10C072A5 14E0A8F2 27F0E156</td>
</tr>
<tr>
<td>BDS 0 E1D1 0</td>
<td>1</td>
<td>36901595 02960070 05E08162 2285EFE5 36D70A6D 3D 450F44 1D D66E1 10C062C2 3A41FFED 33D34166</td>
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<tr>
<td>BDS 0 E2D1 0</td>
<td>??</td>
<td>36901595 02960070 05E08162 2285EFE5 36D70A6D 3D 450F44 1D D66E1 10C062C2 3A41FFED 33D34166</td>
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<tr>
<td>BDS 10 B2D1 0</td>
<td>1</td>
<td>36901595 02960070 05E08162 2283E0B1 1A07A025 3D 450F44 1D D66E1 10C062C2 0C4809A3 0A1C1D05</td>
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<tr>
<td>BDS 11 B1D1 0</td>
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<tr>
<td>BDS 11 B2D1 0</td>
<td>??</td>
<td>36901595 02810175 05E08162 2282E0B3 0E07A026 3D 450F44 1D D66E1 10C062C2 15DFFFD 328E2A6F</td>
</tr>
<tr>
<td>BDS 13 B1D1 0</td>
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<td>36901595 02968070 05E08162 2284002D 1807A025 3D 450F44 1D D66E1 10C062C2 24D0260B 0B14E145</td>
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<tr>
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</tr>
<tr>
<td>BDS 14 B1D1 0</td>
<td>1</td>
<td>36901595 02866070 05E08162 2283C0B8 0807C0C5 3D 450F44 1D D66E1 10C062C2 181E1F07 00C0ADD2 1A4F4D7A</td>
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<tr>
<td>BDS 14 B2D1 0</td>
<td>??</td>
<td>36901595 02866070 05E08162 2283C0B8 0807C0C5 3D 450F44 1D D66E1 10C062C2 181E1F07 00C0ADD2 1A4F4D7A</td>
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<tr>
<td>BDS 23 B1D1 0</td>
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<tr>
<td>BDS 33 B1D1 0</td>
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<td>36901595 02810175 05E08162 2285757B 1707A086 3D 450F44 1D D66E1 10C062C2 0E370018 04A28173</td>
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<tr>
<td>BDS 34 B1D1 0</td>
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<td>38920597 00010A00 33ECB8BE 05C05F95 273B0302 0DCAEB09 0D3A1B00C 3C98F16A 01F0A17C 1A1A298F</td>
</tr>
<tr>
<td>GAL 2 E1B 0</td>
<td>E0</td>
<td>00565556 55555556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9A9A E9F4400</td>
</tr>
<tr>
<td>GAL 4 E1B 0</td>
<td>E0</td>
<td>00565556 55555556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9A9A E9F4400</td>
</tr>
<tr>
<td>GAL 4 E5B1</td>
<td>??</td>
<td>0217B0F7 29388256 E63F207 B3890000 BC074000 000000A AAAB945 DC7F4000</td>
</tr>
<tr>
<td>GAL 9 E1B 0</td>
<td>E0</td>
<td>00565556 55555556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9A9A E9F4400</td>
</tr>
<tr>
<td>GAL 9 E5B1</td>
<td>??</td>
<td>051C1F4E 04E0738F 0E007382 1198A000 00000000A AAAA9A9A 737F4000</td>
</tr>
<tr>
<td>GAL 11 E1B 0</td>
<td>E3</td>
<td>0277BFFC C8C51BEA FC088642 17930000 95A0D000 0000002A AAAA739D FC3F4000</td>
</tr>
<tr>
<td>GAL 11 E5B1</td>
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<td>00565556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9A9A E9F4400</td>
</tr>
<tr>
<td>GAL 24 E1B 0</td>
<td>E7</td>
<td>02E25E4C 00E05304 38C81C28 7FC0000 38D50400 0000002A AAAA9C78 8FF4000</td>
</tr>
<tr>
<td>GAL 24 E5B1</td>
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<td>00565556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9A9A E9F4400</td>
</tr>
<tr>
<td>GAL 25 E1B 0</td>
<td>E0</td>
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<tr>
<td>GAL 25 E5B1</td>
<td>??</td>
<td>0217B0F7 29388256 E63F207 B3890000 BC074000 000000A AAAB945 DC7F4000</td>
</tr>
<tr>
<td>GAL 30 E1B 0</td>
<td>E0</td>
<td>00565556 55555556 55555556 55F14000 4415F30D 00000000A AAAA9F55 C6FF4000</td>
</tr>
<tr>
<td>GLO 1 L1CF 1</td>
<td>2</td>
<td>323/2054 10A100106 7AA0C20D 07911700</td>
</tr>
<tr>
<td>GLO 2 L1CF 4</td>
<td>2</td>
<td>323/2054 10A100329 1C07E5 65214030</td>
</tr>
</tbody>
</table>
### GNSS Navigation Data Bits, F9P Receiver Output

**UBX - RXM (Receiver Manager) - SFBBK (Subframe Data NG)**

<table>
<thead>
<tr>
<th>SV</th>
<th>MSG</th>
<th>DATA</th>
<th>Strip parity bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLO</td>
<td>2110F 4</td>
<td>2 3/2504</td>
<td>10A0022 91C07E5 65214000</td>
</tr>
<tr>
<td>GLO</td>
<td>2120F 4</td>
<td>2 3/2504</td>
<td>10A0022 91C07E5 65214000</td>
</tr>
<tr>
<td>GLO</td>
<td>7110F 5</td>
<td>6 5/2501</td>
<td>39A442C3 4440F5EC 0E4D0000</td>
</tr>
<tr>
<td>GLO</td>
<td>7120F 5</td>
<td>10 1/2501</td>
<td>551C238A 5F50889C 3E27D000</td>
</tr>
<tr>
<td>GLO</td>
<td>8110F 6</td>
<td>2 3/2504</td>
<td>10A0408 2CE2077F 380D8000</td>
</tr>
<tr>
<td>GLO</td>
<td>8120F 6</td>
<td>1 3/2504</td>
<td>08E23427 79E8A0F7 23E4A000</td>
</tr>
<tr>
<td>GLO</td>
<td>13110F-2</td>
<td>2 3/2504</td>
<td>10A0486 3408330A 8630F800</td>
</tr>
<tr>
<td>GLO</td>
<td>13120F-2</td>
<td>2 3/2504</td>
<td>10A0486 3408330A 8630F800</td>
</tr>
<tr>
<td>GLO</td>
<td>14110F-7</td>
<td>2 3/2504</td>
<td>10A0093 6E09893 26744830</td>
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<tr>
<td>GLO</td>
<td>14120F-7</td>
<td>2 3/2504</td>
<td>10A0093 6E09893 26744830</td>
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<td>2 3/2504</td>
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<tr>
<td>GLO</td>
<td>15120F 0</td>
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<td>7B7C390F 8B0908C4 1E593000</td>
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<td>GLO</td>
<td>17110F 4</td>
<td>2 3/2504</td>
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<tr>
<td>GLO</td>
<td>17120F 4</td>
<td>5 2/2504</td>
<td>23990000 90001100 62630000</td>
</tr>
<tr>
<td>GLO</td>
<td>20110F 3</td>
<td>2 3/2504</td>
<td>10A02B4 E80464C2 D30C7000</td>
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<tr>
<td>GLO</td>
<td>23110F 3</td>
<td>11 1/2500</td>
<td>5C4A72C2 8F7405A4 1A578000</td>
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<tr>
<td>GLO</td>
<td>24110F 2</td>
<td>1 3/2504</td>
<td>02E120D7 6C06759 09054000</td>
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<tr>
<td>GPS</td>
<td>3110CA 0</td>
<td>3</td>
<td>22C03C3C 1DAC08B3 00022B07 1F83B6A6 000145FD 360A0940 07C6477A 0113C4E2 9F3C02 0846D75B</td>
</tr>
<tr>
<td>GPS</td>
<td>3120CM 0</td>
<td>45 ??</td>
<td>880C5768 3A3DD13F 7E0C3855 0F59800F B18620C1 0001E003 2C01FA0C C01C9000 2C940EDC 3E8B000E</td>
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<tr>
<td>GPS</td>
<td>7110CA 0</td>
<td>3</td>
<td>22C03C3C 1DAC08B3 00022B07 1F83B6A6 000145FD 360A0940 07C6477A 0113C4E2 9F3C02 0846D75B</td>
</tr>
<tr>
<td>GPS</td>
<td>7120CM 0</td>
<td>45 ??</td>
<td>880C5768 3A3DD13F 7E0C3855 0F59800F B18620C1 0001E003 2C01FA0C C01C9000 2C940EDC 3E8B000E</td>
</tr>
<tr>
<td>GPS</td>
<td>8110CA 0</td>
<td>3</td>
<td>22C03C3C 1DAC08B3 00022B07 1F83B6A6 000145FD 360A0940 07C6477A 0113C4E2 9F3C02 0846D75B</td>
</tr>
<tr>
<td>GPS</td>
<td>8120CM 0</td>
<td>45 ??</td>
<td>880C5768 3A3DD13F 7E0C3855 0F59800F B18620C1 0001E003 2C01FA0C C01C9000 2C940EDC 3E8B000E</td>
</tr>
<tr>
<td>GPS</td>
<td>11110CA 0</td>
<td>4/5 ??</td>
<td>22C03C3C 1DA37C7E 1A48B559 9B878A23 1AD5A95A A00ECDB2 25F3F153 030C412F 0003C8B9 81588887</td>
</tr>
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## Satellite System & Signal Settings

### F9P Receiver

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<th>Channels max</th>
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Number of channels available: 60
Number of channels to use: 60

### MADOCA Decoder

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Number of channels available: 60
Number of channels to use: 60
## Satellite System and Signal Settings

### F9P Receiver

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<td>✔ L1</td>
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### MADOCA Decoder

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MADOCA Correction Data Output
Received Directly from QZSS L6E Channel

[14:27:58. 559]

[14:27:59. 510]

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp
Type A: MAD-PI

MADOCA PPP based on RaspberryPi / Dual Frequency Receiver + MADOCA Decoder

RaspberryPi 4 with Touch Screen Display

Antenna L1/L2/L5/L6

GNSS + MADOCA Receiver

RaspberryPi 4 Device

GNSS + MADOCA Receiver
Type B: MAD-WIN

The position accuracy improves to cm (10 – 30 cm) level after initialization time of about 15min.
Type B: MAD-WIN
Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali

After few minutes observation

After two hours observation

After three hours observation
Type C: MADROID / MADOCA PPP based on Android
Dual Frequency Receiver + Online MADOCA Data
Type C: MADROID / MADOCA PPP based on Android
Dual Frequency Receiver + Online MADOCA Data
Position Data from MADOCA PPP

We walked straight along the concrete tiles (30cmx30cm) and PPP results showed perfect straight line. Accuracy is about 15cm.

Receiver: F9 + Online MADOCA Correction Data
Test Area: Tokyo
GNSS Receiver Used: u-blox F9P
MADOCA Correction Data: u-blox D9
(Received online via NTRIP Server)
Local Correction Data: Service provided by GPAS
(Received online via NTRIP Server)
Output from MADOCA PPP
Device: RaspberryPi
MADOCA PPP Observation

- **Connection**
  - **Rover**
    - RX
    - Online (MADOCA)
  - **Correction**
    - DX
    - Online (MADOCA)

- **Processing Mode**
  - PPP-Static
  - PPP-Kinematic

- **Device**
  - OS

- **Solution**
  - 2019-12-27_125516.nmea(482304)

- **Rover**
  - 2019-12-27_125516.ubx(3896320)

- **Correction**
  - 2019-12-27_125516.rtc3(1553408)

- **Record On/Off**

- **Connected**
  - [Connected]
MainWindow

Time: 2019-12-27 12:52:59
Latitude: 35.90304378°
Longitude: 139.93930210°
Altitude: 93.777m
Solution: PPP
Lat Error: 2.328m
Lon Error: 1.949m
Alt Error: 1.722m

MainWindow

Latitude: 35.90304275°
Longitude: 139.93930992°
Altitude: 94.133m
Solution: PPP
Lat Error: 1.395m
Lon Error: 1.144m
Alt Error: 1.011m

Connected

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp
MADOCA PPP at Kashiwa Campus

<table>
<thead>
<tr>
<th></th>
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MADOCA PPP at Kashiwa Campus

10cm
Part - B
Android GNSS Raw Data Measurement
New Tools for Android GNSS Measurements

GSA Raw Measurements Workshop, Prague, 26 June 2019

v1.01

Frank van Diggelen
Google

Many slides in this presentation are based on the presentation document from Dr. Frank van Diggelen
Raw Measurement: Lecture Notes by Dr. Frank van Diggelen, Google Inc.

Download the Lecture Notes from https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Raw.htm
Raw GNSS Measurements

The Android Framework provides access to raw GNSS measurements on several Android devices.

*Note: Google has released version 2.6.3.0 of the GNSS Analysis App. For more information, see the GNSS Analysis app v2.6.3.0 release notes.*

This article lists Android devices that support raw GNSS measurements as well as tools to log and analyze GNSS data. You can find the tools in the GPS Measurement Tools repo on GitHub, which includes the GNSS Logger APK and the GNSS Analysis app for Linux, Windows, macOS, and the Installation and User Manual.

Original equipment manufacturers (OEMs), developers, and researchers can make use of the tools in this page to test new phone designs, validate functionality, develop new algorithms, evaluate improvements to the GNSS system.

https://developer.android.com/guide/topics/sensors/gnss
GNSS Raw Data Compatible Smart-Phones

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</tbody>
</table>

Check ➔ [https://developer.android.com/guide/topics/sensors/gnss](https://developer.android.com/guide/topics/sensors/gnss) for Latest Updates
Android Raw Data Logging APPs

• GNSS Logger
  • Logs Raw Data
  • Some devices also output AGC and Navigation Bit Data
  • Multi Band Compatible

• Geo++ RINEX Logger
  • APP to generate RINEX Observation File
    • Dual Frequency Compatible

• GNSS Compare
  • Compares position accuracy from each type of GPS and GALILEO Signal
Android Raw Data Logging Tool – 1: GnssLogger

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@cis.u-tokyo.ac.jp
GNSS Raw Data Output Format from Smart Phone Device

- #
- # Header Description:
- # Version: v2.0.0.1 Platform: 9 Manufacturer: Xiaomi Model: MI 8
- # Raw,
  - ElapsedRealtimeMillis, TimeNanos, LeapSecond, TimeUncertaintyNanos, FullBiasNanos,
  - BiasNanos, BiasUncertaintyNanos, DriftNanosPerSecond, DriftUncertaintyNanosPerSecond,
  - HardwareClockDiscontinuityCount, Svid, TimeOffsetNanos, State, ReceivedSvTimeNanos,
  - ReceivedSvTimeUncertaintyNanos, Cn0DbHz, PseudorangeRateMetersPerSecond,
  - PseudorangeRateUncertaintyMetersPerSecond, AccumulatedDeltaRangeState,
  - AccumulatedDeltaRangeMeters, AccumulatedDeltaRangeUncertaintyMeters, CarrierFrequencyHz,
  - CarrierCycles, CarrierPhase, CarrierPhaseUncertainty, MultipathIndicator,
  - SnrInDb, ConstellationType, AgcDb, CarrierFrequencyHz
- # Fix,
  - Provider, Latitude, Longitude, Altitude, Speed, Accuracy, (UTC) TimeInMs
- # Nav,
  - Svid, Type, Status, MessageId, Sub-messageId, Data(Bytes)
GnssLogger: Sample GNSS Raw Data

Raw,148210058,6108000000,,1224572056418544947,0.0,1011000.0,,24,0.0,51,16023402,13,38.61924362182617,448.32047602538079,0.00213026441633701321,2484.2876523853806,0.9621916860735094,1.57542003E9,1.17645005E9,0.00213026441633701321,1.57542003E9
Raw,148210058,6108000000,,1224572056418544947,0.0,1011000.0,,24,0.0,16,16023363,1000000000,22.0133236694336,448.7947882361932,2.99792458E8,5.4362,39162390184,3.402823463852886E38,1.17645005E9,0.00213026441633701321,1.7645005E9
Raw,148210059,6108000000,,1224572056418544947,0.0,1011000.0,,2,0.0,99,451783264,42,33.2121467590332,514.7820368047455,2.99792458E8,54362.39162390184,3.402823463852886E38,1.17645005E9,0.00213026441633701321,1.7645005E9
Raw,148210059,6108000000,,1224572056418544947,0.0,1011000.0,,12,0.0,99,451783264,42,33.2121467590332,514.7820368047455,2.99792458E8,54362.39162390184,3.402823463852886E38,1.17645005E9,0.00213026441633701321,1.7645005E9
Raw,148210060,6108000000,,1224572056418544947,0.0,1011000.0,,24,0.0,99,451325376,47,31.866662739501953,540.7229326212153,0.004294544453889282,1.2792.053059872405,0.0021472722291946141,1.6031294999,0.0021472722291946141,1.60312949989,0.3,1.60312949989
Raw,148210060,6108000000,,1224572056418544947,0.0,1011000.0,,24,0.0,99,451325376,47,31.866662739501953,540.7229326212153,0.004294544453889282,1.2792.053059872405,0.0021472722291946141,1.60312949989,0.3,1.60312949989
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
Raw,148210061,6108000000,,1224572056418544947,0.0,1011000.0,,23,0.0,17,163750,51,30.87108235908203,751.232553423079,0.561522050942092,4.3454.136294113628,3.4028234638528286E38,1.603687555E9,0.0,0.3,1.603687555E9
GnssLogger: Sample GNSS Raw Data, Header

### Header Description:

### Version: v2.0.0.1 Platform: 8.1.0 Manufacturer: Xiaomi Model: MI 8

```plaintext
#Raw,ElapsedRealtimeMillis,TimeNanos,LeapSecond,TimeUncertaintyNanos,FullBiasNanos,BiasNanos,BiasUncertaintyNanos,DriftNanosPerSecond,DriftUncertaintyNanosPerSecond,HardwareClockDiscontinuityCount,Svid,TimeOffsetNanos,State,ReceivedSvTimeNanos,ReceivedSvTimeUncertaintyNanos,Cn0DbHz,PseudorangeRateMetersPerSecond,PseudorangeRateUncertaintyMetersPerSecond,AccumulatedDeltaRangeState,AccumulatedDeltaRangeMeters,AccumulatedDeltaRangeUncertaintyMeters,CarrierFrequencyHz,CarrierCycles,CarrierPhase,CarrierPhaseUncertainty,MultipathIndicator,SnrInDb,ConstellationType,AgcDb,CarrierFrequencyHz
```

### Fix,Provider,Latitude,Longitude,Altitude,Speed,Accuracy,(UTC)TimeInMs

### Nav,Svid,Type,Status,MessageId,Sub-messageId,Data(Bytes)

#
### GnssLogger: Sample GNSS Raw Data

<table>
<thead>
<tr>
<th>Raw</th>
<th>678357857,828940000000</th>
<th>-1227744676059580169</th>
<th>0.0, 5.135445098385752</th>
<th>0.2, 0.0, 16431, 1504929579420, 11, 42.886016845703125, -253.99484677373584, 0.0013739581918343902</th>
<th>1, -230928.6182155476, 6.869790959171951E-4, 1.57542003E9, 0, 1, 1.57542003E9</th>
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</thead>
<tbody>
<tr>
<td>Raw</td>
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<td>-1227744676059580169</td>
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<td>0.5, 0.0, 16431, 1504926917641, 12, 42.140777587890625, -299.9095448909793, 0.0014970472548156977</td>
<td>1, -262724.97200484236, 7.485236274078488E-4, 1.57542003E9, 0, 1, 1.57542003E9</td>
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<tr>
<td>Raw</td>
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<td>0.0, 5.135445098385752</td>
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</tr>
<tr>
<td>Raw</td>
<td>678357858,828940000000</td>
<td>-1227744676059580169</td>
<td>0.0, 5.135445098385752</td>
<td>0.7, 0.0, 16431, 1504921150324, 19, 34.2019112626953, -228.1697012801305, 0.003542420221492648, 1, 213920.67928652398, 0.09691804650992876, 1.57542003E9, 0, 1, 1.57542003E9</td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>678357858,828940000000</td>
<td>-1227744676059580169</td>
<td>0.0, 5.135445098385752</td>
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</tr>
<tr>
<td>Raw</td>
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<td>0.0, 5.135445098385752</td>
<td>0.13, 0.0, 16431, 1504920021810, 19, 34.32540512084961, 666.6443721854594, 0.0032926779240369797, 1, 561690.3480669406, 0.001646338962018498, 1.57542003E9, 1, 1, 1.57542003E9</td>
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</tr>
<tr>
<td>Raw</td>
<td>678357858,828940000000</td>
<td>-1227744676059580169</td>
<td>0.0, 5.135445098385752</td>
<td>0.17, 0.0, 16431, 1504916630146, 20, 33.56485366821289, 744.6819117466221, 0.003812001552432776, 1, 619849.6424447118, 0.0019060007762163877, 1.57542003E9, 1, 1, 1.57542003E9</td>
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</tr>
<tr>
<td>Raw</td>
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<td>-1227744676059580169</td>
<td>0.0, 5.135445098385752</td>
<td>0.19, 0.0, 16431, 1504921921584, 23, 31.828954696655273, 735.126564052538, 0.004389062523841858, 1, 599416.7818672012, 0.09734136766110336, 1.57542003E9, 0, 1, 1.57542003E9</td>
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</tr>
</tbody>
</table>
GnssLogger: Sample GNSS Raw Data, Position and NMEA

Fix,gps,35.850232,139.862279,37.854518,0.008482,4.000000,1543710718999
NMEA,$GPGLSV,4,1,14,02,71,324,32,06,60,115,39,05,43,288,35,09,29,045,25*74
,1543710720204
NMEA,$GPGLSV,4,2,14,07,26,093,34,19,24,182,23,30,22,130,27,13,22,207,23*72
,1543710720204
NMEA,$GPGLSV,4,3,14,29,11,323,22,23,04,042,,17,03,169,*4A
,1543710720204
NMEA,$GPGLSV,4,4,14,06,,39,09,,30,30,,36,8*68
,1543710720204
NMEA,$GLGSV,2,1,07,83,80,264,26,68,65,326,32,82,37,165,23,69,32,254,33*6D
,1543710720204
NMEA,$GLGSV,2,2,07,67,28,037,24,84,26,329,19,77,08,073,11*5F
,1543710720204
NMEA,$QZGSV,2,1,05,01,83,285,31,03,41,201,33,02,07,171,22*53
,1543710720204
NMEA,$QZGSV,2,2,05,01,,34,03,,33,8*71
,1543710720205
NMEA,$BDGSV,1,1,02,203,38,224,23,202,20,250,*60
,1543710720205
NMEA,$GAGSV,2,1,08,104,75,259,30,112,61,159,30,119,42,045,29,109,22,236,25*6F
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NMEA,$GPGSA,A,3,02,05,06,07,09,13,19,29,30,,,,1.6,0.7,1.4*3A
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NMEA,$GNGSA,A,3,02,05,06,07,09,13,19,29,30,,,,1.6,0.7,1.4*24
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NMEA,$NGNQA,A,3,67,68,69,82,83,84,,,,,,,1.6,0.7,1.4*24
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NMEA,$QZGSA,A,3,01,02,03,,,,,,,,,,1.6,0.7,1.4*2B
,1543710720206
NMEA,$SIMGSA,A,3,,,,,,,,,,,,1.6,0.7,1.4*24
,1543710720206
NMEA,$BDGSA,A,3,203,,,,,,,,,,,,1.6,0.7,1.4*17
,1543710720206
NMEA,$SGAGSA,A,3,104,109,112,119,,,,,,,,,1.6,0.7,1.4*20
,1543710720206
NMEA,$GPRMC,003159.00,A,3551.013922,N,13951.736758,E,000.0,337.0,021218,,,A*51
,1543710720206
GnssLogger: Sample GNSS Raw Data, Navigation Bit Data

Nav,101,769,1,5,9,76,34,58,55,7,116,-65,67,-77,-42,88
Nav,102,769,1,5,9,76,34,58,55,7,116,-65,67,-77,-42,88
Nav,103,769,1,5,9,76,34,58,55,7,116,-65,67,-77,-42,88
Nav,105,769,1,5,9,76,34,58,55,7,116,-65,67,-77,-42,88
Nav,106,769,1,5,9,76,34,58,55,7,116,-65,67,-77,-42,88
GNSS Raw Data Analysis Tool for GnssLogger

- GNSS Analysis APP
  - Matlab-based Tool
  - Linux, Windows, MacOS
  - Version 2.6.3.0
  - Release Notes: https://developer.android.com/guide/topics/sensors/gnss#releaseGNSS Analysis app v2.6.3.0 release notes.

The GNSS Analysis app is built on MATLAB, but you don’t need to have MATLAB to run it. The app is compiled into an executable that installs a copy of the MATLAB Runtime.
Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Data logged by Mi8 Smart-phone inside the car
Position Output from Android GNSS Receiver, Komaba

- Standard Position Computation
  - No DGPS or RTK Corrections
  - All visible GNSS Satellites are used
  - Frequency: L1/L5/E5
  - Surrounding: Tall Buildings around
Position Output from Android GNSS Receiver, Hongo

Smart-Phone is kept under the Tree
Red Circle Radius : 5m
Position Output from Android GNSS Receiver

Smart-Phone is kept in an Open Area
Red Circle Radius: 5m
Position Output from Android GNSS Receiver, Melbourne

Smart-Phone is kept on a Bench in the park
Red Circle Radius: 5m
SEE Next SLIDE
Smart-Phone is kept on a Bench in the park
Red Circle Radius: 5m
Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Location:
Kennedy Space Center
Florida

Data logged by Mi8 Smartphone inside the car
Driving from Hotel to Kennedy Space Center
Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Data logged by Mi8 Smart-phone inside the car Driving from Hotel to Kennedy Space Center

© 2018 Google
GNSS Position Data from Mi8 Android Device

Yellow Circles : Mi8 Device
White Circle   : 5m Radius

Location: SUVA, FIJI
GNSS Position Data from P20 Android Device

Red Circles       : P20 Device
White Circle      : 5m Radius

Location: SUVA, FIJI
GNSS Position Data from Mi8 & P20 Android Devices

Red Circles : P20 Device
Yellow Circles : Mi8 Device
White Circle : 5m Radius

Location: SUVA, FIJI
Android Raw Data Logging APP Geo++ RINEX Logger

**Logging**

```
Logging ... 00:07
```

**Ready**

```
Ready ... 00:00
```

**GNSS Compare**

```
GNSS Compare

NMEA
MODIFY
DELETE

GPS L1
Pedestrian EKF
Relativistic path range correction
Tropospheric correction
Klobuchar Iono Correction
NMEA

GPS L5
Pedestrian EKF
Relativistic path range correction
Tropospheric correction
Klobuchar Iono Correction
NMEA

GPS IF
Pedestrian EKF
Relativistic path range correction
Tropospheric correction
NMEA

GPS L1
Pedestrian EKF
```

Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp
Geo++ RINEX Logger

This file was generated by the Geo++ RINEX Logger App for Android devices (Version 2.0.0). If you encounter any issues, please send an email to android@geopp.de

Supports both L1 & L5

Android Raw Data Logging APP: RTKDROID

- External GNSS Receiver can be connected to Android Device
- Base-Station is connected via NTRIP Address
- VRS Correction also supported
- Supported File Format
  - ubx (u-blox)
  - Other formats will be included if requested
    - SBF (Septentrio) will be included in near future
- Real-Time RTK
- Raw Data can be logged for Post-Processing
- Output from RTKDROID can be send to other APKs in the device
Android APP to Input GNSS Data for GIS: SW Maps

• Excellent APP to collect GIS Data in the field

• Internal or External GNSS Receiver can be used
  • External Receiver can be connected via BT or USB Cable

• Many Popular File Formats are Supported
  • u-blox
  • Topcon
  • Trimble
  • Septentrio
  • Garmin
  • Or Any Receiver with NMEA output
  • Output from RTKDROID can be send to SW Maps

RTKDROID and SW MAPS run in many Android Devices that has OS 5.0 or later
Contact and Additional Information

• Homepage
  • Main Page : https://home.csis.u-tokyo.ac.jp/~dinesh/
  • Webinar Page : https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm
    https://gnss.peatix.com/
  • Training Data etc. : https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
  • Low-Cost Receiver : https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
  • Facebook : https://www.facebook.com/gnss.lab/

• Contact
  • E-mail : dinesh@csis.u-tokyo.ac.jp
  • Skype : mobilemap