



Workshop on GNSS for Policy and Decision Makers 21st January 2022

Low-Cost and Smart-Phone Receiver Systems

Dinesh Manandhar, Associate Professor (Project)

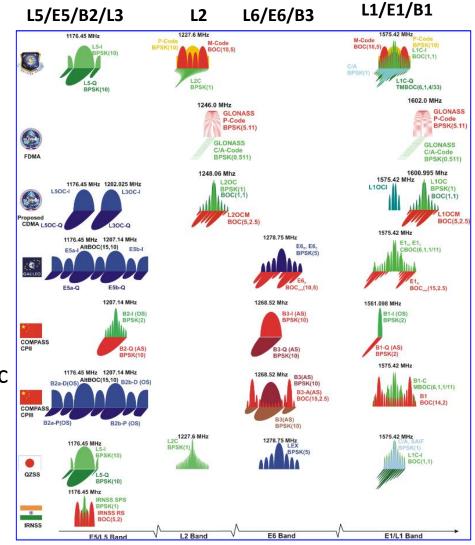
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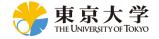


High-End Survey Grade Receivers

- 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 (including antenna)

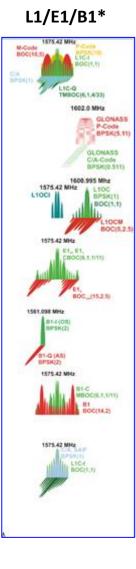






Low-Cost Receivers

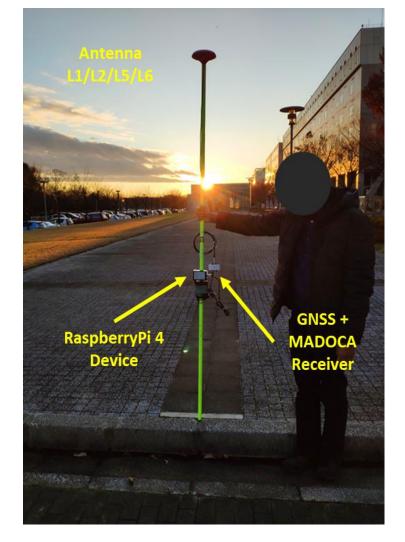
- Multi-System
 - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Frequency
 - L1/E1/B1-Band
 - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
 - Future trend for Mass Market System will be L1/L5
 - Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market
- Low Cost:
 - Less than \$1,000
 - Our Target: \$100 including everything. (L1 band only receiver)
 - But, currently about \$300 including Antenna and all necessary Hardware, Software
 - This is using Dual-Band Receiver and Antenna
 - In future, dual band low-cost receivers based on L1/L2 and L1/L5 will be available







Low-Cost High-Accuracy Receiver Systems RTKDROID, MADROID, MAD-WIN, MAD-π

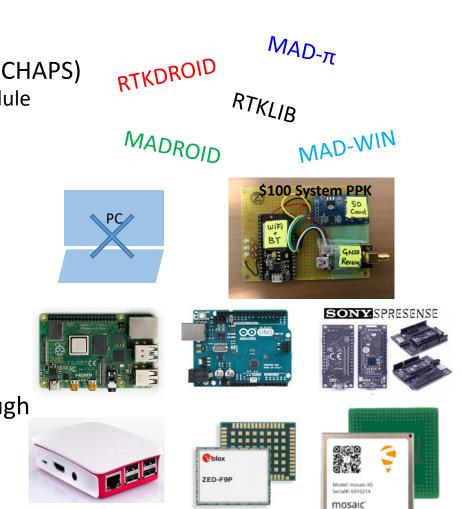






Objectives

- Develop Low-Cost High-Accuracy Positioning Systems (L-CHAPS)
 - System Integration of commercially available receiver or module
 - For RTK and MADOCA
 - Avoid use of computer to minimize the cost
 - Use Single Board Computer (SBC)
 - RaspberryPi, Arduino, Spresense
 - Use Tablet or Smart-Phone
 - Android devices are quite flexible and easier to use
- Develop Easy to Use System in Field
 - A user without GNSS knowledge shall be able to use
 - Self-understanding interface
 - Suitable for remote operation and data logging
 - Operate with mobile power-banks
- Promote GNSS and MADOCA Technologies Abroad through
 - Lectures, Trainings, Seminars, Workshops and Events
 - Joint Research and Joint Projects

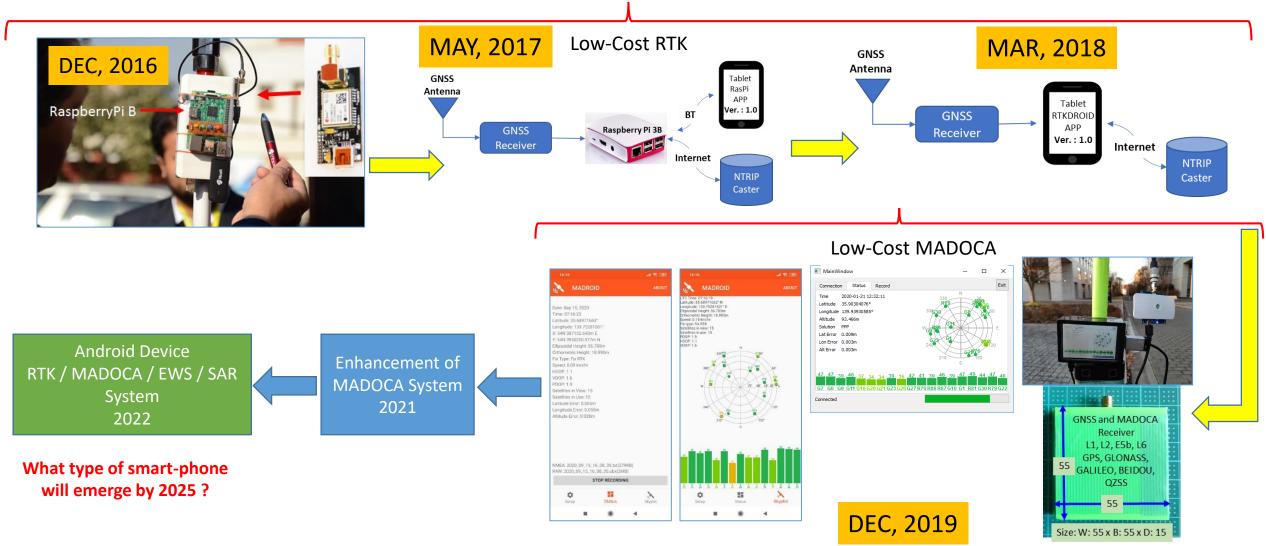


We have no intention to prefer any brand names mentioned in these slides. They are used only for reference.





Low-Cost High-Accuracy Receiver system Development Cycle

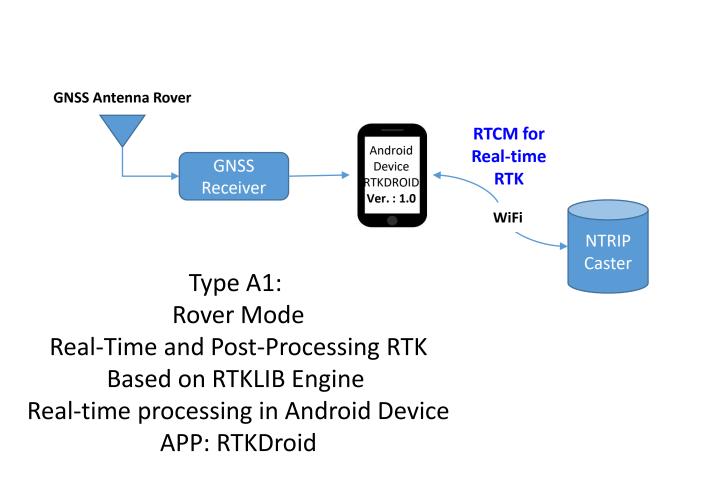


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Type – A1: GNSS Receiver with Android Device







GNSS Receiver Module



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)

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onnection USB	~	UTC Time: 07:16:19 Latitude: 35.68971662° N			
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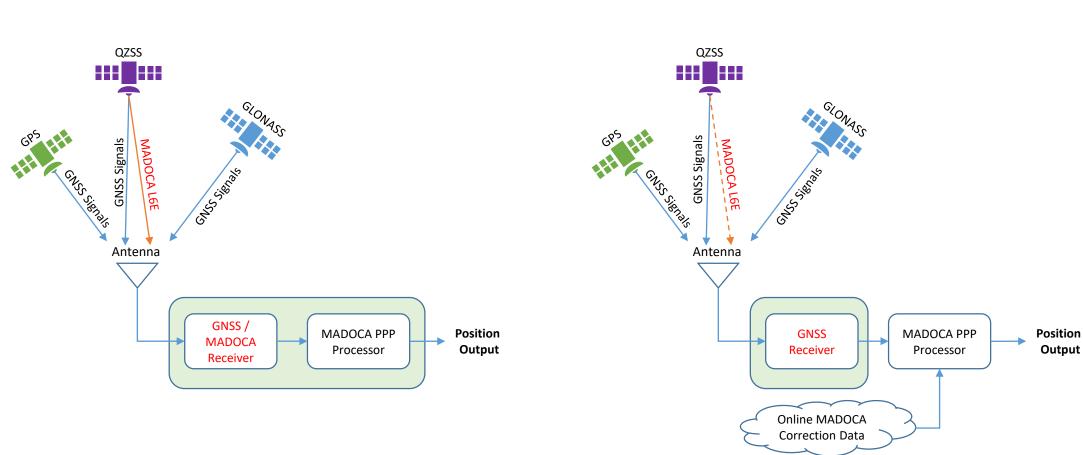
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GNSS Receiver + MADOCA Decoder



MADOCA System: Direct from QZSS or Online Correction Data



GNSS Receiver Only



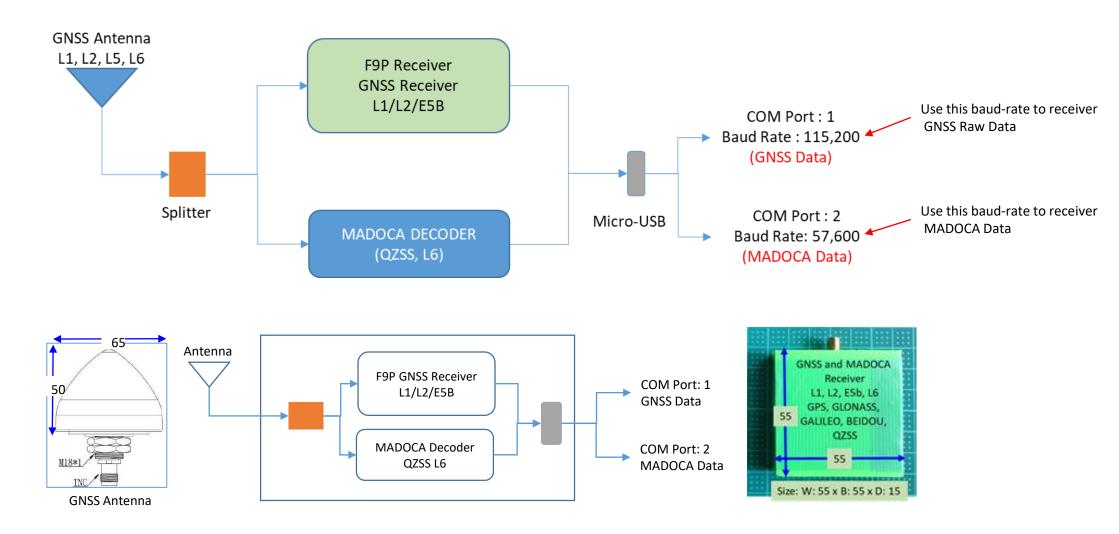
Low-Cost MADOCA Receiver Systems: Product Types

	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction Data only)
GNSS Receiver Data Format	UBX, SBF, RTCM3	UBX SBF, RTCM3 (For online GNSS data)	UBX
MADOCA Correction Data Format (Satellite)	UBX only	UBX only	NA
MADOCA Correction Data Format (Online)	Online Services from GPAS, UTokyo (Test Level) UBX or RTCM3	Online Services from GPAS, UTokyo (Test Level) Online Services UBX or RTCM3	GPAS Services, RTCM3 UTokyo Online Service in the next release
System Architecture	Antenna L1/L2 GNSS + MADOCA Decoder (Windows)	Antenna L1/L2 GNSS + MADOCA Decoder	Antenna L1/L2 GNSS + MADOCA Decoder





MADOCA PPP Receiver System







MAD-WIN / MAD-PI User Interface

MADOCA Demo 2020 - C X Connection Status Record About Exit Rover	MADOCA Demo 2020 - C X Connection Status Record About Exit Rover	Cases	GNSS Receiver	MADOCA Correction Data	Selection Setting in the Program
RX O Online Setup Correction DX O Online (MADOCA) Setup Processing Mode @ PPP-Static O PPP-Kinematic	RX O Online Setup Correction O DX Online (MADOCA) Setup Processing Mode PPP-Static O PPP-Kinematic	Case A	Connect Receiver Directly	Connect MADOCA Receiver Directly	RX and DX
Not Connected	Not Connected	Case B	Connect Receiver Directly	Get MADOCA correction data through NTRIP	RX and Online (MADOCA)
Connection Status Record About Exit Rover O RX Online Setup Correction O DX Online (MADOCA) Setup	Connection Status Record About Exit Rover O RX O Inline Setup Correction DX O Online (MADOCA) Setup	Case C	Connect Receiver though NTRIP	Get MADOCA correction data through NTRIP	Online and Online (MADOCA)
Processing Mode PPP-Static O PPP-Kinematic Start/Stop Not Connected	Processing Mode PPP-Static O PPP-Kinematic Start/Stop Not Connected	Case D	Connect Receiver though NTRIP	Connect MADOCA Receiver Directly	Online and DX



MAD-WIN / MAD-PI User Interface

■ MADOCA Demo 2020 — □ ×	■ MADOCA Demo 2020 — □ ×	■ MADOCA Demo 2020 — □ ×
Connection Status Record About Rover Online Setup RX Online Setup Correction Online (MADOCA) Setup Processing Mode Online PPP-Static Start/Stop Start/Stop	Connection Status Record About Time 2020-09-30 01:12:24 N 30 60 Latitude 35.68970411" V 40 60 60 Longitude 139.75278573" V 40 60 60 60 Altitude 57.353m V 40 60	Connection Status Record About Device Windows Solution 2020-09-30_010212.nmea(365568) Rover 2020-09-30_010212.ubx(2855936) Correction 2020-09-30_010212.ubx(345088) Record On/Off
Connected	Connected	Connected

Log Files:

1. Solution: MADOCA PPP Solution in NEMA format

2. Rover: Rover RAW Data in receiver's proprietary format Can be used for PPK (Post-Processing Kinematic) Solution or Post-Processing PPP

3. Correction: MADOCA PPP Correction Data in receiver's proprietary format

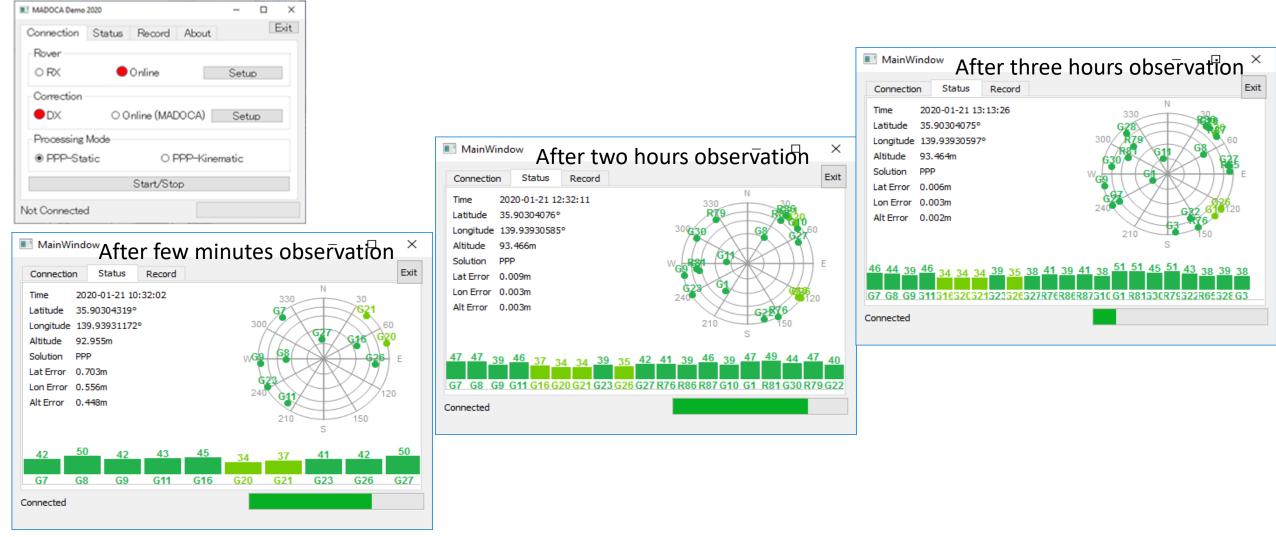
Can be used for Post-Processing MADOCA

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MAD-WIN Data Observation

Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali

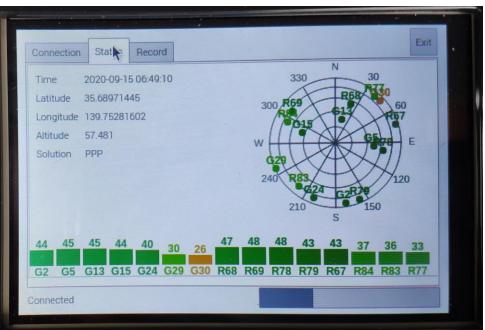




MAD-PI:MADOCA with RaspberryPi Device

- MAD-Pi has been tested with RaspberryPi-3B device
 - It also works with RaspberryPi-4B
 - If the device does not work, please try with a different USB port
- Do not remove and insert SD Card several times. It may get damaged.
- Observation data can be logged to an external USB memory disk. Memory drive of upto 64GB is supported.
 - Files are created at 6-hour interval with Date/Time based filename.
- Ras-Pi 4 device consumes more power than Ras-Pi 3 device. Continuous operation of the device will generate heat. Keep the device in well ventilated area
 - Do not keep the device in a closed box
- We have set both Ras-Pi 3 and Ras-Pi 4 devices with touch screens for easy operation.
 - Mouse and External keyboard can be connected either via BT or USB ports
- Ras-Pi device can be connected by an Android device using BT





Raspberry-Pi device with Touch Screen



MADROID: MADOCA with Android Device

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MADROID: MADOCA with Android Device

Connection USB Device u-blox GNSS receiver Format ubx Processing Settings Rover Mode PPP-Static Elevation Mask 10 Antenna Model TWIVP6000	- ¢ 	PRECEIVER Sy MADROID UTC Time: 05:27:17 Latitude: 139.93857286* E Ellipsoidal Height: 59.349im Orthometric Height: 59.349im Orthometric Height: 59.349im Orthometric Height: 13.385m Speed: 0.15 km/hr Fix type: PPP Satellites in vise: 13 Satellites in vise: 13 PDOP: 3.4 HOOP: 1.8 VDOP: 3.0 N	35° 10° 10° 10° 10° 10° 10° 10° 10° 10° 10	Date: Dec 25, 2019 Time: 05:34:17 Latitude: 35:9020231 Longitude: 139:9385: X: 54N 404216.762m Y: 54N 3973601.765r Ellipsoidal Height: 59. Orthometric Height: 2 Fix Type: PPP Speed: 0.11 km/hr HDOP: 1.9 VDOP: 3.0 PDOP: 3.5 Satellites in View: 13 Satellites in View: 13 Latitude Error: 0.191r Longitude Error: 0.17	0° 7932° E m N .848m 21.884m	
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Port 2101		. 				
Mount Point MDC0				NMEA: 2019_12_25_ UBX: 2019_12_25_14		.8)
START ROVER					STOP RECORDING	
Setup Status	skyplot	Setup Statu	X	Setup	Status	, N Skyplot
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GNSS Data from Android Device





GNSS Data from Android Smart-Phone

- Android device can output GNSS only position data
 - Since it uses multiple satellite systems and some device also uses L1 and L5 bands Accuracy is much better
- Many Android devices with OS 7.0 or higher can output Raw Data
 - These data are used for High-Accuracy data processing such as RTK
- Some devices have Multi-Frequency (L1/L5) GNSS receiver
 - Multi-System (GPS, GLONASS, GALILEO, BEIDOU, QZSS, NavIC)
 - Multi-Frequency (L1/E1/B1, L5/E5)
 - Outputs more than 40 channels
 - Some devices output NAV BIT Data, AGC values and Antenna Phase Center
- Google APIs are available to process GNSS raw data from a smart-phone



GNSS Raw Data Compatible Smart-Phones

	This List is Old. F	lease ch	leck for	New Li	st	Raw [Data ou	tput used i	in Syste	m Score	Satellite Systems used in System Score				em	
S. No.	This List is Old. Model	Android version	Score	Functio n Score Max: 5 (E)	Total Score (D + E)	AGC	NAV MSG	Accumul ated delta range	HW clock	L5 Suppor t	GPS	GLO	GAL	BDS	QZSS	SBAS
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31	Samsung S8	7	5	3	8	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no
33	Huawei P10	7	5	3	8	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no
42	Huawei Mate 20 X	9	4	4	8	no	yes	yes	yes	yes	yes	yes	yes	no	yes	no
19	Google Pixel 2 XL	8	5	2	7	yes	no	no	yes	no	yes	yes	yes	yes	yes	no
20	Google Pixel 2	8	5	2	7	yes	no	no	yes	no	yes	yes	yes	yes	yes	no
22	Samsung Note 8	7.1	4	3	7	no	yes	yes	yes	no	yes	yes	yes	yes	no	no
1	Pixel 3 XL	9	4	3	7	yes	no	yes	yes	no	yes	yes	yes	yes	no	no
2	Pixel 3	9	4	3	7	yes	no	yes	yes	no	yes	yes	yes	yes	no	no
43	Huawei Mate 20 RS	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
44	Huawei Mate 20 Pro	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
45	Huawei Mate 20	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
10	Huawei P20	8.1	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no
11	Samsung Galaxy S9	8	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no
18	Huawei Mate 10 Pro	8	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no

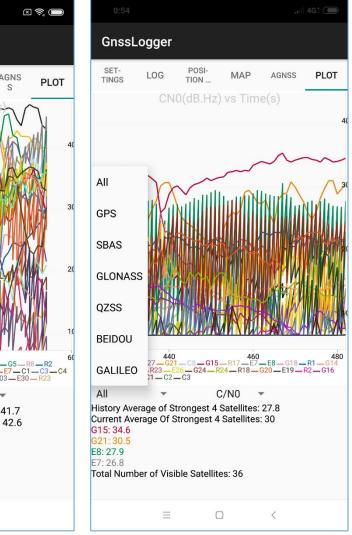
Check > <u>https://developer.android.com/guide/topics/sensors/gnss</u> for Latest Updates



Android Raw Data Logging Tool – 1: GnssLogger

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GnssLogger		GnssLogger
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Switch is ON Switch is ON	Measurements	AccumulatedDeltaRangeMeters = 170 AccumulatedDeltaRangeUncertaintyM CarrierFrequencyHz = 1.57542003E9 MultipathIndicator = 1 CarrierFreqHz = 1.57542003E9
Switch is ON Switch is ON	GnssStatus	GnssMeasurement: Svid = 30 ConstellationType = 1
Switch is OFF	Auto Scroll	TimeOffsetNanos = 0.0 State = 16 ReceivedSvTimeNanos = 14861213 ReceivedSvTimeUncertaintyNanos = 1
Switch is OFF	Residual Plot	Cn0DbHz = 7.000 PseudorangeRateMetersPerSecond = PseudorangeRateUncertaintyMetersPer 299792458.000 AccumulatedDeltaRangeState = 4 AccumulatedDeltaRangeMeters = 346 AccumulatedDeltaRangeUncertaintyM CarrierFrequencyHz = 1.57542003E9 MultipathIndicator = 0 CarrierFreqHz = 1.57542003E9
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HW Year: 2018 Platform: 8.1.0 Api Level: 27	v2.0.0.1	Time Remaining: N/A
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A	All History Ave Current Ave G24: 45 G15: 42.9 G5: 42.7				
STOP & SEND	G21: 39.9 Total Num	ber of Vis	sible Sate	llites: 39	
<		Ξ	C		<





GNSS Raw Data Analysis Tool for GnssLogger

- GNSS Analysis APP
 - Matlab-based Tool •
 - Linux, Windows, MacOS ٠
 - Version 2.6.3.0
 - New Version V4.0.0.0 is available. Download new version **Release Notes:** ۲ https://developer.android.com/guide/topics/sensors/g nss#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.

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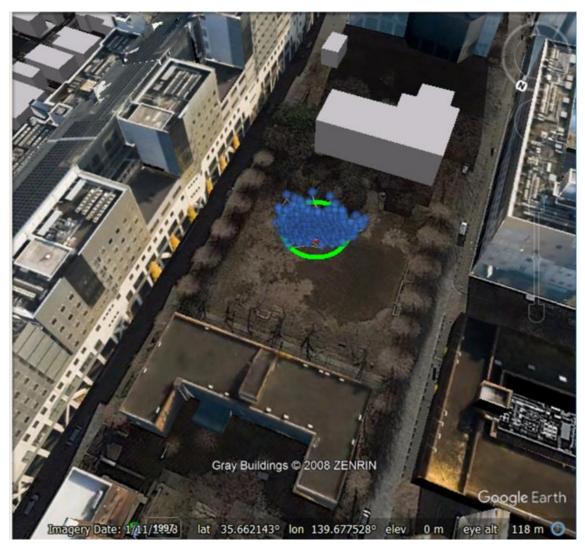
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@csis.u-tokyo.ac.jp





Position Output from Android GNSS Receiver, Tokyo University, Komaba Campus

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

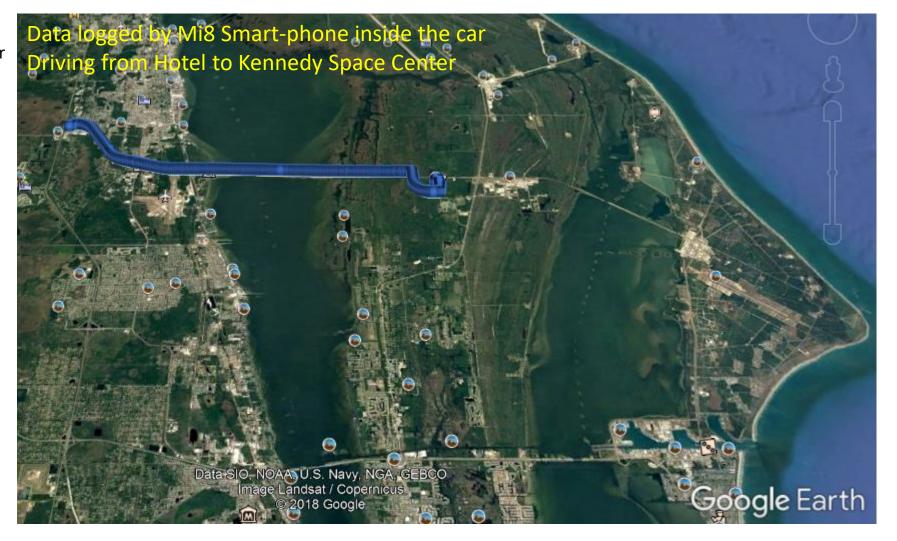






Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Location: Kennedy Space Center Florida







Output from GNSS Analysis Tool, Data Logged by GNSSLogger



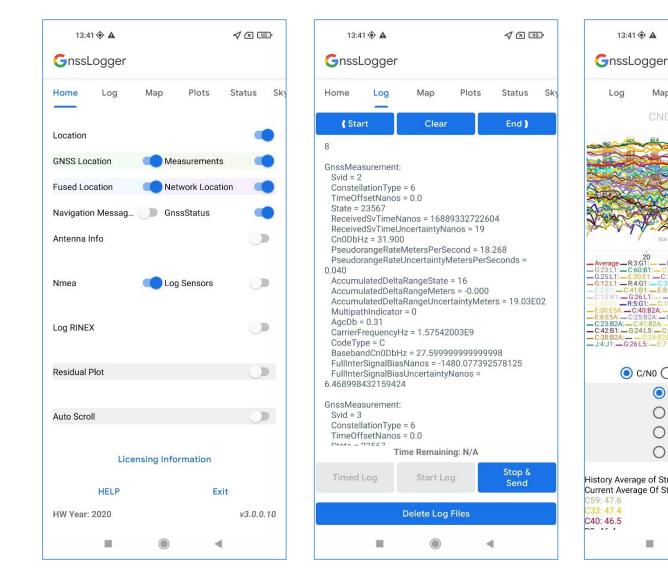


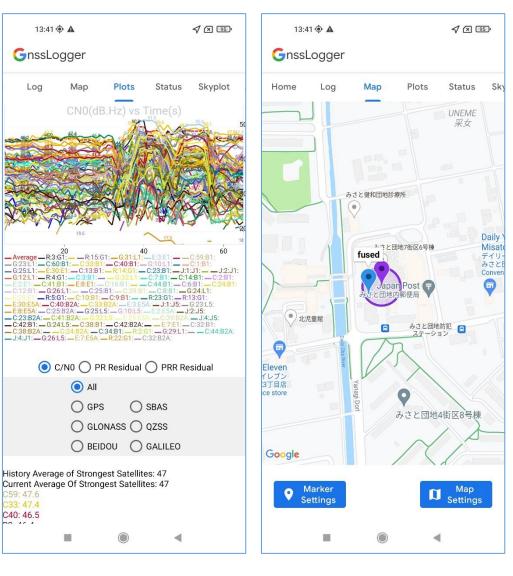
Xiaomi Mi11 Lite 5G Screen Shots

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= Status = = 🗧 📢 🚥	= Status = = 🗧 🗲	= Status = = 🗧 🗲 🗨	= Sky <	≡ sky <
Lat: 35.85 Time: 13:38:26 Long: 139.8 TTFF: 2 sec Alt: 47.3 m E H/V Acc: 3.8/2.5 m Alt (MSL): 8.3 m # Sats: 43/55/64 Speed: 0.0 m/s Bearing: S. Acc: 0.1 m/s B. Acc: PDOP: 0.5 H/V DOP: 0.3/0.4	2 1561.098 33.9 AE 88° 260° 2 E5a 28.2 AE 88° 260° 3 1561.098 40.1 AE 54° 136° 3 E5a 35.5 AE 54° 136° 5 E1 17.0 A 3° 135° 7 E1 25.6 AU 16° 314° 8 E1 37.2 AEU 68° 313° 8 E5a 34.2 AEU 68° 313°	26 * B2a A 1° 62° 32 * B1 A 7° 323° 32 * B2a 19.8 A 7° 323° 32 * B1C 27.4 A 7° 323° 33 * B1 47.0 AEU 52° 189° 33 * B2a 40.2 AE 52° 189° 33 * B2a 40.2 AE 52° 189° 33 * B2a 40.2 AE 52° 189° 34 * B1 A 6° 135° 34 * B2a 20.5 AU 6° 135°	9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9	Avg 32.705.0 C/N0 648-45 (dB-Hz) 1 10 18 27 Legend Legend
ID GNSS CF C/N0 Flags Elev Azim 10 L1 43.0 AEU 39* 220* 10 L1 43.0 AEU 39* 220* 10 L1 37.0 AE 39* 220* 12 L1 33.3 AEU 48* 48* 23 L1 46.2 AEU 19* 188* 23 L5 40.2 AEU 19* 188* 24 L1 32.5 AEU 20* 74* 24 L5 32.4 AEU 20* 74* 25 L1 30.8 AEU 82* 106* 25 L5 26.6 L8 2* 106* 26 L1 24.4 AE 3* 221* 26 L5 20.2 AE 3* 221*	25 E1 31.6 AEU 36° 43° 25 E5a 27.7 AEU 36° 43° 30 E1 38.0 AEU 35° 224° 30 E5a 40.0 AEU 35° 224° 193 L1 39.9 AEU 66° 177° 193 L5 34.2 AE 66° 177° 194 L5 25.5 AE 76° 183° 194 L5 25.5 AE 76° 183° 195 L5 24.4 AEU 7° 174° 1 B1 35.4 AEU 47° 172° 2 B1 33.6 AU 19° 248°	34 2 B1C 20.7 A 6° 135° 35 81 A A A 35 82a 18.5 A 38 82a 18.5 A 38 82a 22.4 A 4° 210° 39 81 36.3 AEU 66° 334° 39 82a 24.3 AEU 66° 334° 39 81C 34.0 AEU 66° 334° 40 81 43.0 AEU 27° 192° 40 81c 41.2 AEU 27° 192°	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Global Navigation Satellite Systems (GNSS) -
20 L5 20.2 AE 3 221 29 L1 30.9 AEU 18" 142" 31 L1 41.4 AEU 26" 277" 32 L1 37.1 AEU 60" 319" 32 L5 29.2 AEU 60" 319" 2 L1 A 2" 154" 3 L1 46.0 AEU 52" 164" 4 L1 35.9 AEU 68" 313" 5 L1 33.7 AEU 16" 329"	3 1 H1 41.2 AEU 37° 223° 4 1 B1 A 42° 148° 6 1 33.1 AEU 52° 315° 7 1 B1 37.6 A 19° 206° 8 1 31.7 AEU 41° 308° 9 1 31.7 AEU 41° 308° 10 1 26.0 AEU 8° 210° 12 1 12.3.9 AU 9° 109° 13 1 41.3 AEU 9° 233°	41 B1 40.0 AEU 52° 291° 41 B2a 34.4 AEU 52° 291° 41 B1C 43.7 AEU 52° 291° 41 B1C 43.7 AEU 52° 291° 42 B1 28.2 AU 8° 158° 42 B2a 23.3 AU 8° 158° 42 B1C 31.5 A 8° 158° 42 B1C 31.5 A 8° 158° 44 B1 AU 11° 85° 44 B2a 21.9 AU 11° 85° 44 B1C 35.1 AU 11° 85°	12 44 23 32:04.3 C/N0 1 (dB-Hz) 1 10 18 27 36	Satellite-based Augmentation Systems (SBAS) WAAS (USA) EGNOS (European Union) GAGAN (India) MSAS (Japan)
13 L1 20.1 A U 32* 33* 14 L1-C 38.6 AE 66* 306* 15 L1 41.1 AEU 26* 246* 22 L1 A 2* 29* 23 L1 21.7 A 2* 85* 2 1561.098 34.2 AE 88* 260* 2 E5a 26.3 AE 88* 260* 3 E1 40.2 AEU 54* 136* 3 E5a 33.5 AEU 54* 136* 5 E1 18.4 A 3* 135* 5 E5a 16.8 A 3* 135*	14 1	56 B1 A 12° 210° 59 1602.000 47.1 A 49° 179° 60 1602.000 47.1 A 49° 179° 60 1602.000 47.1 A 49° 179° 61 181 A 37° 223° 62 B1 A 48° 171° 4 15 30.1 AEU 39° 222° 9 2 L5 15.8 A 12° 288° ID SBAS CF C/N0 Flags Elev Azim 128 11 42.0 38.2 42° 42°	Legend Global Navigation Satellite Systems (GNSS) Image: Colspan="2">	 SDCM (Russia) - BDSBAS/SNAS (China) SACCSA (ICAO) Signal Availability - Not in view of device - In view - Used in fix
7 E1 21.6 AU 16* 314*	26 B1 A 1° 62°			



Xiaomi Mi11 Lite 5G Screen Shots







Sample GNSS Raw Data from Mi11 Lite 5G

Sample GNSS raw data can be downloaded from the following website: <u>https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm</u> Data were taken at the same time by using 4 or 5 different types of devices. This will help to compare accuracy from different devices as well.

		Smart-Phone Data								
	Xiaomi Mi8 (a)	Xiaomi Mi8 (b)	Xiaomi Mi8 (c)	Xiaomi Mi11 Lite 5G	OppoReno 3 A					
Day 1	<u>Data 01</u>	<u>Data 02</u>	<u>Data 03</u>	Data 08 Data 09	<u>Data 10</u>					
Day 2	<u>Data 04</u>	<u>Data 05</u> <u>Data 06</u>	<u>Data 07</u>							

GNSS Raw Data from android devices open new opportunities to develop location based applications with high accuracy that were not possible before.