# Dataset Description

## GENERAL DESCRIPTION

Data sets consist of timestamped multi-sensor imaging data recorded from the rear of a moving vehicle platform at Alvie Estates, Kincraig, Kingussie, Inverness-shire and at The University of Birmingham (UoB), Birmingham, Edgbaston, UK. The sensors comprise of:

- Scanned high resolution FMCW radar (Polarad)—[Alvie, UoB]
- ZED stereo camera—[Alvie, UoB]
- Spatial FOG combined GNSS and IMU—[Alvie]
- Velodyne Puck VLP-16 lidar—[Alvie, UoB]

Data sets comprise of both on and off-road imagery. Off road imagery collected at Alvie Estates includes examples of trackways, forestry, water filled/covered regions, gulleys and vehicles. On road imagery collected at UoB includes a selection of common road scene actors.

***Note:*** *For off-road (Alvie) data collection, the Velodyne included a GNSS module for positioning and accurate timing/timestamping—described in more detail in timestamping section below. For on-road measurements (UoB), the Spatial FOG GNSS/IMU sensor was not utilised at this stage of data collection.*

Base filenames for off-road data: 'alvie_offroad***i***' – where ***i*** numerates any of 9 consecutive datasets

Base filenames for on-road data: 'uob_onroad***j***' – where ***j*** numerates either of 2 datasets

## SENSOR SETUP DESCRIPTION

- Scanned high resolution FMCW radar (bespoke hardware design)
    - Mechanically scanned in azimuth (turntable)
    - Linear FMCW waveform with 1 ms duration
    - 5 GHz bandwidth
    - Single transmit, 2 quadrature receivers
    - Outputs complex down converted intermediate frequency (IF) data sampled at 4.096 MS/s (alternatively referred to as FMCW beat frequency data)
    - Approximately 1.7° two-way antenna azimuth pattern
    - 132 chirps transmitted across the scan field of view
    - Azimuth angle scanned between chirps – 0.45°
    - Duration of single scan = 1s (scan rate calculable from timestamps)
    - Counter clock wise initial scan direction
- Spatial FOG (Advanced Navigation)
    - Inertial and GPS data measured at 10 Hz rate
    - Further description found in user manual accessible at https://www.advancednavigation.com/sites/default/files/product_documents/Spatial%20FOG%20Reference%20Manual.pdf (last accessed 26/03/19)
- ZED Stereo Camera (Stereo Labs)
    - 30 frames per second video
    - 1280 x 720 resolution
    - Further description found at https://www.stereolabs.com/zed/ (last accessed 26/03/19)
- VLP-16 lidar (Velodyne)

- Point cloud data giving position and intensity of return
- Rotation speed: 600 rpm
- Return mode: Strongest return
- Further description found in user manual accessible at https://velodynelidar.com/vlp-16.html (Last accessed 26/03/19).

## DATA TIMESTAMPING

Sensor data is timestamped using the data collection pc 64 bit CPU 'hardware performance counter' and is also referenced to a global navigation satellite system (GNSS) timestamp. High resolution radar, ZED stereo camera and Spatial FOG sensors share a common hardware performance counter (same pc) and spatial FOG data output provides corresponding GNSS based Unix time reference.

**For the on-road data**, the Velodyne also uses the common performance counter—same pc as other sensors. **However for the off-road measurements**, the Velodyne uses a separate hardware performance counter, as it is controlled by a different pc to the other sensors. In this data it uses its own GNSS module as a time reference, measuring microseconds since the top of the hour in UTC time; this allows alignment with the other sensor data.

Sensors do not necessarily start and end their data collection at the same time instants and sensor rates vary, thus alignment using the timestamp data is required to synchronise sensor data. For the off-road data, conversion needs to be made to align the UTC (Velodyne) and Unix (Spatial FOG) GNSS derived timestamps.

## DATA TYPES AND STRUCTURE

Base filenames for the data are…..

### Spatial FOG IMU

- Filenames containing Spatial FOG IMU/GNSS data end in '_fog.mat'. Files are in MATLAB readable .mat format.
- Data is stored in a structure with 14 fields. 13 of these fields comprise of data types contained within the Spatial FOG 'System State Packet' (Packet ID 20), of which further information is contained within the Spatial FOG Reference Manual.
- In summary the fields are: system status, filter status, Unix timestamp (secs, usecs), latitude, longitude, height, velocity, acceleration, g-force, orientation, angular velocity, latitude/longitude/height standard deviation. The length of the fields corresponds to the number of data samples taken over the measurement duration.
- The 14$^{th}$ field of the data structure contains the 64 bit performance counter timestamp for (labelled hires_counter). Timestamping is performed on a sample to sample basis.

### High Resolution Radar

Filenames end in '_rdr.mat' and are in the MATLAB .mat format.

Each .mat file consists of three arrays, one for performance counter timestamps, named tStamp and two for radar data from each receiver, named rx1 and rx2.

***Note:*** *For on-road data, only rx1 was utilised at this stage of data collection.*

The radar receiver data arrays are three dimensional arrays.

- The first dimension of size 4096 spans the IF beat frequency output samples—4096 samples per received chirp, 1 ms duration, at a sample rate 4.096 MS/s.

- The second dimension (of size 132) denotes the chirp number within the scan, which also relates to the azimuth (angular) position within the scan.
- Third dimension denotes the scan number (in the case of off-road data this = 30, on-road = 90).

All measurements start with counter clock wise scan direction. In some circumstances, radar chirps may be dropped within a measurement, if this occurs the corresponding array entries for the given chirp and scan number will consist of a vector of zeros.

The performance counter timestamp is recorded in a two dimensional array, the first dimension relates to the chirp number within a scan, the second to the scan number. Timestamps are recorded at the chirp level.

## ZED Stereo Camera

Filenames end in '_zed.svo'. ZED stereo camera video data is stored in the Stereo Labs proprietary .svo format (fully rectified left and right camera imagery), using GPU compression. Files and video contained may be accessed, exported and processed to form stereo imagery using Stereo Labs example software through the ZED SDK found at https://www.stereolabs.com/developers/release/ (requires GPU).

Performance counter timestamp is saved in the corresponding '_zed.dat', counter values are stored as int64 data types. Timestamping is made on a video frame basis.

## VLP-16 Lidar

Velodyne point cloud data filenames end in '_velo_data.dat'. The data structure within the file conforms to the Velodyne datagram description found in the VLP-16 manual, consisting of 1206 bytes per datagram (this is the payload length, the UDP header is not stored).

The datagrams contain the UTC timestamp (derived from the GNSS input) measured in microseconds since the top of the UTC hour (as per the description in the manual). Additionally, the hardware performance counter timestamp is appended to the start of each datagram, constituting the first 8 bytes as type int64. After this addition, the total datagram size becomes 1214 bytes.

Sensor positioning data from the GNSS module is found in the corresponding '_velo_pos.dat' (**for off-road data only**), also conforming to the data structure within the VLP-16 manual. This data also contains the NMEA navigation strings to allow extraction of absolute UTC time for use with the datagram UTC top of the hour timestamp.