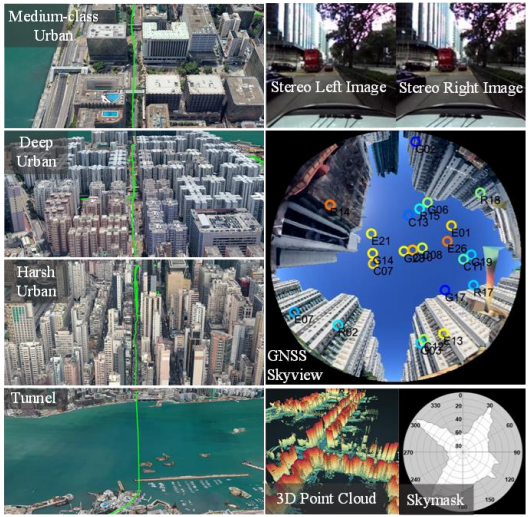
Hong Kong UrbanNav:

An Open-Source Multisensory Dataset for Benchmarking Urban Navigation Algorithms



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Benchmarks are important to foster R&D

GOOGLE · COMMUNITY PREDICTION COMPETITION · A MONTH TO GO

Join Competition ···

Google Smartphone Decimeter Challenge 2023

Improve high precision GNSS positioning and navigation accuracy on smartphones.

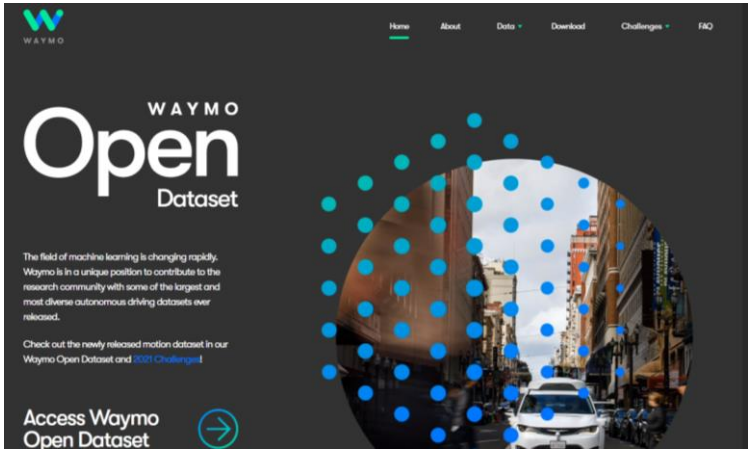
The KITTI Vision Benchmark Suite

A project of Karlsruhe Institute of Technology and Toyota Technological Institute at Chicago

Karlsruhe Institute of Technology

home | setup | stereo | flow | sceneflow | depth | odometry | object | tracking | road | semantics | raw data | submit results

A. Geiger | P. Lenz | C. Stiller | R. Urtasun Log in



ION/IAG WG 4.1.5 Initiative

Objectives

- Open-sourcing multi-sensors positioning data collected for in Asian-Pacific urban canyons (UrbanNav)
- Raising the **awareness** of the urgent **navigation requirement in highly-urbanized areas**, especially in Asian-Pacific regions
- **Benchmarking positioning and sensor fusion algorithms** based on the open-sourcing data

Most of economic activities are in urbanized cities.
Positioning and navigation are fundamental for many applications

Smart device Apps

Intelligent Vehicles

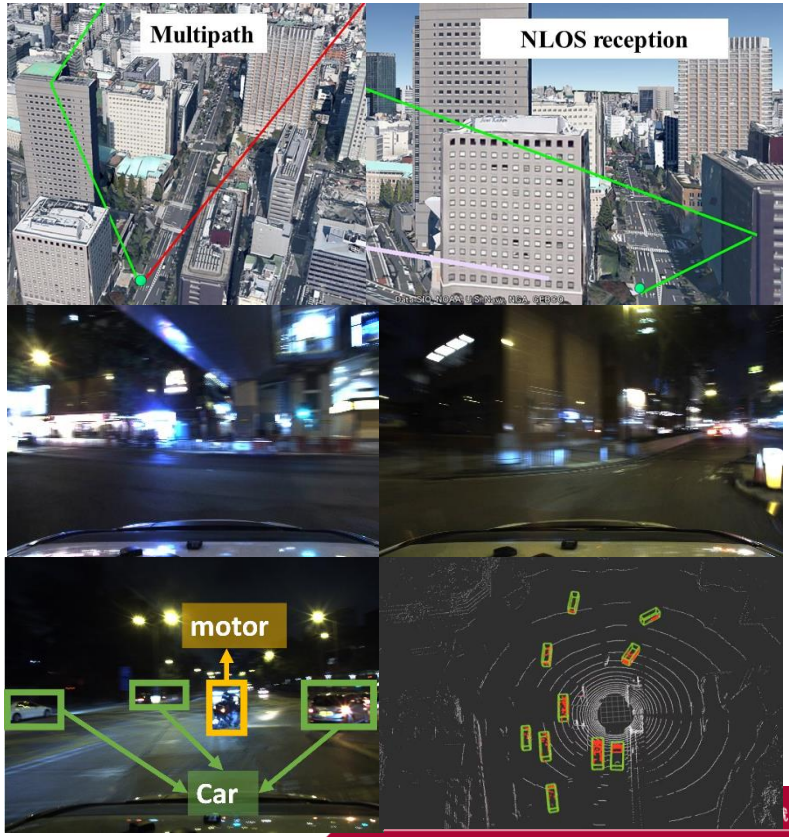
Autonomous driving

Sensors and their challenges in urban areas

- GNSS
  - Multipath and NLOS

- Visual sensor
  - Image blur (various),
  - high dynamics
  - dynamic objects
  - repetitive features

- LiDAR
  - high dynamics
  - dynamic objects
  - repetitive features



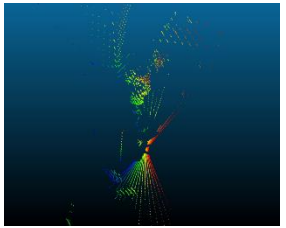
UrbanNav

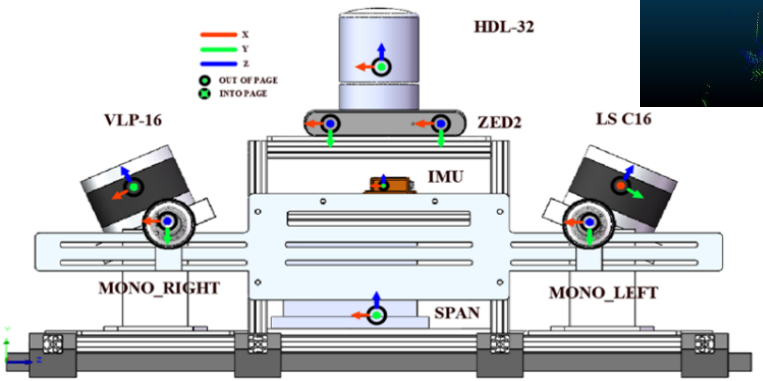
Our focus today!

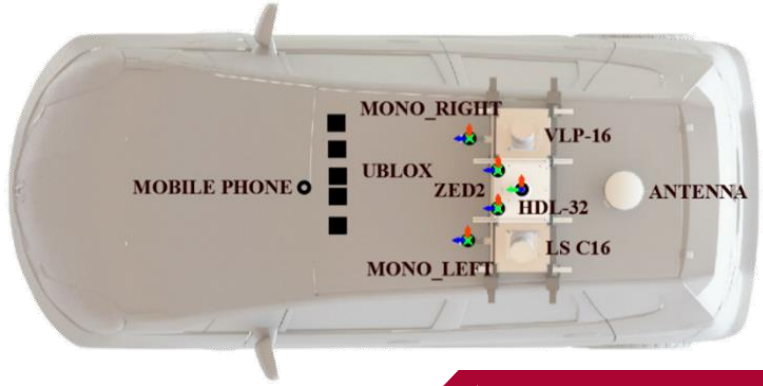
Led by Dr Taro Suzuki and Prof Nobuaki Kubo

Platform, Sensors and Data

Hong Kong Platform







Sensor	Grade	Sensor Model	Update Frequency	Time Standard	Remarks
GNSS Receiver	Automobile-Level	u-blox ZED-F9P	1 Hz	GPS Time	GPS (L1, L2), GLONASS (G1, G2), GALILEO (E1, E5b), BeiDou (B1I, B2I), QZSS (L1, L2). A ***low-cost patch antenna is used.***
GNSS Receiver	Automobile-Level	u-blox ZED-F9P	1 Hz	GPS Time	GPS (L1, L2), GLONASS (G1, G2), GALILEO (E1, E5b), BeiDou (B1I, B2I), QZSS (L1, L2). ***A NovAtel GPS-703-GGG antenna is used.***
GNSS Receiver	Automobile-Level	u-blox EVK-M8T	1 Hz	GPS Time	GPS (L1), GLONASS (G1), GALILEO (E1), BeiDou (B1I). A ***low-cost patch antenna is used.***
GNSS Receiver	Smartphone-Level	Xiaomi 8	1 Hz	GPS Time	GPS (L1, L5), GLONASS (G1), GALILEO (E1, E5a), BeiDou (B1I), QZSS (L1, L5)
GNSS Receiver	Geodetic-Level	NovAtel FlexPak6	1 Hz	GPS Time	GPS (L1, L2), GLONASS (G1, G2), GALILEO (E1, E5b), BeiDou (B1I, B2I). ***A NovAtel GPS-703-GGG antenna is used.***
Lidar	Automobile-Level	Velodyne 32E	10 Hz	ROS Time	https://github.com/ros-drivers/velodyne/tree/1.6.1
Lidar (Right)	Automobile-Level	Velodyne VLP16	10 Hz	ROS Time	https://github.com/ros-drivers/velodyne/tree/1.6.1
Lidar (Left)	Automobile-Level	Lslidar C16	10 Hz	ROS Time	http://wiki.ros.org/lslidar_c16
Stereo Camera	Automobile-Level	ZED2	27Hz	ROS Time	https://github.com/willdzeng/zed_cpu_ros
IMU	Automobile-Level	Xsens-MTI-30	400 Hz	ROS Time	https://github.com/ethz-asl/ethzasl_xsens_driver

GNSS data

- RINEX 3.03
- NMEA with GNRMC, GNGGA, GNGSA messages

IMU data (csv)

- utc_time, week, gps_time, angular_velocity_x, angular_velocity_y, angular_velocity_z, linear_acceleration_x, linear_acceleration_y, linear_acceleration_z, orientation.x, orientation_y, orientation_z, orientation_w,

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	utc_time	week	gps_time	angular_velo	angular_velo	angular_velo	linear_accele	linear_accele	linear_accele	orientation_x	orientation_y	orientation_z	orientation_w
2	(sec)	(weeks)	(sec)	(rad/sec)	(rad/sec)	(rad/sec)	(m/s^2)	(m/s^2)	(m/s^2)				
3	1621218775.5486	2158	95593.5486	-0.0562474	0.01148433	-0.009869	-0.0244974	0.04438007	9.71346474	0.01489172	-0.00065	0.90305219	0.42927212
4	1621218775.5514	2158	95593.5514	0.03300161	0.00405014	-0.0017032	-0.2323184	0.00374167	9.74676323	0.01490486	-0.0006106	0.90305136	0.42927348
5	1621218775.5536	2158	95593.5536	-0.0351176	-0.0031441	-0.0161335	-0.3525298	-0.0638624	9.77287006	0.01488958	-0.0006516	0.90304266	0.42929224
6	1621218775.5561	2158	95593.5561	0.02593398	0.00036061	-0.0039637	-0.3650503	-0.1249721	9.81584358	0.01491301	-0.0006199	0.90304958	0.42927691
7	1621218775.5587	2158	95593.5587	0.00337362	-0.011459	-0.000219	-0.3414191	-0.1525407	9.8532486	0.01492776	-0.0006222	0.90304922	0.42927717
8	1621218775.5612	2158	95593.5612	-0.0022441	-0.0062644	-0.0072688	-0.2520469	-0.1804297	9.8916502	0.01493363	-0.000628	0.90304525	0.4292853
9	1621218775.5637	2158	95593.5637	0.00998229	-0.0179395	-0.0074074	-0.0571797	-0.1512456	9.88388729	0.01495924	-0.0006262	0.90304086	0.42929364

ROS bag data

- Point Cloud, Image, IMU, and SPAN (ground truth)

sensor_msgs/PointCloud2 Message

File: sensor_msgs/PointCloud2.msg

Raw Message Definition

```
# This message holds a collection of N-dimensional points, which may
# contain additional information such as normals, intensity, etc. The
# point data is stored as a binary blob, its layout described by the
# contents of the "fields" array.

# The point cloud data may be organized 2d (image-like) or 1d
# (unordered). Point clouds organized as 2d images may be produced by
# camera depth sensors such as stereo or time-of-flight.

# Time of sensor data acquisition, and the coordinate frame ID (for 3d
# points).
Header header

# 2D structure of the point cloud. If the cloud is unordered, height is
# 1 and width is the length of the point cloud.
uint32 height
uint32 width

# Describes the channels and their layout in the binary data blob.
PointField[] fields

bool    is_bigendian # Is this data bigendian?
uint32  point_step   # Length of a point in bytes
uint32  row_step     # Length of a row in bytes
uint8[] data         # Actual point data, size is (row_step*height)

bool is_dense        # True if there are no invalid points
```

Compact Message Definition

```
std_msgs/Header header
uint32 height
uint32 width
sensor_msgs/PointField[] fields
bool is_bigendian
uint32 point_step
uint32 row_step
uint8[] data
bool is_dense
```

autogenerated on Wed, 02 Mar 2022 00:06:56

sensor_msgs/Image Message

File: sensor_msgs/Image.msg

Raw Message Definition

```
# This message contains an uncompressed image
# (0, 0) is at top-left corner of image
#

Header header        # Header timestamp should be acquisition time of image
                     # Header frame_id should be optical frame of camera
                     # origin of frame should be optical center of camera
                     # +x should point to the right in the image
                     # +y should point down in the image
                     # +z should point into to plane of the image
                     # If the frame_id here and the frame_id of the CameraInfo
                     # message associated with the image conflict
                     # the behavior is undefined

uint32 height        # image height, that is, number of rows
uint32 width         # image width, that is, number of columns

# The legal values for encoding are in file src/image_encodings.cpp
# If you want to standardize a new string format, join
# ros-users@lists.sourceforge.net and send an email proposing a new encoding.

string encoding      # Encoding of pixels -- channel meaning, ordering, size
                     # taken from the list of strings in include/sensor_msgs/image_encodings.h

uint8 is_bigendian   # is this data bigendian?
uint32 step          # Full row length in bytes
uint8[] data         # actual matrix data, size is (step * rows)
```

Compact Message Definition

```
std_msgs/Header header
uint32 height
uint32 width
string encoding
uint8 is_bigendian
uint32 step
uint8[] data
```

autogenerated on Mon, 28 Feb 2022 22:12:14

sensor_msgs/Imu Message

File: sensor_msgs/Imu.msg

Raw Message Definition

```
# This is a message to hold data from an IMU (Inertial Measurement Unit)
#
# Accelerations should be in m/s^2 (not in g's), and rotational velocity should be in rad/sec
#
# If the covariance of the measurement is known, it should be filled in (if all you know is the
# variance of each measurement, e.g. from the datasheet, just put those along the diagonal)
# A covariance matrix of all zeros will be interpreted as "covariance unknown", and to use the
# data a covariance will have to be assumed or gotten from some other source
#
# If you have no estimate for one of the data elements (e.g. your IMU doesn't produce an orientation
# estimate), please set element 0 of the associated covariance matrix to -1
# If you are interpreting this message, please check for a value of -1 in the first element of each
# covariance matrix, and disregard the associated estimate.

Header header

geometry_msgs/Quaternion orientation
float64[9] orientation_covariance # Row major about x, y, z axes

geometry_msgs/Vector3 angular_velocity
float64[9] angular_velocity_covariance # Row major about x, y, z axes

geometry_msgs/Vector3 linear_acceleration
float64[9] linear_acceleration_covariance # Row major x, y z
```

Compact Message Definition

```
std_msgs/Header header
geometry_msgs/Quaternion orientation
float64[9] orientation_covariance
geometry_msgs/Vector3 angular_velocity
float64[9] angular_velocity_covariance
geometry_msgs/Vector3 linear_acceleration
float64[9] linear_acceleration_covariance
```

autogenerated on Mon, 28 Feb 2022 22:12:14

novatel_msgs/INSPVAX Message

File: novatel_msgs/INSPVAX.msg

Raw Message Definition

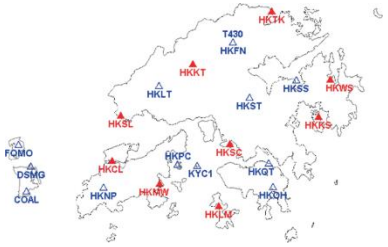
```
# message 1465
novatel_msgs/CommonHeader header

# Table 29 in the SPAN on OEM6 manual:
# See: http://www.novatel.com/assets/Documents/Manuals/OM-20000144UM.pdf#page=121
uint32 ins_status
uint32 INS_STATUS_INACTIVE=0
uint32 INS_STATUS_ALIGNING=1
uint32 INS_STATUS_HIGH_VARIANCE=2
uint32 INS_STATUS_SOLUTION_GOOD=3
uint32 INS_STATUS_SOLUTION_FREE=6
uint32 INS_STATUS_ALIGNMENT_COMPLETE=7
uint32 INS_STATUS_DETERMINING_ORIENTATION=8
uint32 INS_STATUS_WAITING_INITIALPOS=9

# Table 30 in the SPAN on OEM6 manual:
# See: http://www.novatel.com/assets/Documents/Manuals/OM-20000144UM.pdf#page=124
uint32 position_type
uint32 POSITION_TYPE_NONE=0
uint32 POSITION_TYPE_SBAS=52
uint32 POSITION_TYPE_PSEUDORANGE_SINGLE_POINT=53
uint32 POSITION_TYPE_PSEUDORANGE_DIFFERENTIAL=54
uint32 POSITION_TYPE_RTK_FLOAT=55
uint32 POSITION_TYPE_RTK_FIXED=56
uint32 POSITION_TYPE_OMNISTAR=57
uint32 POSITION_TYPE_OMNISTAR_HP=58
uint32 POSITION_TYPE_OMNISTAR_XP=59
uint32 POSITION_TYPE_PPP_CONVERGING=73
uint32 POSITION_TYPE_PPP=74

float64 latitude
float64 longitude
float64 altitude

float32 undulation

float64 north_velocity
float64 east_velocity
float64 up_velocity

float64 roll
float64 pitch
float64 azimuth

float32 latitude_std
float32 longitude_std
float32 altitude_std

float32 north_velocity_std
float32 east_velocity_std
float32 up_velocity_std

float32 roll_std
float32 pitch_std
float32 azimuth_std

uint32 extended_status
uint32 EXTENDED_STATUS_POSITION_UPDATE_APPLIED=1
uint32 EXTENDED_STATUS_PHASE_UPDATE_APPLIED=2
uint32 EXTENDED_STATUS_ZUPT_APPLIED=4
uint32 EXTENDED_STATUS_WHEEL_SENSOR_APPLIED=8
uint32 EXTENDED_STATUS_HEADING_UPDATE_APPLIED=16
uint32 EXTENDED_STATUS_INS_SOLUTION_CONVERGED=64
```

For GNSS data, we open-sourced a package, the GraphGNSSLib, which provide easy access to the GNSS RINEX file and publish the data as customized ROS message.

https://github.com/weisongwen/GraphGNSSLib

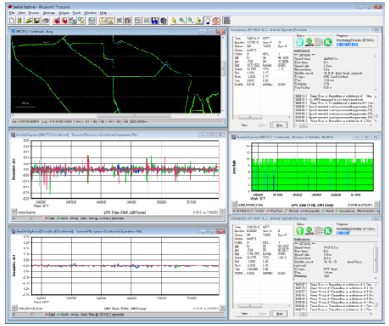
Ground truth – NovAtel SPANCPT system

GPS-703-GGG



Hong Kong SatRef (CORS)

SPAN-CPT



Inertial Explorer®

txt we provided

UrbanNav_TST_GT_raw TXT

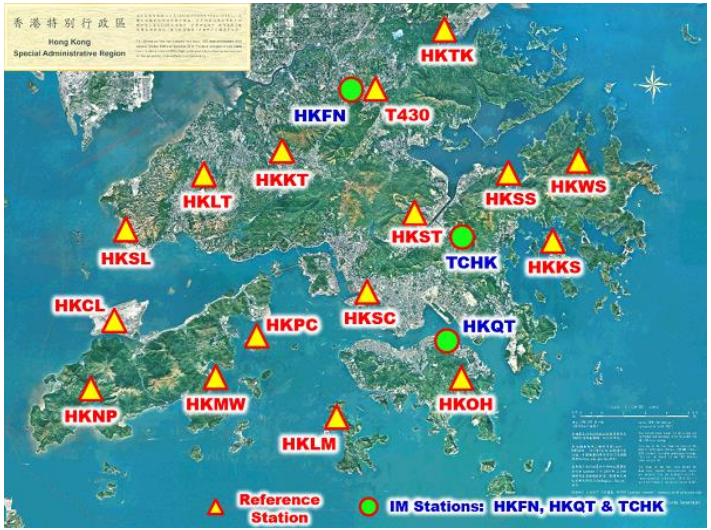
檔案 編輯 檢視 說明

UTCTime (sec)	Week (weeks)	GPSTime (sec)	Latitude (+/-D M S)	Longitude (+/-D M S)	H-Ell (m)	VelBdyX (m/s)	VelBdyY (m/s)	VelBdyZ (m/s)	AccBdyX (m/s^2)	AccBdyY (m/s^2)	AccBdyZ (m/s^2)	Roll (deg)	Pitch (deg)	Heading Q (deg)	
1621218775.00	2158.00000	95593.00	22 18 04.31949	114 10 44.60559	3.472	-0.000	0.002	-0.010	0.381	-0.040	0.019	-1.7398149928	0.4409540487	-132.534729738	2
1621218776.00	2158.00000	95594.00	22 18 04.31949	114 10 44.60559	3.471	-0.000	-0.000	-0.011	0.127	0.144	0.088	-1.7380961194	0.4408681050	-132.534460448	2
1621218777.00	2158.00000	95595.00	22 18 04.31952	114 10 44.60556	3.486	0.001	0.000	-0.013	0.086	-0.124	0.066	-1.7378955842	0.4377855921	-132.534718279	2
1621218778.00	2158.00000	95596.00	22 18 04.31961	114 10 44.60552	3.481	0.002	0.003	-0.015	0.185	0.027	0.067	-1.7364746489	0.4379746682	-132.534557851	2
1621218779.00	2158.00000	95597.00	22 18 04.31971	114 10 44.60544	3.469	0.002	0.001	-0.015	0.156	-0.024	0.026	-1.7364345418	0.4371152315	-132.535159457	2
1621218780.00	2158.00000	95598.00	22 18 04.31983	114 10 44.60534	3.458	0.004	0.003	-0.016	0.471	-0.013	0.000	-1.7351683051	0.4362156877	-132.535067783	2
1621218781.00	2158.00000	95599.00	22 18 04.31999	114 10 44.60515	3.441	0.004	0.003	-0.019	0.084	0.067	0.066	-1.7337702881	0.4344624369	-132.535531879	2
1621218782.00	2158.00000	95600.00	22 18 04.32010	114 10 44.60475	3.418	0.010	0.050	-0.033	0.202	0.573	-0.005	-1.7356954263	0.4902742557	-132.533028054	2
1621218783.00	2158.00000	95601.00	22 18 04.31506	114 10 44.59799	3.394	0.017	0.463	-0.031	0.558	0.426	-0.158	-1.7686806065	0.5990216452	-132.531412313	2
1621218784.00	2158.00000	95602.00	22 18 04.29526	114 10 44.57271	3.374	0.041	1.544	-0.040	0.315	1.009	0.058	-1.5297743947	0.7285158365	-132.501836231	2
1621218785.00	2158.00000	95603.00	22 18 04.25089	114 10 44.51770	3.357	0.108	2.676	-0.067	0.633	0.910	0.911	-1.5508878894	1.0749375786	-132.340388184	2
1621218786.00	2158.00000	95604.00	22 18 04.18249	114 10 44.43134	3.358	0.075	3.778	-0.021	-0.435	0.643	-0.105	-1.1529973486	0.8302559522	-131.839519938	3
1621218787.00	2158.00000	95605.00	22 18 04.09941	114 10 44.32355	3.358	0.163	4.027	-0.038	1.067	0.160	0.058	-1.3285974537	0.5668214171	-130.477541963	3
1621218788.00	2158.00000	95606.00	22 18 04.01938	114 10 44.21733	3.359	0.045	3.835	-0.061	-0.234	-0.122	0.289	-0.8712568120	0.7731492487	-131.171479797	3
1621218789.00	2158.00000	95607.00	22 18 03.92948	114 10 44.11670	3.371	0.033	4.111	-0.017	-1.594	-0.104	-0.853	0.4321534170	0.7870320161	-140.389625876	3
1621218790.00	2158.00000	95608.00	22 18 03.81136	114 10 44.05316	3.351	-0.119	4.094	-0.091	-3.203	0.736	0.851	1.0967844593	-0.0318507238	-165.275194000	3
1621218791.00	2158.00000	95609.00	22 18 03.67911	114 10 44.06864	3.310	-0.300	4.263	-0.055	-2.094	0.120	0.154	0.5159370354	0.3674492932	160.017337520	1
1621218792.00	2158.00000	95610.00	22 18 03.56501	114 10 44.16158	3.279	-0.077	4.670	-0.043	-1.017	0.503	0.092	-0.7373680344	0.4082553473	135.4190733525	2
1621218793.00	2158.00000	95611.00	22 18 03.45636	114 10 44.28593	3.240	0.089	5.141	-0.066	1.424	0.978	0.124	-1.9939618820	0.4177091510	132.9382749615	2
1621218794.00	2158.00000	95612.00	22 18 03.32784	114 10 44.42013	3.212	0.200	5.913	-0.072	0.169	0.659	0.468	-1.8710853532	0.3043494512	136.4075344110	2
1621218795.00	2158.00000	95613.00	22 18 03.17057	114 10 44.56215	3.199	0.158	6.695	-0.074	0.736	0.903	0.369	-1.6424007085	0.2558256555	140.7697313955	2
1621218796.00	2158.00000	95614.00	22 18 02.98647	114 10 44.70685	3.170	0.110	7.268	-0.096	-0.997	-0.896	0.350	-0.5889662359	0.3472983675	143.2517387274	2
1621218797.00	2158.00000	95615.00	22 18 02.78724	114 10 44.86482	3.154	0.108	7.992	0.033	-0.982	0.364	-1.483	-0.8127234437	0.3944585236	141.6117788191	2
1621218798.00	2158.00000	95616.00	22 18 02.58089	114 10 45.04571	3.143	0.116	8.460	-0.094	-1.001	-0.475	-0.338	-0.7942971210	0.3561276471	138.4315250111	2
1621218799.00	2158.00000	95617.00	22 18 02.36734	114 10 45.24807	3.135	0.179	9.023	-0.091	0.243	0.410	-0.032	-1.2147908468	0.5503374214	137.4398945959	2
1621218800.00	2158.00000	95618.00	22 18 02.14243	114 10 45.46203	3.119	0.168	9.420	-0.089	-0.123	1.136	-0.976	-0.0659245239	0.3831941734	137.1374769125	2
1621218801.00	2158.00000	95619.00	22 18 01.90873	114 10 45.68596	3.102	0.207	9.695	-0.151	0.607	-0.237	0.229	0.0660964112	0.9454261986	137.4662802023	2
1621218802.00	2158.00000	95620.00	22 18 01.66830	114 10 45.91414	3.109	0.157	9.924	-0.081	-0.534	0.482	-0.256	0.1896834077	0.2569486528	137.5202241788	2
1621218803.00	2158.00000	95621.00	22 18 01.42785	114 10 46.14267	3.079	0.221	9.787	-0.125	-1.156	2.593	-1.036	-0.5712962175	0.6151962418	137.7076157552	2
1621218804.00	2158.00000	95622.00	22 18 01.18940	114 10 46.36491	3.077	0.180	9.622	-0.114	-0.533	1.479	1.457	-0.0291578222	0.6307520479	137.9494612406	2
1621218805.00	2158.00000	95623.00	22 18 00.95718	114 10 46.58367	3.081	0.238	9.362	-0.040	-0.533	-1.512	-1.116	-0.2336922959	0.4444891983	137.5559022607	2
1621218806.00	2158.00000	95624.00	22 18 00.73274	114 10 46.79853	3.086	0.148	9.073	0.042	1.097	0.511	-0.951	-0.9991180736	0.4806485648	137.3869370069	2
1621218807.00	2158.00000	95625.00	22 18 00.53052	114 10 46.98945	3.108	0.137	7.372	-0.058	0.611	-1.682	-0.351	-0.2178958495	0.2351934453	137.4053461408	2
1621218808.00	2158.00000	95626.00	22 18 00.37752	114 10 47.13509	3.107	0.098	5.125	-0.010	-0.265	-1.914	0.543	-0.9697998232	0.1493872859	137.8166782715	2
1621218809.00	2158.00000	95627.00	22 18 00.28474	114 10 47.22196	3.124	0.048	2.412	0.019	0.078	-2.453	-0.131	-0.7529925935	0.1339976395	137.8834335842	2

We also compare the SPAN result with image data to make sure the GT is trustworthy.

Hong Kong CORS network - SatRef

- Maintained by Survey and Mapping Office of Lands Department, HK Government

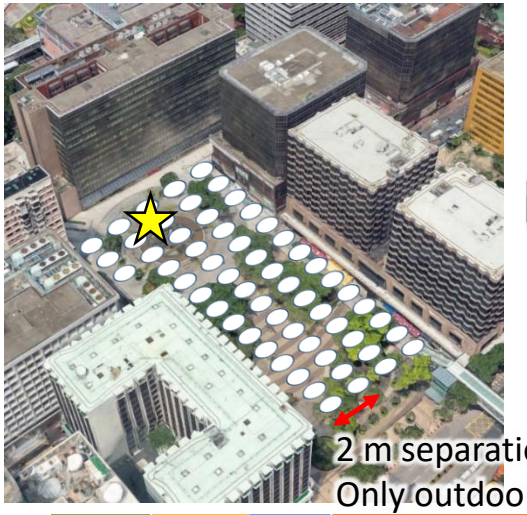


SatRef Services

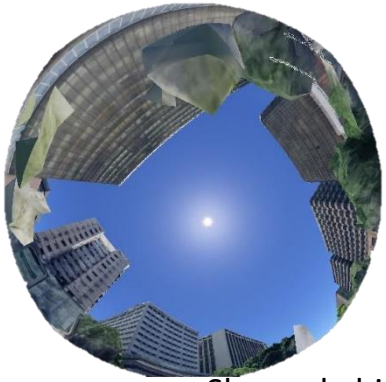
- GNSS Raw Data (RINEX Format)
- GNSS Data Automatic Computation Service
- Network Real Time Kinematic (RTK) Differential GNSS (DGNSS)
- GNSS Raw Data Streams (RTCM Format)

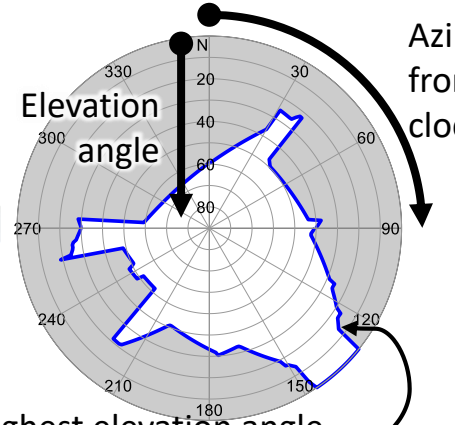
https://www.geodetic.gov.hk/en/satref/satref.htm

3D Building Model Resources – Skymask & Format



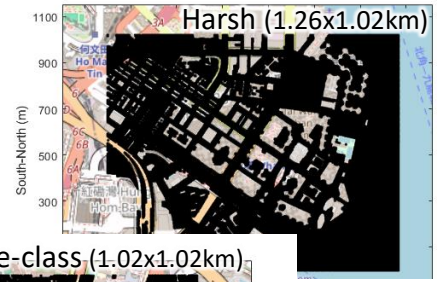
2 m separations
Only outdoor locations

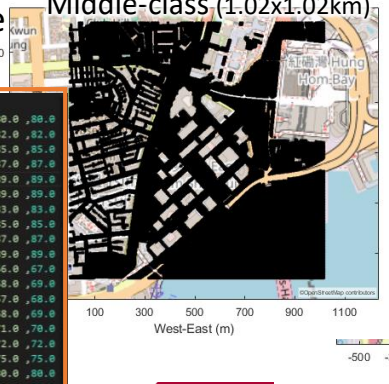


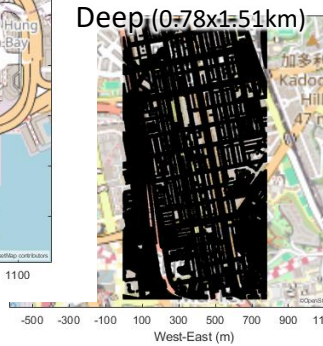


Azimuth angle start from north, rotating in clockwise

Skymask: highest elevation angle of obstacle at each azimuth angle







Latitude(deg)	Longitude(deg)	Altitude(m)	Skymask(1*361 ,deg)
22.29566762	114.17304114	5.000	82.0 ,82.0 ,82.0 ,82.0 ,82.0 ,82.0 ,82.0 ,81.0 ,81.0 ,81.0 ,81.0 ,81.0 ,81.0 ,81.0 ,81.0 ,81.0 ,80.0 ,80.0 ,80.0 ,80.0 ,80.0 ,80.0
22.29568568	114.17304114	5.000	83.0 ,82.0 ,82.0 ,82.0
22.29570374	114.17304114	5.000	85.0 ,85.0
22.29572180	114.17304114	5.000	87.0 ,87.0
22.29573986	114.17304114	5.000	89.0 ,89.0
22.29575792	114.17304114	5.000	89.0 ,89.0
22.29577598	114.17304114	5.000	83.0 ,83.0
22.29579404	114.17304114	5.000	85.0 ,85.0
22.29673323	114.17304111	5.000	87.0 ,87.0
22.29694996	114.17304111	5.000	89.0 ,89.0
22.29696803	114.17304111	5.000	64.0 ,64.0
22.29698609	114.17304111	5.000	66.0 ,66.0
22.29700415	114.17304111	5.000	68.0 ,68.0 ,68.0 ,69.0 ,69.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,68.0 ,67.0 ,67.0 ,66.0 ,66.0 ,67.0 ,67.0 ,68.0
22.29702221	114.17304111	5.000	70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,70.0 ,69.0 ,69.0 ,69.0 ,68.0 ,68.0 ,69.0
22.29704027	114.17304110	5.000	72.0 ,72.0 ,72.0 ,72.0 ,73.0 ,73.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,72.0 ,71.0 ,71.0 ,71.0 ,71.0 ,71.0 ,70.0
22.29705833	114.17304110	5.000	74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,74.0 ,73.0 ,73.0 ,73.0 ,72.0 ,72.0
22.29707639	114.17304110	5.000	76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,77.0 ,77.0 ,77.0 ,77.0 ,77.0 ,77.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,76.0 ,75.0 ,75.0
22.29709445	114.17304110	5.000	81.0 ,80.0 ,80.0 ,80.0
22.29732925	114.17304110	5.000	89.0 ,89.0
22.29767241	114.17304109	5.000	49.0 ,49.0 ,49.0 ,48.0 ,48.0 ,47.0 ,47.0 ,46.0 ,45.0 ,44.0 ,44.0 ,43.0 ,43.0 ,42.0 ,85.0 ,85.0 ,85.0 ,86.0 ,86.0 ,86.0 ,86.0 ,86.0 ,86.0
22.29769047	114.17304109	5.000	52.0 ,51.0 ,51.0 ,50.0 ,50.0 ,49.0 ,49.0 ,48.0 ,48.0 ,47.0 ,46.0 ,46.0 ,45.0 ,44.0 ,43.0 ,43.0 ,42.0 ,41.0 ,40.0 ,54.0 ,61.0 ,73.0 ,73.0 ,74.0 ,74.0
22.29770854	114.17304109	5.000	55.0 ,54.0 ,54.0 ,53.0 ,53.0 ,52.0 ,52.0 ,51.0 ,50.0 ,50.0 ,49.0 ,49.0 ,48.0 ,47.0 ,46.0 ,45.0 ,45.0 ,43.0 ,43.0 ,42.0 ,41.0 ,40.0 ,38.0 ,37.0 ,36.0

Latitude & Longitude (degree)

Height (meter)

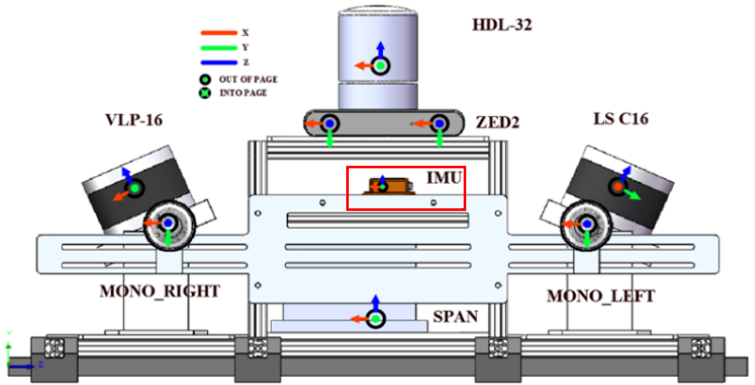
Skymask (array in 1x361 for azimuth angle 0° to 360°)

Resolution: 1° at azimuth angle; 0.1° at elevation angle

❄ Can be indexed by rounding the azimuth angle

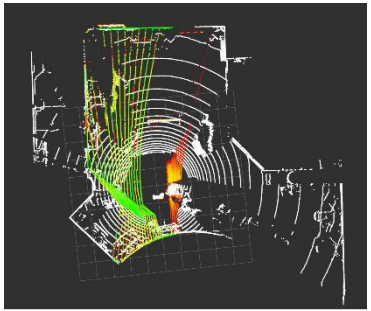
Sensor Calibration

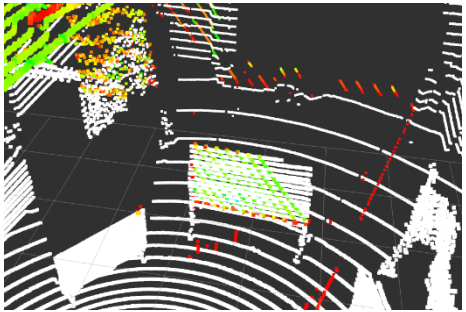
- ✓ A precise manufacturer supports the machining of the sensor rack. (Stainless steel)
- ✓ Measurements from the CAD drawing are used as initial guesses for the calibration methods.
- ✓ We align all sensor measurements to the IMU sensor



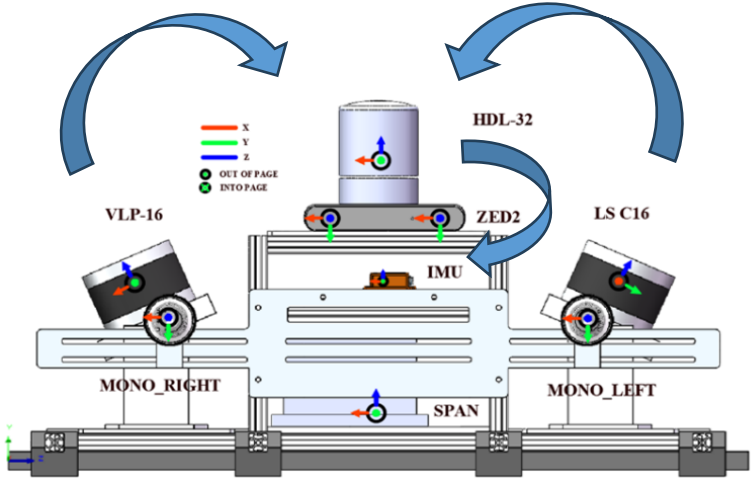
LiDAR Extrinsic (between IMU) Parameters

- Uses Continuous-time batch optimization-based method (Lv et al., 2020)
  - Using the extrinsic parameters from the 3D drawing as an initial guess.
  - Lv, J., Xu, J., Hu, K., Liu, Y., & Zuo, X. (2020). Targetless calibration of LiDAR-IMU system based on continuous-time batch estimation. Proc. of the 2020 *IEEE IROS*, Las Vegas, NV. 9968 – 9975. https://doi.org/10.1109/ IROS45743.2020.9341405
- Uses the multi-LiDAR calibrator of Autoware (Kato et al., 2018) to calibrate left and right lidar units to the top lidar.





Calibration results



Camera Intrinsic and Extrinsic (between IMU) Parameters

- ✓ We use Kalibr (Furgale et al., 2013) https://github.com/ethz-asl/kalibr , a toolbox that calibrates the intrinsic camera parameters and extrinsic parameters between the IMU and the camera.
  - L. Oth, P. Furgale, L. Kneip, R. Siegwart (2013). Rolling Shutter Camera Calibration, In *Proc. of the IEEE Computer Vision and Pattern Recognition (CVPR)*

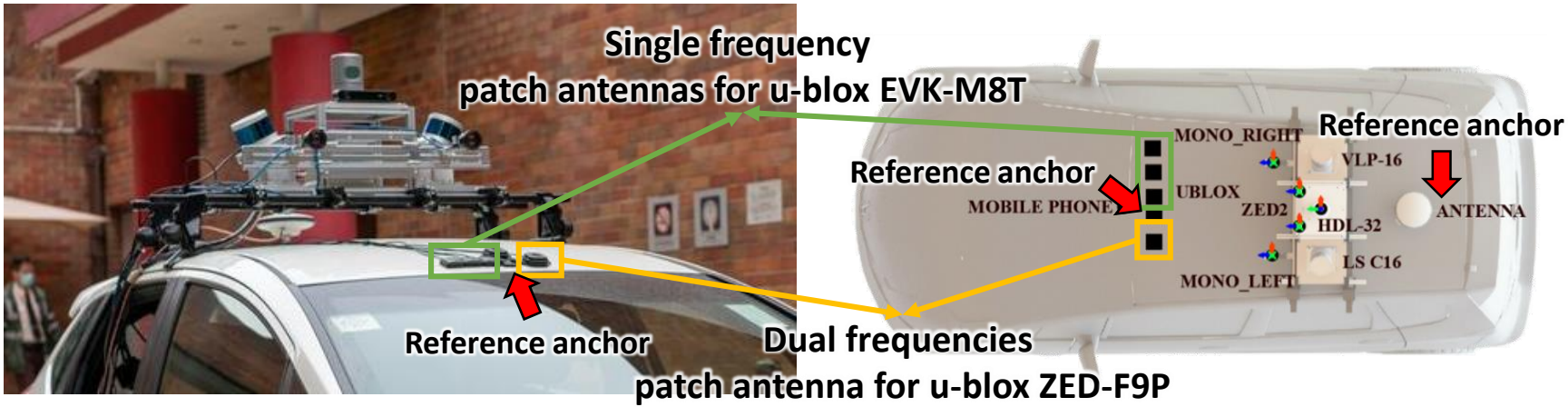
- ✓ Evaluation of the quality of **extrinsic parameter calibration between the cameras and the IMU**, the mean reprojection error of extrinsic parameters between the **left** and **right** cameras and the IMU are **0.57 pixels**, and is **0.68 pixels**, respectively.

GNSS Receiver Level-Arm Calibration

> We calibrate the extrinsic parameters based on the 3D drawing with an accuracy about 10 cm.

> Patch antennas lined up in an array and sticked to the reference anchor

- Single frequency antennas at left
- Dual frequencies antenna at right



IMU Noise Calibration

> Static IMU data are collected within for 2 hours and then processed via **Allan variance analysis** (El-Sheimy et al., 2007).

```
%YAML:1.0
---
type: IMU
name: xsens
Gyr:
   unit: " rad/s"
   avg-axis:
      gyr_n: 1.0270904839480961e-02
      gyr_w: 9.1355383994881894e-05
   x-axis:
      gyr_n: 1.0220930786530373e-02
      gyr_w: 1.0298813991459308e-04
   y-axis:
      gyr_n: 1.0274163606891170e-02
      gyr_w: 8.3221598993689496e-05
   z-axis:
      gyr_n: 1.0317620125021342e-02
      gyr_w: 8.7856413076363080e-05
Acc:
   unit: " m/s^2"
   avg-axis:
      acc_n: 1.1197412605492375e-02
      acc_w: 1.1751767903346351e-04
   x-axis:
      acc_n: 1.2497890470179919e-02
      acc_w: 1.3574860375726287e-04
   y-axis:
      acc_n: 1.1299110889447581e-02
      acc_w: 9.2311660663327679e-05
   z-axis:
      acc_n: 9.7952364568496281e-03
      acc_w: 1.2449277267980000e-04
```

Time synchronization between on-onboard ROS computer and GPS time

- We use Chrony* to receive the NMEA+PPS signal from u-blox M8T to **synchronize ROS computer with GPS time.**

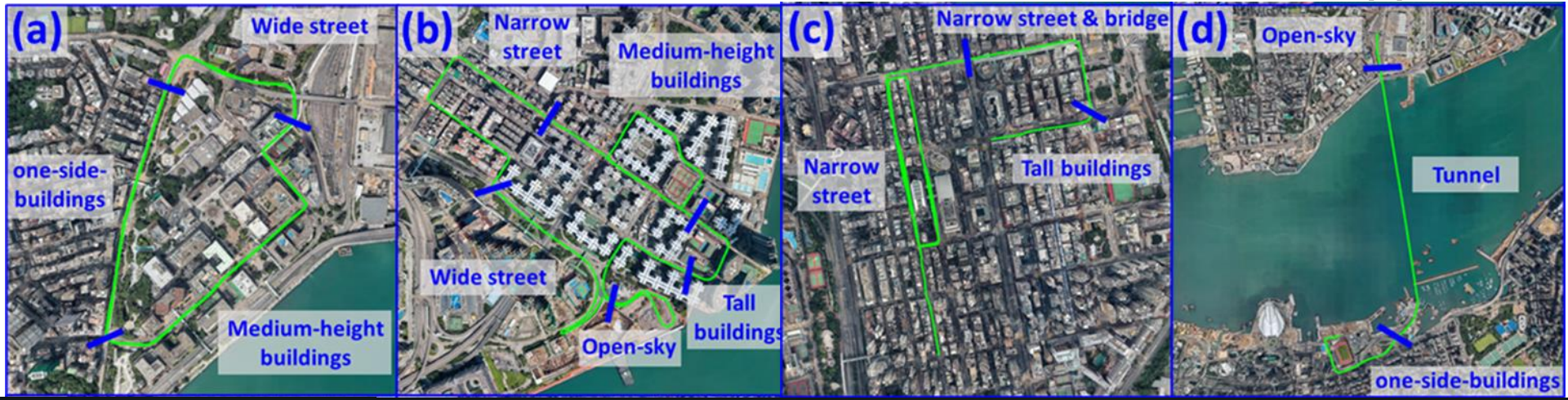
```
function utctime = gps2utc(gps_week, gps_seconds)
    SECONDS_IN_GPS_WEEK = 604800.0;
    utctime = (gps_week * SECONDS_IN_GPS_WEEK + gps_seconds-18) + 315964800  ; % 18 leap seconds
end
```

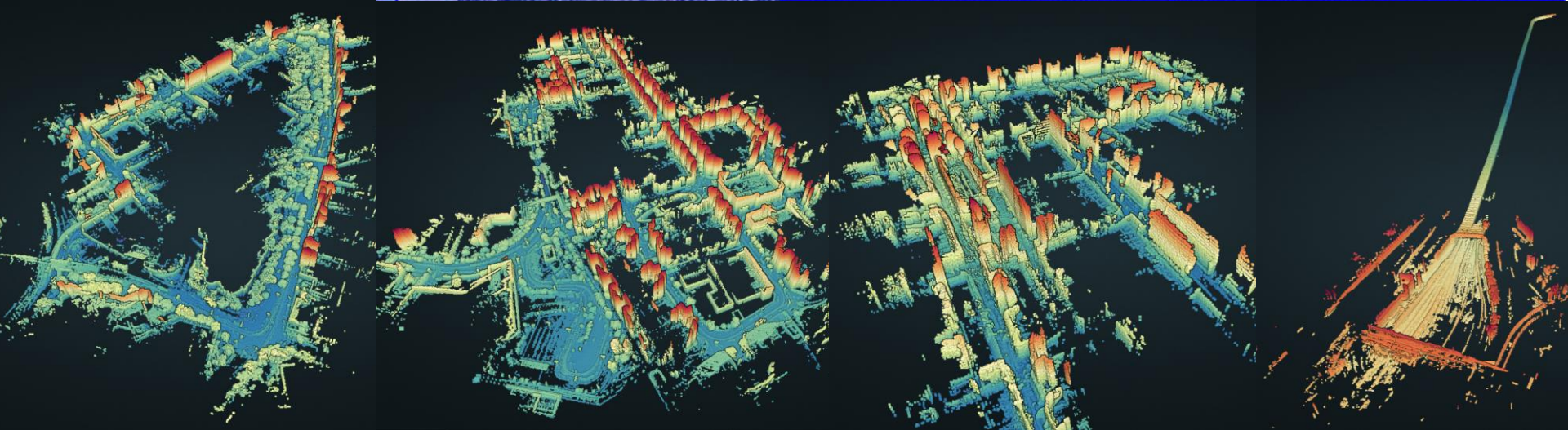
- **ROS timestamp in UTC**
  - LiDARs, Cameras, and IMU
- **GPS timestamp**
  - GNSS receivers, and the ground truth system
- The wire latencies between sensors, i.e., LiDAR, Camera and IMU and ROS computer are NOT considered in this dataset.

*chrony is a versatile implementation of the Network Time Protocol (NTP). It can synchronize the system clock with NTP servers, reference clocks (e.g. GPS receiver)

Environments

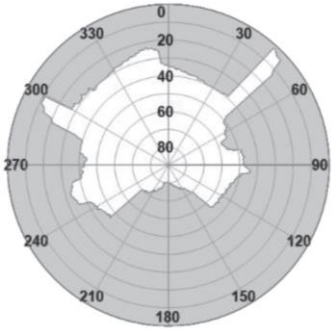
(a) Medium Urban canyon (b) Deep Urban canyon (c) Harsh Urban canyon (d) Tunnel



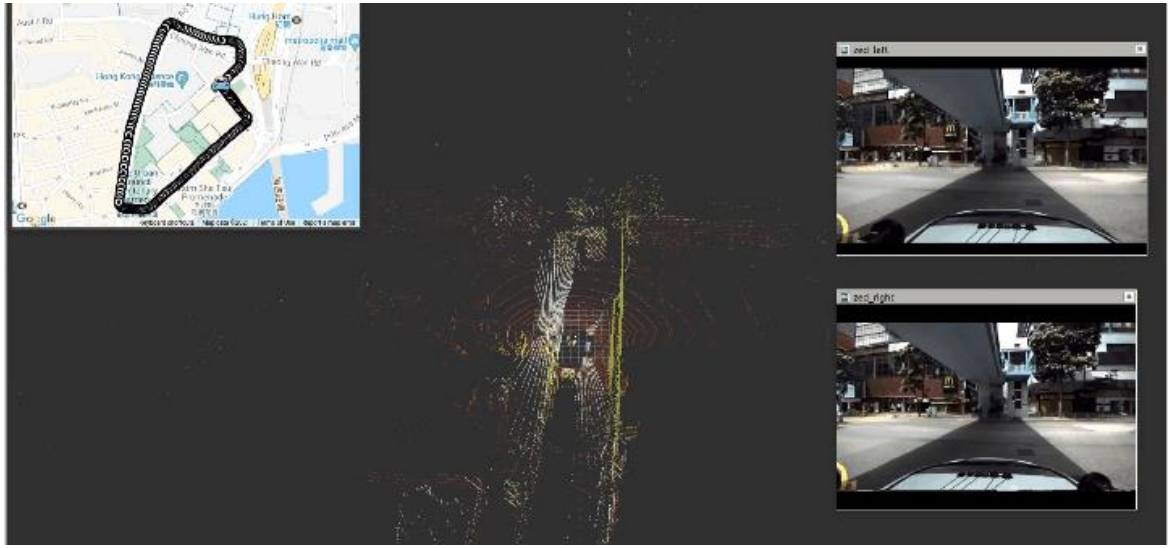


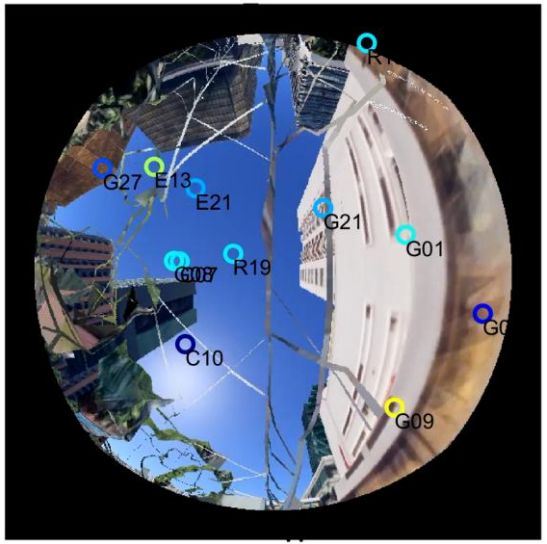
Dataset	*Location*	*Skymask Indicator* μ_{MEA}	*Path Length*	*Total Size*
Middle-Class Urban	Tsim Sha Tsui, Hong Kong	44.3°	3.64 km	33.7 GB (785 s)
Deep Urban	Whampoa, Hong Kong	46.9°	4.51 km	63.9 GB (1,536 s)
Harsh Urban	Nathan Road, Hong Kong	55.2°	4.86 km	147 GB (3,367 s)
Tunnel	Cross Harbor Tunnel, Hong Kong	N/A	3.15 km	17 GB (398 s)

$$\mu_{MEA} = \frac{\sum_{\alpha=1}^{N} \theta_{\alpha}}{N}$$



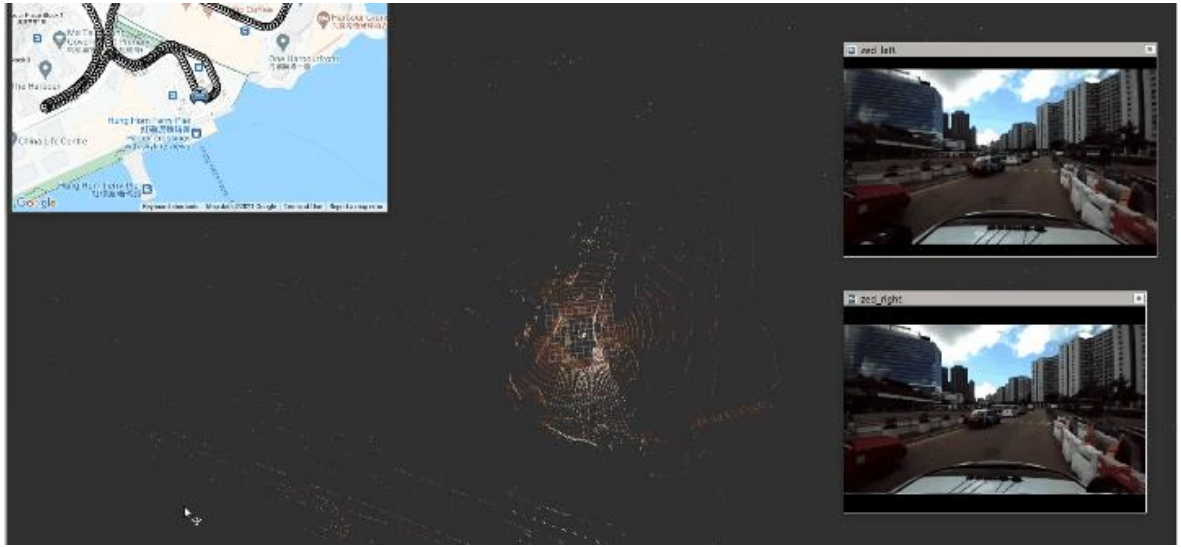
Medium Urban canyon

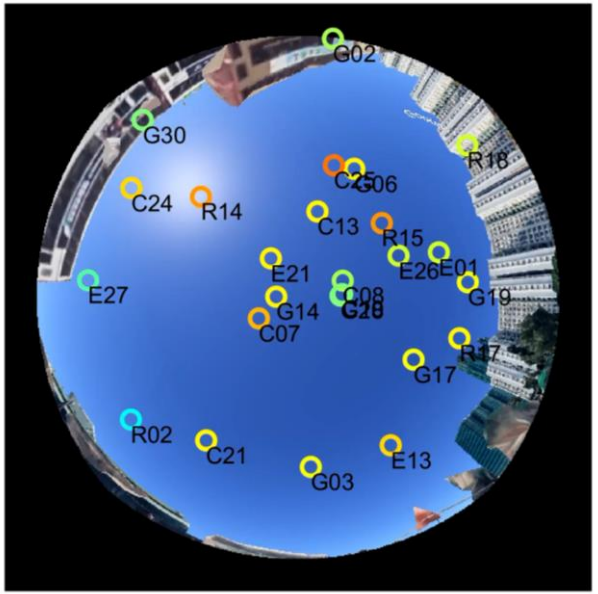




Thanks to Dr Taro Suzuki

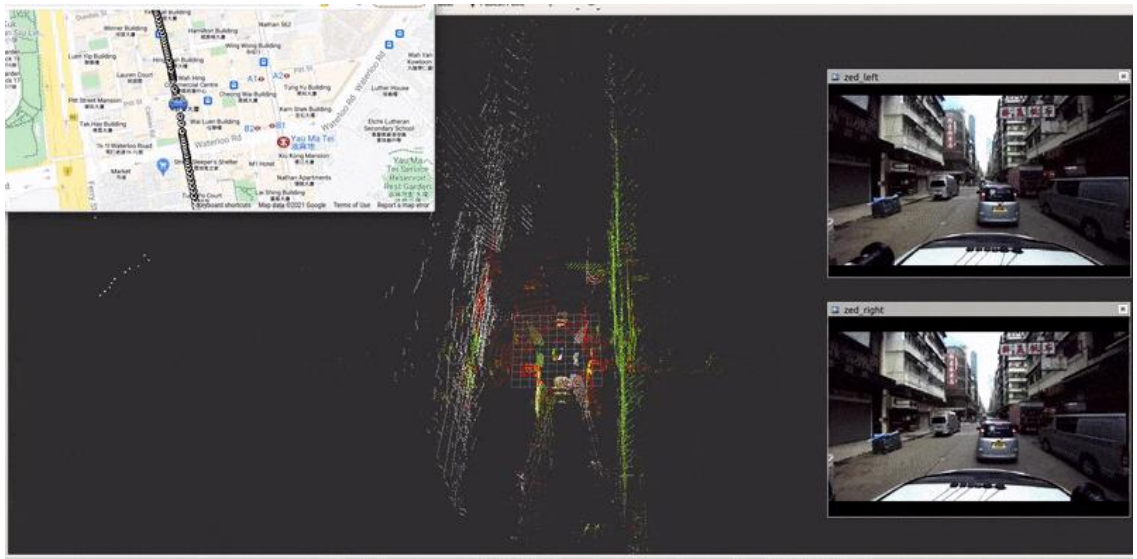
Deep Urban canyon

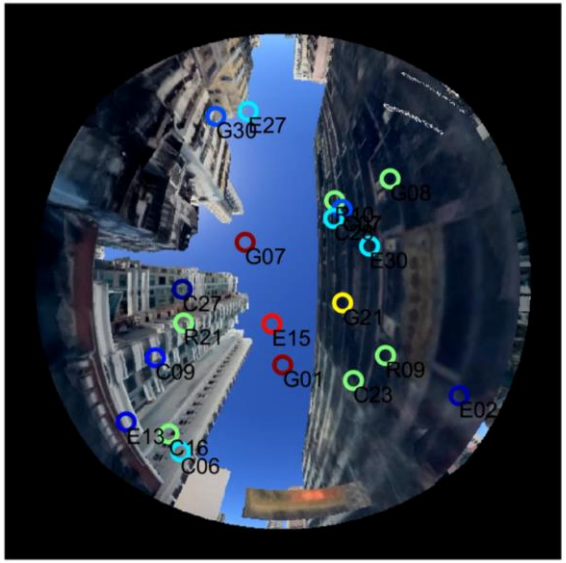




Thanks to Dr Taro Suzuki

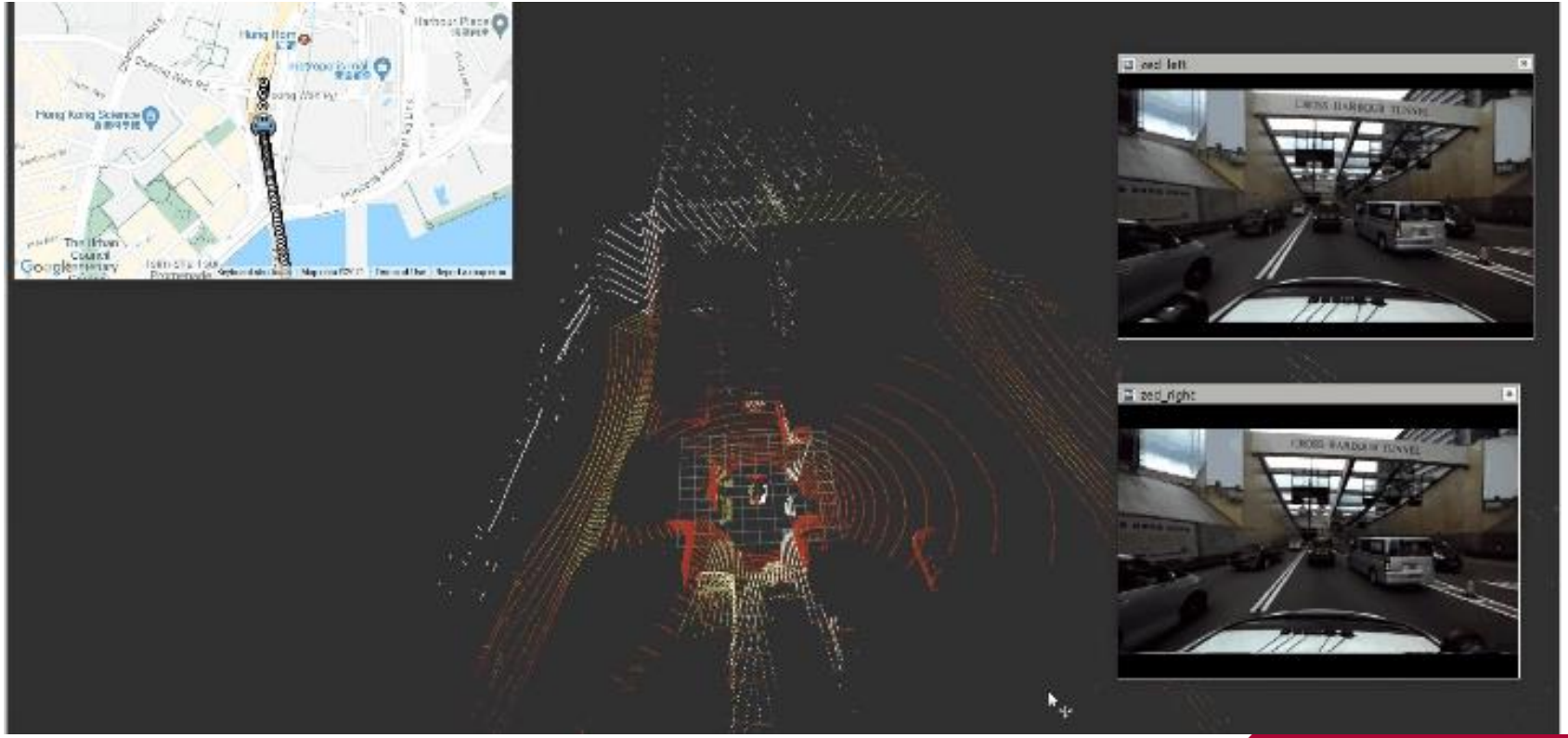
Harsh Urban canyon





Thanks to Dr Taro Suzuki

Tunnel


Hong Kong Science
The Urban Council
Google
cad_left
CROSS HARBOUR TUNNEL
cad_right
CROSS HARBOUR TUNNEL

Data on GitHub

https://github.com/IPNL-POLYU/UrbanNavDataset

Details of the Scenarios

	Total Size	Path length	Sensors	Urban Canyon	Download	3D PointCloud
UrbanNav-HK-Medium-Urban-1	33.7 GB (785s)	3.64 Km	LiDARs/Stereo Camera/IMU/GNSS	Medium	ROS, GNSS, IMU, Ground Truth, Skymask	Medium Urban Map
UrbanNav-HK-Deep-Urban-1	63.9 GB (1536s)	4.51 Km	LiDARs/Stereo Camera/IMU/GNSS	Deep	ROS, GNSS, IMU, Ground Truth, Skymask	Deep Urban Map
UrbanNav-HK-Harsh-Urban-1	147 GB (3367s)	4.86 Km	LiDARs/Stereo Camera/IMU/GNSS	Harsh	ROS, GNSS, IMU, Ground Truth, Skymask	Harsh Urban Map
UrbanNav-HK-Tunnel-1	17 GB (398s)	3.15 Km	LiDARs/Stereo Camera/IMU/GNSS	N/A	ROS, GNSS, IMU, Ground Truth	Tunnel map
(Pilot data) UrbanNav-HK-Data20190428	42.9 GB (487s)	2.01 Km	LiDAR/Camera/IMU/GNSS	Medium	ROS, GNSS	N/A
(Pilot data) UrbanNav-HK-Data20200314	27.0 GB (300s)	1.21 Km	LiDAR/Camera/IMU/GNSS	Light	ROS, GNSS	N/A

The 3D map visualization

LiDARs/Stereo Camera/IMU are recorded under **ROS**
GNSS measurements are stored in **RINEX3.03 and NMEA**

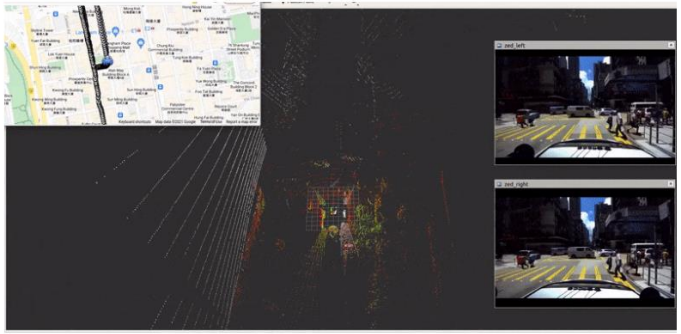
Example:
https://github.com/IPNL-POLYU/UrbanNavDataset#urbannav-hk-harsh-urban-1

README.md

UrbanNav-HK-Harsh-Urban-1

Dataset UrbanNav-HK-Harsh-Urban-1 is collected in an ultra-dense urban canyon of Hong Kong which involves dense vehicles, pedestrians and loops. The coordinates transformation between multiple sensors, and intrinsic measurements of camera can be found via Extrinsic Parameters, IMU Nosie and Intrinsic Parameters of Camera.

- Demo video
- ROS
  - ROSBAG file which includes:
    - 3D LiDAR point clouds (sensor_msgs/PointCloud2): `/velodyne_points`
    - Slant lidars (sensor_msgs/PointCloud2): `/left/lslidar_point_cloud` `/right/velodyne_points`
    - Stereo Camera (sensor_msgs/Image): `/zed2/camera/left/image_raw` `/zed2/camera/right/image_raw`
    - IMU (sensor_msgs/Imu): `/imu/data`
    - Time Reference between latest NMEA and ROS time (sensor_msgs/TimeReference): `/time_reference`
- GNSS (RINEX v3.02)
  - GNSS RINEX files, to use it, we suggest to use the RTKLIB
- IMU, Xsens MTi 10, 400Hz; Phone IMU, Xiaomi 8, 239Hz
- Ground Truth， NovAtel SPAN-CPT + IE, 1Hz



Latitude and longitude on Google map

```
%YAML:1.0

# extrinsic parameters for Dataset UrbanNav-HK-Mongkok-20210518. Be noted that the body is fixed at the IMU frame

################## Extrinsic parameter between IMU and Camera##################
################## camera is ZED2, a stereo camera##################
LEFT_CAMERA_T_IMU:!!opencv-matrix
  rows: 4
  cols: 4
  dt: d
  data:   [0.9995897597632017672, 0.01717080462595868,
           -0.02292132555490840760448, -0.08518352335370896739,
            0.02314658934935549992, -0.01292276982900426,
           0.9996485569546115209, 0.1257734831824675213,
          0.01686853811008714180l, -0.9997690568766732108?,
          -0.01331401395232487720З, 0.07588854970728005484,0.0, 0.0, 0.0, 1.0]
```

```
path:        UrbanNav-HK_TST-20210517_sensors.bag
version:     2.0
duration:    13:05s (785s)
start:       May 17 2021 10:32:55.55 (1621218775.55)
end:         May 17 2021 10:46:01.00 (1621219561.00)
size:        32.8 GB
messages:    386309
compression: none [25462/25462 chunks]
types:       novatel_msgs/INSPVAX      [b5d66747957184042a6cca9b7368742f]
             sensor_msgs/CameraInfo    [c9a58c1b0b154e0e6da7578cb991d214]
             sensor_msgs/Image         [060021388200f6f0f447d0fcd9c64743]
             sensor_msgs/Imu           [6a62c6daae103f4ff57a132d6f95cec2]
             sensor_msgs/PointCloud2   [1158d486dd51d683ce2f1be655c3c181]
             sensor_msgs/TimeReference [fded64a0265108ba86c3d38fb11c0c16]
topics:      /imu/data                          314194 msgs    : sensor_msgs/Imu
             /left/lslidar_point_cloud            7856 msgs    : sensor_msgs/PointCloud2
             /novatel_data/inspvax                 786 msgs    : novatel_msgs/INSPVAX
             /right/velodyne_points               7788 msgs    : sensor_msgs/PointCloud2
             /time_reference                       785 msgs    : sensor_msgs/TimeReference
             /velodyne_points                     7848 msgs    : sensor_msgs/PointCloud2
             /zed2/camera/left/camera_info       11763 msgs    : sensor_msgs/CameraInfo
             /zed2/camera/left/image_raw         11763 msgs    : sensor_msgs/Image
             /zed2/camera/right/camera_info      11763 msgs    : sensor_msgs/CameraInfo
             /zed2/camera/right/image_raw        11763 msgs    : sensor_msgs/Image
```

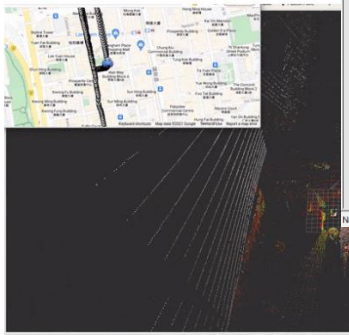
Example:
https://github.com/IPNL-POLYU/UrbanNavDataset#urbannav-hk-harsh-urban-1

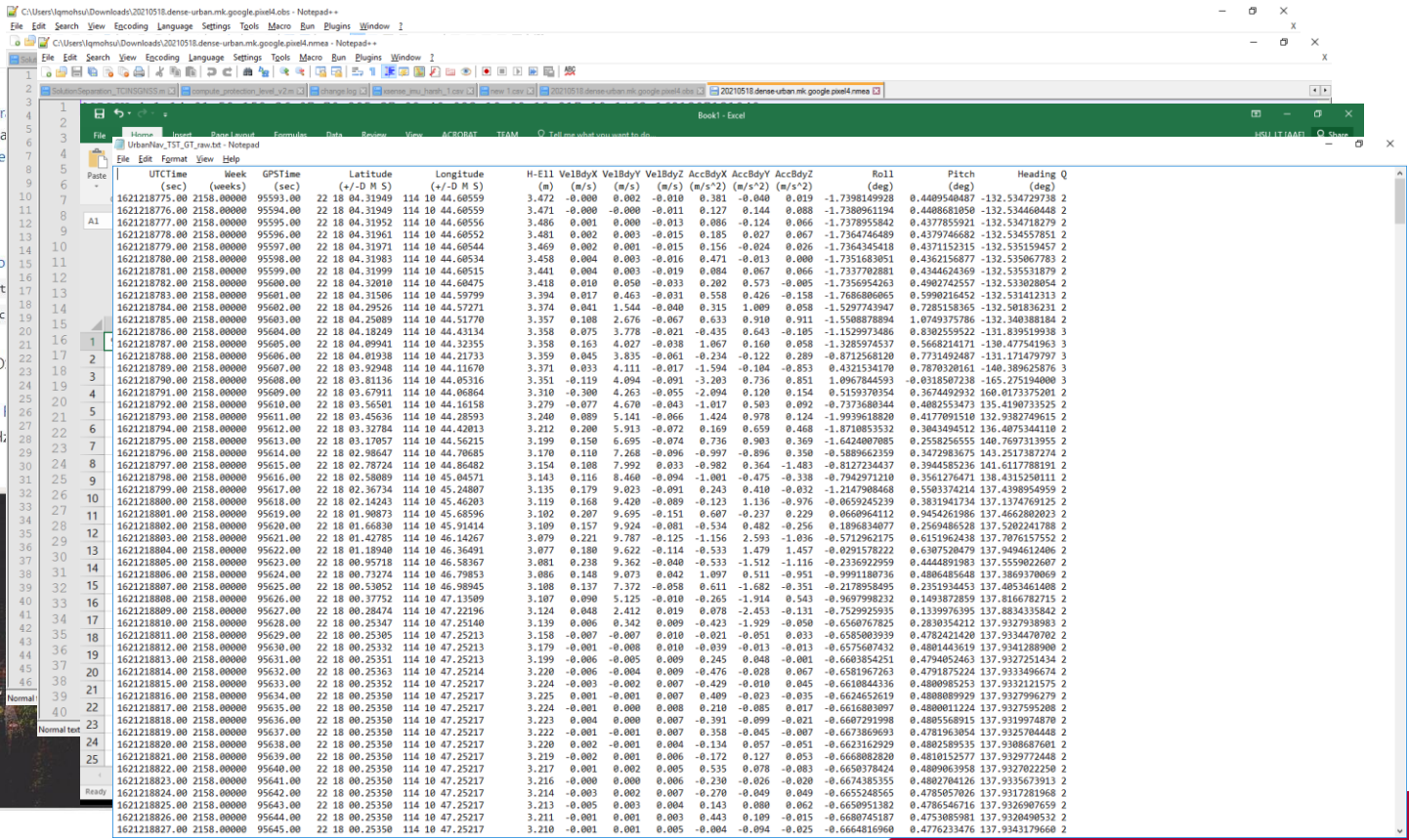
README.md

UrbanNav-HK-Harsh-Urban-1

Dataset UrbanNav-HK-Harsh-Urban-1 is collected in an ultr
vehicles, pedestrians and loops. The coordinates transforma
of camera can be found via Extrinsic Parameters, IMU Nosie

- Demo video
- ROS
  - ROSBAG file which includes:
    - 3D LiDAR point clouds (sensor_msgs/PointClo
    - Slant lidars (sensor_msgs/PointCloud2): `/left`
    - Stereo Camera (sensor_msgs/Image): `/zed2/c`
    - IMU (sensor_msgs/Imu): `/imu/data`
    - Time Reference between latest NMEA and RO
- GNSS (RINEX v3.02)
  - GNSS RINEX files, to use it, we suggest to use the
- IMU, Xsens MTi 10, 400Hz; Phone IMU, Xiaomi 8, 239Hz
- Ground Truth : NovAtel SPAN-CPT + IE, 1Hz





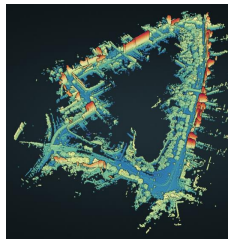
UTCTime (sec)	Week (weeks)	GPSTime (sec)	Latitude (+/-D M S)	Longitude (+/-D M S)	H-Ell (m)	VelBdyX (m/s)	VelBdyY (m/s)	VelBdyZ (m/s)	AccBdyX (m/s^2)	AccBdyY (m/s^2)	AccBdyZ (m/s^2)	Roll (deg)	Pitch (deg)	Heading Q (deg)
1621218775.00	2158.00000	95593.00	22 18 04.31949	114 10 44.60559	3.472	-0.000	0.002	-0.010	0.381	-0.040	0.019	-1.7398149928	0.4409540487	-132.534729738 2
1621218776.00	2158.00000	95594.00	22 18 04.31949	114 10 44.60559	3.471	-0.000	-0.000	-0.011	0.127	0.144	0.088	-1.7380961194	0.4408681050	-132.534460448 2
1621218777.00	2158.00000	95595.00	22 18 04.31952	114 10 44.60556	3.486	0.001	0.000	-0.013	0.086	-0.124	0.066	-1.7378955842	0.4377855921	-132.534718279 2
1621218778.00	2158.00000	95596.00	22 18 04.31961	114 10 44.60552	3.481	0.002	0.003	-0.015	0.185	0.027	0.067	-1.7364746489	0.4379746682	-132.534557851 2
1621218779.00	2158.00000	95597.00	22 18 04.31971	114 10 44.60544	3.469	0.002	0.001	-0.015	0.156	-0.024	0.026	-1.7364345418	0.4371152315	-132.535159457 2
1621218780.00	2158.00000	95598.00	22 18 04.31983	114 10 44.60534	3.458	0.004	0.003	-0.016	0.471	-0.013	0.000	-1.7351683051	0.4362156877	-132.535067783 2
1621218781.00	2158.00000	95599.00	22 18 04.31999	114 10 44.60515	3.441	0.004	0.003	-0.019	0.084	0.067	0.066	-1.7337702881	0.4344623369	-132.535531879 2
1621218782.00	2158.00000	95600.00	22 18 04.32010	114 10 44.60475	3.418	0.010	0.050	-0.033	0.202	0.573	-0.005	-1.7356954263	0.4902742557	-132.533028054 2
1621218783.00	2158.00000	95601.00	22 18 04.31506	114 10 44.59799	3.394	0.017	0.463	-0.031	0.558	0.426	-0.158	-1.7686806065	0.5990216452	-132.531412313 2
1621218784.00	2158.00000	95602.00	22 18 04.29526	114 10 44.57271	3.374	0.041	1.544	-0.040	0.315	1.009	0.058	-1.5297743947	0.7285158365	-132.501836231 2
1621218785.00	2158.00000	95603.00	22 18 04.25089	114 10 44.51770	3.357	0.108	2.676	-0.067	0.633	0.910	0.911	-1.5508878894	1.0749375786	-132.340388184 2
1621218786.00	2158.00000	95604.00	22 18 04.18249	114 10 44.43134	3.358	0.075	3.778	-0.021	-0.435	0.643	-0.105	-1.1529973486	0.8302559522	-131.839519938 3
1621218787.00	2158.00000	95605.00	22 18 04.09941	114 10 44.32355	3.358	0.163	4.027	-0.038	1.067	0.160	0.058	-1.3285974537	0.5668214171	-130.477541963 3
1621218788.00	2158.00000	95606.00	22 18 04.01938	114 10 44.21733	3.359	0.045	3.835	-0.061	-0.234	-0.122	0.289	-0.8712568120	0.7731492487	-131.171479797 3
1621218789.00	2158.00000	95607.00	22 18 03.92948	114 10 44.11670	3.371	0.033	4.111	-0.017	-1.594	-0.104	-0.853	0.4321534170	0.7870320161	-140.389625876 3
1621218790.00	2158.00000	95608.00	22 18 03.81136	114 10 44.05316	3.351	-0.119	4.094	-0.091	-3.203	0.736	0.851	1.0967844593	-0.0318587238	-165.275194000 3
1621218791.00	2158.00000	95609.00	22 18 03.67911	114 10 44.06864	3.310	-0.300	4.263	-0.055	-2.094	0.120	0.154	0.5159370354	0.3674492932	160.0173375201 2
1621218792.00	2158.00000	95610.00	22 18 03.56501	114 10 44.16158	3.279	-0.077	4.670	-0.043	-1.017	0.503	0.092	-0.7373680344	0.4082553473	135.4190733525 2
1621218793.00	2158.00000	95611.00	22 18 03.45636	114 10 44.28593	3.240	0.089	5.141	-0.066	1.424	0.978	0.124	-1.9939618820	0.4177091510	132.9382749615 2
1621218794.00	2158.00000	95612.00	22 18 03.32784	114 10 44.42013	3.212	0.200	5.913	-0.072	0.169	0.659	0.468	-1.8710853532	0.3043494512	136.4075344110 2
1621218795.00	2158.00000	95613.00	22 18 03.17057	114 10 44.56215	3.199	0.150	6.695	-0.074	0.736	0.903	0.369	-1.6424007085	0.2558256555	140.7697313955 2
1621218796.00	2158.00000	95614.00	22 18 02.98647	114 10 44.70685	3.170	0.110	7.268	-0.096	-0.997	-0.896	0.358	-0.5889662359	0.3472983675	143.2517387274 2
1621218797.00	2158.00000	95615.00	22 18 02.78724	114 10 44.86482	3.154	0.108	7.992	0.033	-0.982	0.364	-1.483	-0.8127234437	0.3944585236	141.6117788191 2
1621218798.00	2158.00000	95616.00	22 18 02.58089	114 10 45.04571	3.143	0.116	8.460	-0.094	-1.001	-0.475	-0.338	-0.7942971210	0.3561276471	138.4315250111 2
1621218799.00	2158.00000	95617.00	22 18 02.36734	114 10 45.24807	3.135	0.179	9.023	-0.091	0.243	0.410	-0.032	-1.2147988468	0.5583374214	137.4398954959 2
1621218800.00	2158.00000	95618.00	22 18 02.14243	114 10 45.46203	3.119	0.168	9.420	-0.089	-0.123	1.136	-0.976	-0.0659245239	0.3831941734	137.1374769125 2
1621218801.00	2158.00000	95619.00	22 18 01.90873	114 10 45.68596	3.102	0.207	9.695	-0.151	0.607	-0.237	0.229	0.0660964112	0.9454261986	137.4662802023 2
1621218802.00	2158.00000	95620.00	22 18 01.66830	114 10 45.91414	3.109	0.157	9.924	-0.081	-0.534	0.482	-0.256	0.1896834077	0.2569486528	137.5202241788 2
1621218803.00	2158.00000	95621.00	22 18 01.42785	114 10 46.14267	3.079	0.221	9.787	-0.125	-1.156	2.593	-1.036	-0.5712962175	0.6151962438	137.7076157552 2
1621218804.00	2158.00000	95622.00	22 18 01.18940	114 10 46.36491	3.077	0.180	9.622	-0.114	-0.533	1.479	1.457	-0.0291578222	0.6307520479	137.9494612406 2
1621218805.00	2158.00000	95623.00	22 18 00.95718	114 10 46.58367	3.081	0.238	9.362	-0.040	-0.533	-1.512	-1.116	-0.2336922959	0.4444891983	137.5559022607 2
1621218806.00	2158.00000	95624.00	22 18 00.73274	114 10 46.79853	3.086	0.148	9.073	0.042	1.097	0.511	-0.951	-0.9991180736	0.4806485648	137.3869700069 2
1621218807.00	2158.00000	95625.00	22 18 00.53052	114 10 46.98945	3.108	0.137	7.372	-0.058	0.611	-1.682	-0.351	-0.2178958495	0.2351934453	137.4053461408 2
1621218808.00	2158.00000	95626.00	22 18 00.37752	114 10 47.13509	3.107	0.090	5.125	-0.010	-0.265	-1.914	0.543	-0.9697998232	0.1493872859	137.8166782715 2
1621218809.00	2158.00000	95627.00	22 18 00.28474	114 10 47.22196	3.124	0.048	2.412	0.019	0.078	-2.453	-0.131	-0.7529925935	0.1339976395	137.8834335842 2
1621218810.00	2158.00000	95628.00	22 18 00.25347	114 10 47.25140	3.139	0.006	0.342	0.009	-0.423	-1.929	-0.050	-0.6560767825	0.2830354212	137.9327938983 2
1621218811.00	2158.00000	95629.00	22 18 00.25305	114 10 47.25213	3.158	-0.007	-0.007	0.010	-0.021	-0.051	0.033	-0.6585003939	0.4782421420	137.9334470702 2
1621218812.00	2158.00000	95630.00	22 18 00.25332	114 10 47.25213	3.179	-0.001	-0.008	0.010	-0.039	-0.013	-0.013	-0.6575607432	0.4801443619	137.9341288900 2
1621218813.00	2158.00000	95631.00	22 18 00.25351	114 10 47.25213	3.199	-0.006	-0.005	0.009	0.245	0.048	-0.001	-0.6603854251	0.4794052463	137.9327251434 2
1621218814.00	2158.00000	95632.00	22 18 00.25363	114 10 47.25214	3.220	-0.006	-0.004	0.009	-0.476	-0.028	0.067	-0.6581967263	0.4791875224	137.9333496674 2
1621218815.00	2158.00000	95633.00	22 18 00.25352	114 10 47.25217	3.224	-0.003	-0.002	0.007	-0.429	-0.010	0.045	-0.6610844336	0.4800985253	137.9332121575 2
1621218816.00	2158.00000	95634.00	22 18 00.25350	114 10 47.25217	3.225	0.001	-0.001	0.007	0.409	-0.023	-0.035	-0.6624652619	0.4808089929	137.9327996279 2
1621218817.00	2158.00000	95635.00	22 18 00.25350	114 10 47.25217	3.224	-0.001	0.000	0.008	0.310	-0.085	0.017	-0.6616803097	0.4800011224	137.9327595208 2
1621218818.00	2158.00000	95636.00	22 18 00.25350	114 10 47.25217	3.223	0.004	0.000	0.007	-0.391	-0.099	-0.021	-0.6607291998	0.4805568915	137.9319974870 2
1621218819.00	2158.00000	95637.00	22 18 00.25350	114 10 47.25217	3.222	-0.001	-0.001	0.007	0.358	-0.045	-0.007	-0.6673869693	0.4781963054	137.9325704448 2
1621218820.00	2158.00000	95638.00	22 18 00.25350	114 10 47.25217	3.220	0.002	-0.001	0.004	-0.134	0.057	-0.051	-0.6623162929	0.4802589535	137.9308687601 2
1621218821.00	2158.00000	95639.00	22 18 00.25350	114 10 47.25217	3.219	-0.002	0.001	0.006	-0.172	0.127	0.053	-0.6668082820	0.4810152577	137.9329772448 2
1621218822.00	2158.00000	95640.00	22 18 00.25350	114 10 47.25217	3.217	0.001	0.002	0.005	0.535	0.078	-0.083	-0.6650378424	0.4809063958	137.9327022250 2
1621218823.00	2158.00000	95641.00	22 18 00.25350	114 10 47.25217	3.216	-0.000	0.000	0.006	-0.230	-0.026	-0.020	-0.6674385355	0.4802704126	137.9335673913 2
1621218824.00	2158.00000	95642.00	22 18 00.25350	114 10 47.25217	3.214	-0.003	0.002	0.007	-0.270	-0.049	0.049	-0.6655248565	0.4785057026	137.9317281968 2
1621218825.00	2158.00000	95643.00	22 18 00.25350	114 10 47.25217	3.213	-0.005	0.003	0.004	0.143	0.080	0.062	-0.6650951382	0.4786546716	137.9326907659 2
1621218826.00	2158.00000	95644.00	22 18 00.25350	114 10 47.25217	3.211	-0.001	0.001	0.003	0.443	0.109	-0.015	-0.6680745187	0.4753085981	137.9320490532 2
1621218827.00	2158.00000	95645.00	22 18 00.25350	114 10 47.25217	3.210	-0.001	0.001	0.005	-0.004	-0.094	-0.025	-0.6664816960	0.4776233476	137.9343179660 2

Benchmark using open-sourced codes

Evaluation – RTKLIB [1]

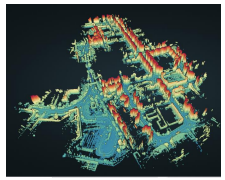
RKTLIB 2.4.3 b34 settings, GPS+GLO+GAL+BDS+QZS,
El mask: 15 deg, SNR mask: 15dBHz

Receiver	Availability (%)	Mean (m)	STD (m)
Novatel Flexpak 6	37.74	2.00	1.87
Ublox F9P	83.61	10.86	12.65
Xiaomi Mi 8	80.43	19.10	25.36



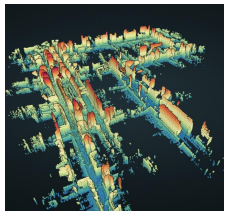
Medium
Urban
Canyon

Receiver	Availability (%)	Mean (m)	STD (m)
Novatel Flexpak 6	83.11	3.77	4.84
Ublox F9P	99.94	10.42	10.19
Xiaomi Mi 8	97.79	52.72	29.56



Deep
Urban
Canyon

Receiver	Availability (%)	Mean (m)	STD (m)
Novatel Flexpak 6	68.60	13.42	72.75
Ublox F9P	27.01	32.78	79.32
Xiaomi Mi 8	40.46	46.94	253.01



Harsh
Urban
Canyon

[1] http://www.rtklib.com/ , https://github.com/tomojitakasu/RTKLIB

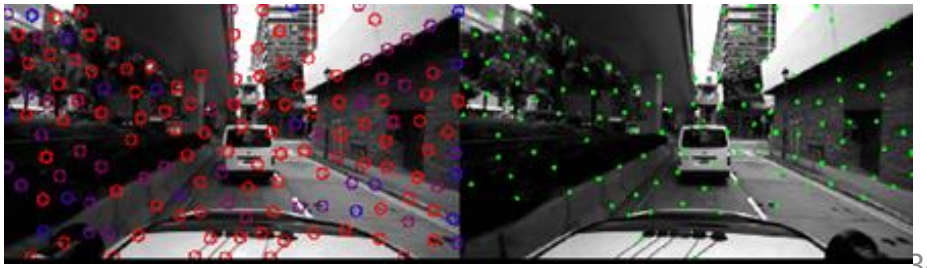
Evaluation - Visual Inertial Odometry via VINS-Fusion [2]

The mean error is defined by the relative pose error (RPE) in the EVO [3], which is widely used in SLAM field. We look at the translation (displacement between two epochs).

Scenario (1Hz)	Mean	STD	Max
Middle	0.48m	0.54m	2.91m
Deep	0.33m	0.38m	2.37m
Harsh	0.53m	0.96m	8.13m
Tunnel	Fail	Fail	Fail

[2] T. Qin, P. Li and S. Shen, "VINS-Mono: A Robust and Versatile Monocular Visual-Inertial State Estimator," in *IEEE Transactions on Robotics*, vol. 34, no. 4, pp. 1004-1020, Aug. 2018, doi: 10.1109/TRO.2018.2853729 https://github.com/HKUST-Aerial-Robotics/VINS-Fusion

[3] https://github.com/MichaelGrupp/evo

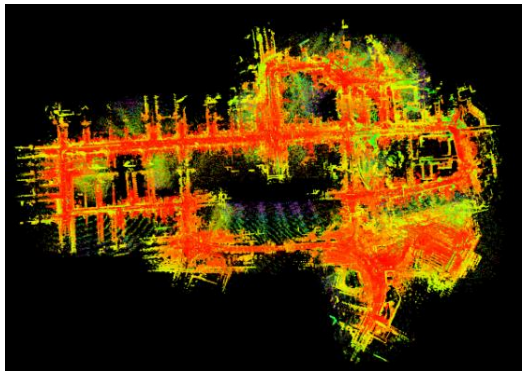


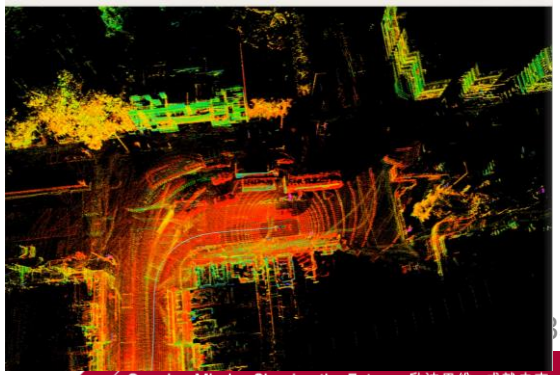
Evaluation - LiDAR Inertial Odometry – LIO-SAM [4]

The mean error is defined by the relative pose error (RPE) in the EVO [3], which is widely used in SLAM field. We look at the translation (displacement between two epochs).

Scenario (1Hz)	Mean	STD	Max
Middle	0.14m	0.13m	1.90m
Deep	0.08m	0.22m	7.41m
Harsh	0.07m	0.14m	2.19m
Tunnel	Fail	Fail	Fail

[4] T. Shan, B. Englot, D. Meyers, W. Wang, C. Ratti and D. Rus, "LIO-SAM: Tightly-coupled Lidar Inertial Odometry via Smoothing and Mapping," 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2020, pp. 5135-5142, doi: 10.1109/IROS45743.2020.9341176. https://github.com/TixiaoShan/LIO-SAM
[3] https://github.com/MichaelGrupp/evo





Conclusion

- **Open-Source Multi-Sensory Dataset in Urban Canyons**
  - LiDAR, Camera, GNSS and INS are included.
  - Middle-, Deep- and Harsh Urban Canyons, and Tunnel

Qualitative Comparison of Sensors

√, ☺, 😐, ☹, and ☠ denote available, satisfactory, normal, unsatisfactory, and unavailable, respectively.

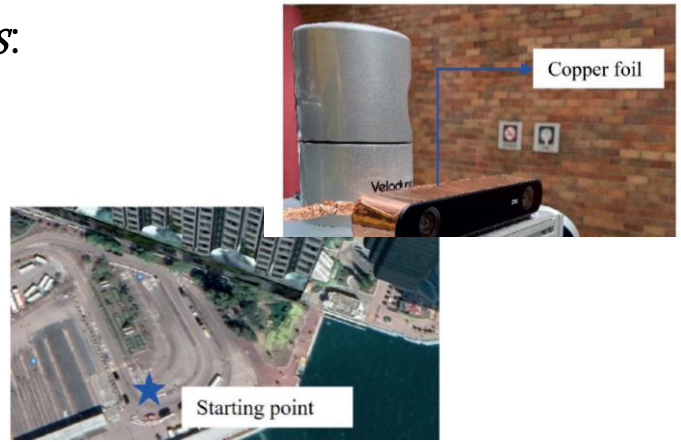
Sensor Technology	Absolute Positioning	Relative Positioning	Middle-Class Urban	Deep Urban	Harsh Urban	Tunnel
GNSS	√	√	☺	😐	☹	☠
Lidar		√	☺	☺	☺	☠
Camera		√	😐	☺	☹	☹
INS		√	☺	☺	☺	☺

Lesson Learned

- *Sensor interference:*
  - GNSS receivers were affected by electromagnetic interference from the camera.
  - The electronic shutter of a CMOS camera operates at a frequency that is close to the frequencies used by GNSS signals, it can generate harmonic frequencies that interfere with GNSS reception.

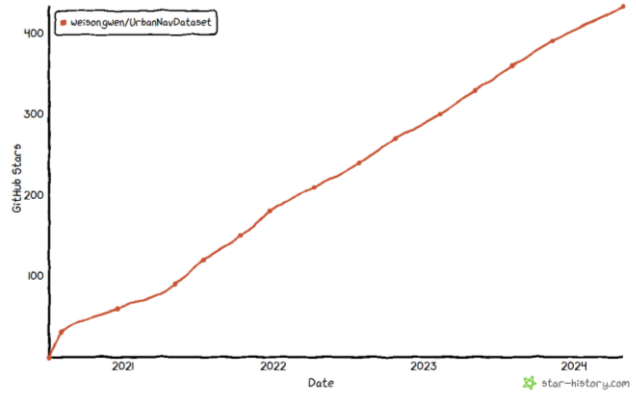
- *Ground truth acquisition in GNSS-challenged environments*:
  - Starting from Open-sky to get a fix before the experiment start.

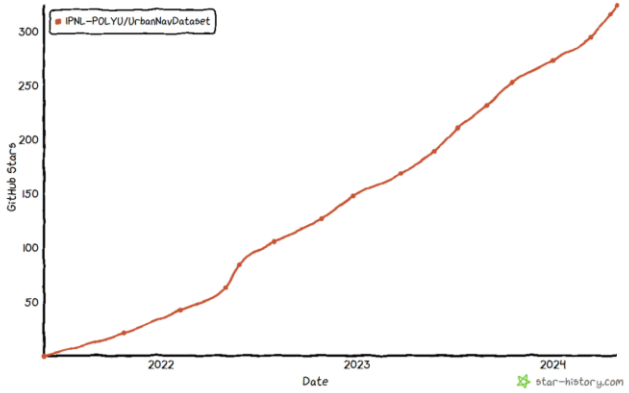
- *Update and maintenance of the dataset*:
  - (Pilot) https://github.com/ weisongwen/UrbanNavDataset
    - 54 Forks and 432 Stars
  - (Official) https://github.com/IPNL-POLYU/UrbanNavDataset
    - 58 Forks and 323 Stars



Research Institutions that used UrbanNav

- Hong Kong Polytechnic University
- Zhejiang University
- Wuhan University
- Zhejiang University of Technology
- Northeastern University
- Poznan University of Technology
- Harbin Institute of Technology (Shenzhen)
- Sichuan University
- Xi'an Jiaotong University
- University of Science and Technology of China
- Politecnico di Torino
- University of Hong Kong
- Hohai University
- Chiba Institute of Technology
- Leibniz University Hannover
- The University of Queensland
- Beijing University of Posts and Telecommunications
- Arizona State University
- University of Calgary
- Beijing Jiaotong University
- University of Shanghai for Science and Technology
- Inner Mongolia University
- Technischen Universität Chemnitz
- Shanghai Jiao Tong University
- Seoul National University
- University of Chinese Academy of Sciences
- Peking University
- Nanjing University of Aeronautics & Astronautics
- Stanford University
- Tianjin University
- Purdue University
- Shenzhen Institute of Advanced Technology
- CEA, LIST
- Shanghai Jiao Tong University
- Open Spatial Dataset for GNSS and Autonomous Navigation
- University of Bonn





Thank you for your attention!

Questions, Comments and Collaboration are welcome.

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Google: UrbanNav Dataset

https://github.com/IPNL-POLYU/UrbanNavDataset

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