CO-existence Simulation Modeling of Radars for Self-driving

(104526-COSMOS)

Data Repository Description

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Version History

Version	Date	Incorporated by	Comments
1	22-12-21	COSMOS Team, University of Birmingham	First version
2	16-01-22	Anum Pirkani	Second Version
3	29-01-22	Anum Pirkani	Third Version

This document is approved by the Principle Investigator (PI) of the COSMOS project.

Prof. Marina Gashinova

Date: 31/01/2022

Revisions in Version 2

Filenames corresponding to serial 3b corrected.

Serial 3d MIRA GPS information corrected

Serial 3d Video file updated: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1

Revisions in Version 3

University of Birmingham repository link updated.

Arrangement of facades and radar height with respect to the ground added.

University of Birmingham repository links corresponding to cases 2b, 2d, 3b, 3d updated.

GPS data corresponding to JLR vehicle added for subcases.

Table of Contents

Abbreviations

UoB	University of Birmingham
JLR	Jaguar Land Rover
IMU	Inertial measurement unit
ACC	Adaptive cruise control
CTA	Cross traffic alert
HDF5	Hierarchical Data Format 5
RAM	Radar absorbent material
VR	Victim Radar
FoV	Field of view
RLG	Radarlog
RBK	Radarbook

1. Introduction

This report describes the measurement scenarios, and data structure of various sensors used for data collection campaign conducted by the University of Birmingham (UoB) and the project partners from 15/09/21 – 19/09/21 at Horiba MIRA test track.

- The subset of collected dataset corresponding to cases 1b (Radarlog), 2g (interference at 9m), and 3d with interference are stored in the University of Birmingham repository and available at: https://edata.bham.ac.uk/777/.
- The subset of collected dataset corresponding to case 2d is stored in the University of Birmingham repository, and available at: https://edata.bham.ac.uk/785/.
- The subset of collected dataset corresponding to case 2f (for TI interference) is stored in the University of Birmingham repository, and available at: https://edata.bham.ac.uk/786/.
- The subset of collected dataset corresponding to case 3b is stored in the University of Birmingham repository, and available at: https://edata.bham.ac.uk/787/.
- The subset of collected dataset corresponding to case 3d is stored in the University of Birmingham repository, and available at: https://edata.bham.ac.uk/788/.

This dataset titled: '***COSMOS dataset for co-existence/interference analysis and simultaneous scene representation by automotive radar and video with GPS/IMU ground truth,'*** is the first part of the University of Birmingham data collection for the Innovate UK funded COSMOS project – 104526-COSMOS: CO-existence Simulation Modeling of Radars for Self-driving.

- Chapter 2 provides a list of sensors used during the measurement campaign, their configuration, and parameters. The data structure of raw data collected with the sensors is included in Appendix.
- Chapter 3 gives a detailed description of the measurement scenarios corresponding to which data is stored in the UoB repository.
- Chapter 4 includes a list of Appendix for data and repository description, and MATLAB scripts to assist in the data post-processing.

1.1 Objectives during the Trials

The objectives of the described radar trials were to conduct radar measurements at the background of interference in the 76 – 81 GHz frequency band to:

- Estimate the impact of interference in an adaptive cruise control (ACC) and cross-traffic alert (CTA) scenarios.
- Analyse radar field of view shadowing due to a close target.
- Identify an oncoming vehicle from the received interference which is otherwise blind due to radar field of view (FoV) obstruction.
- Estimate the multipath interference in a reflective scenario.

1.2 Repository Overview

The full dataset collected during the trails is over 2 TB. Depending upon the scenario and data collection duration, the size of raw data captured from INRAS Radarlog varies from 1 GB to 7 GB whereas for INRAS Radarbook, it varies from 1 GB to 4 GB. Therefore, due to extremely large files sizes, only the most suitable representative of the defined use-cases is included in the repository. Moreover, the full post-processed radar imagery is only shown for a few example cases.

Additional data may be available on request.

The defined use-cases and brief description of each use-case that will include a corresponding file in the repository is given in Table 1.

Table 1: Overview of the Data included in UoB repository

ID	Scenario	Description
1	Radar Calibration	Radar calibration to validate sensor operation and path loss models
2	Adaptive Cruise Control (ACC)	Analysis of interference in various scenarios for adaptive cruise control.
3	Cross-Traffic Alert (CTA)	Analysis of interference effect in a T-junction scenario.
4	Radar blind region estimation	Estimating the blind region created in the field of view of radar due to reflective surface in radar propagation path
5	Beamfilling on radar Propagation	Estimating beamfilling on radar signal propagation due to the presence of a moving target

1.3 Measurement Site and Scene

The measurement site is located on Horiba MIRA test track, Nuneaton, U.K. A Google Map plan view of the trials site is shown in Figure 1 (a) and the panoramic photo of the test area is shown in Figure 1 (b).

(a) (b)

Figure 1: Pictorial representation of the test area. (a) Google Map plan view. (b) Panoramic photo.

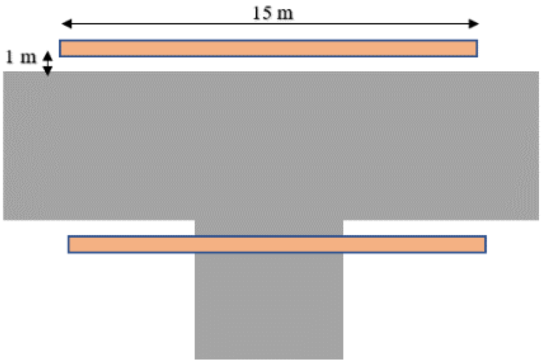
To replicate a representative of reflective roadside scene, Horiba MIRA provided with the brick wall facades that were placed around the test track. The modified test scene in demonstrated in Figure 2.

Figure 2: Brick wall Facades to replicate a reflective roadside scenario.

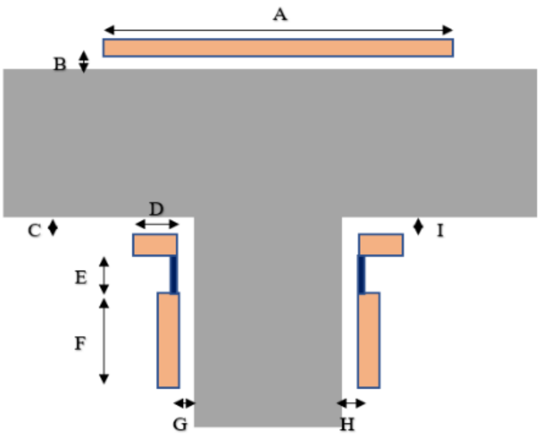
The data contained in this repository was recorded from 15th November 2021 to 19th November 2021. The weather conditions were moderate except for the latter half of 16th November where there was light rain.

1.4 Arrangement of Facades

1.4.1 Facade Parallel Wall Setup



1.4.2 Facade Complete Junction Wall Setup



Label	Dimensions
A	12 m
B	1 m
C	0.85 m
D	3 m
E	2.6 m (Aluminium Plate)
F	6 m
G	0.43 m
H	0.75 m
I	1.1 m

All the stated measurements are with respect to the lane marking at the end of each lane.

2. Hardware Configuration

Data collection for the trials is performed using two vehicles:

a) UoB vehicle, which is used as the victim vehicle. The victim radars and supporting equipment is installed on this vehicle
b) Jaguar Land Rover (JLR) vehicle, which is used as the interferer vehicle. The interferer radars and supporting equipment is installed on this vehicle.

Most of the equipment including all the sensors is installed at the front of both the vehicles as demonstrated in Figure 3(a) for UoB vehicle and Figure (b) for JLR vehicle. The power supplies are secured at the boot of the vehicles whereas IMU is placed on the roof of the vehicles as indicated in Figure 3.

(a) (b)

Figure 3: Equipment setup. (a) UoB vehicle. (b) JLR vehicle.

2.1 Radar Heights from Ground

The installation location of radars and their respective heights from ground are given:

Installation Location and Heights of Radars.

Radar	Installation Location	Height from ground (m)
Radarlog	Victim Vehicle: Front Radar	0.85
Radarbook	Victim Vehicle: Corner Radar	0.9
TI AWR1243	Interferer Vehicle: Front Radar	0.5
NXP Dolphin	Interferer Vehicle: Corner Radar	0.62

All the measurements were performed with the radar's chassis cover on. For NXP radar, the bumper cover was taken off.

2.2 Equipment used during the Trials

The list of equipment used during trials is mentioned in Table 2.

Table 2: Equipment used during COSMOS Trials 2.

Equipment	Model	Description
Radars	INRAS Radarlog	• Front Victim Radar • MIMO mode • 4Tx – 16Rx
	INRAS Radarbook	• Corner Victim Radar • MIMO mode • 4Tx – 8Rx
	TI AWR1243	• Corner Interferer Radar • Doppler mode • 1 Tx – 4 Rx
	NXP Dolphin	• Corner Interferer Radar • Doppler mode • 1Tx – 4Rx
Video/ Camera	Stereo labs ZED stereo camera	• Front of victim vehicle
	Go Pro	• Front of interferer vehicle
Lidar	Velodyne VLP-16	
GPS/ Ground Truth	• Advanced Navigation Spatial FOG IMU/ GNSS • MIRA IMU System	
Radar Absorbent	77 GHz RF absorber	

Radarlog, LIDAR and ZED stereo camera are configured to record timestamped data.

2.3 Calibration Targets

For the calibration of radars, a trihedral corner reflector and sphere are used as the road actors. The calibration dataset corresponding to corner reflector is included in the repository.

The dimensions and estimated RCS of the corner reflector at 77 GHz are given in Table 3.

Table 3: Specifications of corner reflector used during COSMOS Trials.

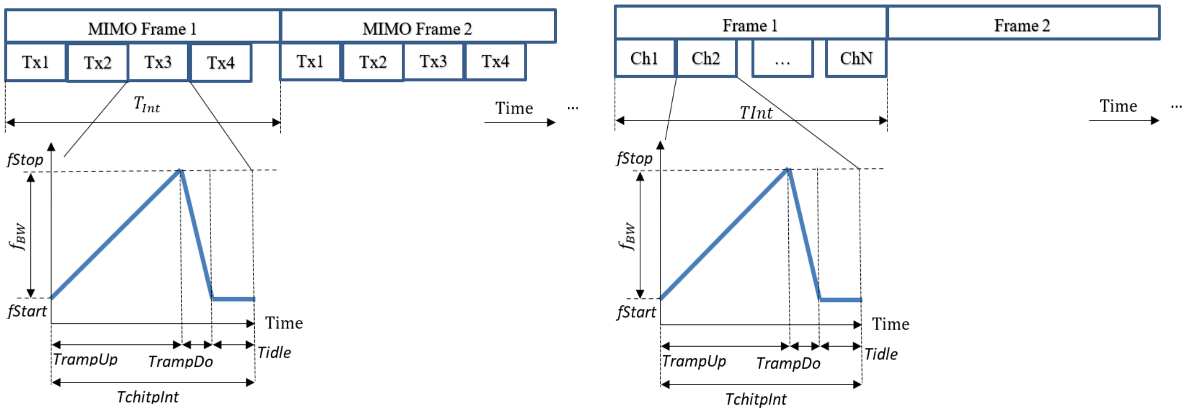
Reflectors	Parameters	
Trihedral Corner Reflector (Square plate).	Edge length	7 cm
	Max RCS at 77 GHz	17 dBsm

2.4 Radar Operation

For the COSMOS trials, the victim radars (INRAS Radarlog and INRAS Radarbook) are operated in MIMO configuration (all transmitters are active in time-division multiplexing MIMO mode) in order to have a better spatial resolution.

Interferer radars (TI AWR1243 and NXP Dolphin) are operated in the Doppler configuration (only one active transmitter) in order to have a higher active time of transmission as compared to the MIMO mode (and increased probability of interference).

The chirp and frame configuration for MIMO and Doppler modes are demonstrated in Figure 4 (a) and 4 (b), respectively.



(a) (b)

Figure 4: Chirp and Frame configuration. (a) MIMO mode. (b) Doppler mode

2.4.1 INRAS Radarlog

INRAS Radarlog is a 77GHz radar with four transmit elements at 3.5λ spacing and sixteen receive elements at $\lambda/2$ spacing. It is configured to operate in MIMO mode and installed as front victim sensor.

The computer connected to Radarlog runs Inras RadServe software which captures the radar data, and time stamp information. The radar data and configuration settings are then stored to a HDF5 (Hierarchical Data Format version 5) file. The RadServe software enables high data transfer rate (up to 2.5Gbit/s) and ensures synchronization between the captured Radarlog data and time stamping information. However, due to ~5m cables running to the back seat of the vehicle used to operate radar, the data rate is reduced, resulting in frame losses. To prevent these frame losses, the radar data capture duration of 10-20s is used for static cases and 30s for the dynamic cases.

The active transmitters of Radarlog cycle from chirp-to-chirp in the order: TX1-TX2-TX3-TX4. With four transmit elements and sixteen receive elements, the Radarlog produces a virtual array of 64-elements, but the spatial configuration of the antennas on the Radarlog, gives three overlapping virtual elements. After removing these overlapping elements, an equivalent of a 61-element $\lambda/2$ spaced antenna array (one-way only) is formed. Removal of the overlapping elements is done before MIMO processing of the radar signals from the Radarlog.

Raw data recorded to file is the de-ramped FMCW IF signal.

2.4.2 INRAS Radarbook

The Inras Radarbook is a 77 GHz radar with four transmit elements at 3.5λ spacing and eight receive elements at $\lambda/2$ spacing. It is configured to operate in MIMO mode and installed as corner victim sensor.

The active transmitters cycle from chirp-to-chirp in the order: TX1-TX2-TX3-TX4. With four transmit elements and eight receive elements the Radarbook would produce a virtual array of 32-elements, but the spatial configuration of the antennas on the Radarbook, gives three overlapping virtual elements. Removing these overlapping elements, an equivalent virtual array of 29-element $\lambda/2$ spaced antenna array (one-way only) is emulated. Removal of the overlapping elements is usually done before MIMO processing of the radar signals from the Radarbook.

Raw data recorded to file is collected using MATLAB and is stored as a MATLAB .mat file in the form of the de-ramped FMCW IF signal.

N.B. Due to the low-pass anti-aliasing filter, with a cut-off of 3.25MHz, within the Radarbook, the effective maximum unambiguous range is 49.9m.

2.4.3 TI AWR1243

The Texas Instruments TI AWR1243 is a 77GHz radar with three transmit elements at 1.5λ spacing and four receive elements at $\lambda/2$ spacing. The radar is installed as a front interferer radar, configured to operate in Doppler mode. This is to ensure maximum transmission time from TI radar allowing a higher probability of overlap with the transmitted signal from victim radars.

In Doppler mode only one transmitter is used, while data is received on all four receivers. Therefore, a beam pattern with 4 element $\lambda/2$ spaced antenna array (one-way) is formed.

TI radar is operated using mm wave Radar studio which is configured through LUA commands sent from MATLAB. The data is saved in the form of .bin files along with .json files that contain the configuration settings for each file.

2.4.4 NXP Dolphin

The NXP Dolphin is a 77GHz radar with three transmit elements at 1.5λ spacing and four receive elements at $\lambda/2$ spacing. This radar is installed as a corner interferer sensor and operated in Doppler mode to allow maximum transmission time (and compromising on frame losses) and maximise the probability of overlap with the victim sensor.

In Doppler mode the only one transmitter is used, and data is received on all four receivers. Therefore, a beam pattern of 4 element $\lambda/2$ spaced antenna array (one-way) will be achieved.

NXP radar as interferer is configured using MATLAB operated through Windows however, without the timestamping information. The radar data is stored in the form of .mat files.

2.5 Radar Parameters

Operating parameters used for the radars for the defined use cases along with the reference variable names are given in Table 4. These parameters have been determined to give the optimal range/ azimuth resolutions, negligible data transfer loss to the computer, and a higher probability of interference.

Table 4: Radar Parameters for COSMOS Trials

Parameter	Symbol	INRAS Radarlog	INRAS Radarbook	TI AWR1243	NXP Dolphin	Unit
Sweep Time (Ramp-Up)	T_{rampUp}	204.8	51.2	250	102.4	us
Sweep Bandwidth	f_{BW}	1000	1000	950	1000	MHz
Start Frequency	f_c	76	76	76.05	76.1	GHz
Mode of Operation		MIMO	MIMO	Doppler	Doppler	
Chirp Ramp-Down Time	T_{rampDo}	18.8	10	4	4	us
Chirp Interval Time	$T_{chirpInt}$	230	100	266	150	us
Chirps per Frame		4	4	255	32	Chirps
Active Frame Duration	T_{active}	0.92	0.4	69.2	4.8	ms
MIMO Frame Interval	T_{Int}	1	2.4	70	10	ms
Active Duty Cycle		92	16.7	98	48	%
Chirps in Doppler Interval*		128	128			
Antenna Configuration		4*16	4*8	1*4	1*4	Elements
Azimuth Resolution		1.9	4	28.6	28.6	Degree
Sampling Frequency		10	10	8	10	MHz
Transmit Antenna Gain		14.4	15	10.5	15	dBi
Receive Antenna Gain		14.4	15	10.5	15	dBi
Transmit Power		10	10	10	10	dBm
Number of fast time samples	$n_{samples}$	2048	512	2000	1024	
Range Resolution	R_{res}	0.15	0.15	0.15	0.15	m
Maximum unambiguous range	R_{unamb}	300	50	300	150	m
Maximum unambiguous Doppler Velocity	v_{unamb}	±1	±1.4	±3.7	±6.5	ms^{-1}

* Chirps in Doppler interval: This defines the number of individual chirps which are incorporated into a single coherent Doppler processing interval. This is equal to the number of Doppler bins after Doppler FFT in the example post-processed results.

It is to be mentioned that for the TI AWR1243, with the selected parameters, it results in a higher interference duration at the victim sensors (in comparison to interference received from NXP radar).

2.6 Video

A ZED stereo video camera has been used to provide ground truth the radar measurements. Camera data is supplied as an H.264 encoded video file in an MP4 container and is timestamped to allow for co-registration with the radar data. However, there is some degree of error due to latency.

The computer connected to ZED captures video snapshots from the webcam, that are later synchronised with the radar data using time stamp information.

It is to be noted that the video ground truth is captured from the front radar perspective.

3. Measurement Scenarios

In this section, the test scenarios are shown diagrammatically along with the example post-processed results.

The relevant dataset corresponding to each use case, scenario description and the purpose of performed experiment is described in Table 5.

All the measurements are performed at the city circuit region of Horiba MIRA facility.

3.1 Radar Calibration

These measurements are intended to serve as reference measurements to evaluate the performance and functionality of radars used during the trials. Serial 1a – 1c in Table 5 corresponds to the radar calibration use case.

For these measurements, a trihedral corner reflector is used as a reference target, placed at various distances and azimuth angles in front of the victim radars. The setup is shown in Figure 5.

(a) (b)

Figure 5: Initial Calibrations. (a) Inras Radarlog covered with RAM to estimate the inherent noise floor. (b) Corner reflector placed at 5m from Inras Radarlog.

The echo signal from reference target (reflector) is observed after various stages of the radar signal processing chain to evaluate return power, and beamforming performance (principally the azimuth beamwidth and sidelobe level). Sidelobe levels are of particular concern due to their performance limitation which results from the effective one-way propagation, inherent to MIMO operation.

Examples of the post-processed results for radar calibration with the corner reflector at 27m and 0^o for case 1b from Table 5 is shown in Figure 6 along with the ground truth for scene visualization.

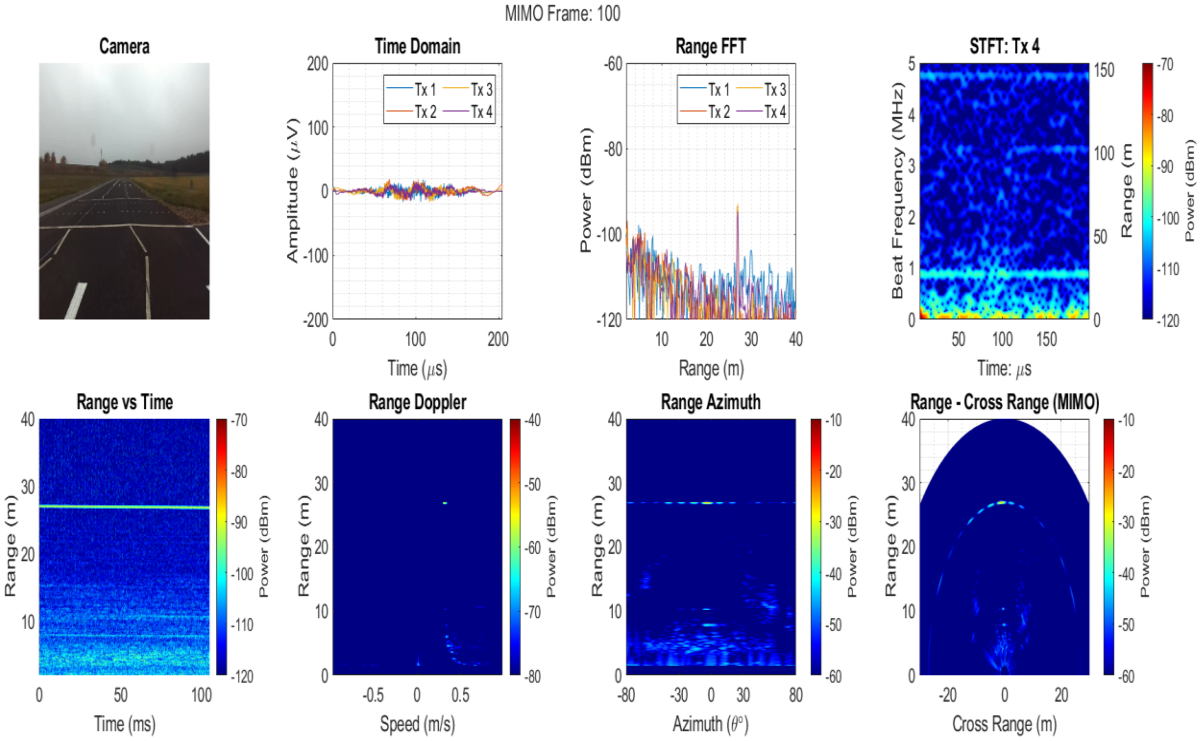


Figure 6: Initial Radarlog calibration with corner reflector placed at 27 m, 0^o from the radar.

* STFT: Short time Fourier transform

* FFT: Fast Fourier transform

3.2 Adaptive Cruise Control

These measurements are performed to analyse the severity of interference in scenarios where adaptive cruise controlling is useful. Serials 2a – 2h in Table 5 corresponds to this use case.

The measurements are performed with static and dynamic scene in the three sub-scenarios:

3.2.1 Without Facades

Serials 2a – 2e in Table 5 correspond to the measurements without additional facades in the test area. Data collection is done with the following road actors:

- Victim vehicle (UoB) with victim radars installed
- Interferer vehicle (JLR) with interferer radars installed
- Reference corner reflector for calibration.

* No additional reflectors are included in the scene.

In one of the included data set (Serial 2c from Table 5), a pedestrian is also incorporated in the scenario to estimate the detectability of pedestrian in the background of interference.

3.2.2 With Facades

Serials 2f – 2g in Table 5 correspond to this use case. Data collection is done using the following road actors:

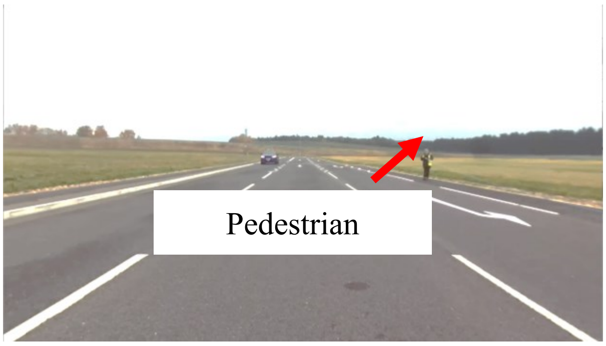
- Victim vehicle (UoB) with victim radars installed
- Interferer vehicle (JLR) with interferer radars
- Reference corner reflector for calibration
- Additional road infrastructure in the form of brick wall facades around the road (see Figure 2).

3.2.3 Facades with 3D Infrastructure

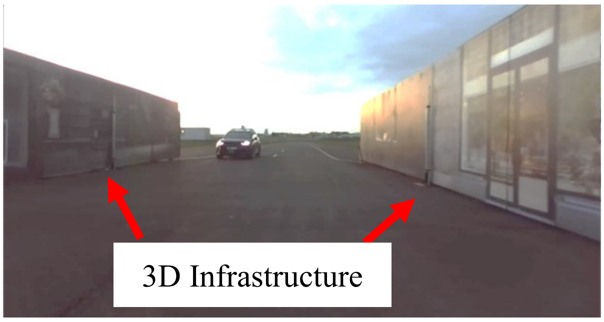
Serials 2h in Table 5 correspond to this use case. Data collection is done using the following road actors:

- Victim vehicle (UoB) with victim radars installed
- Interferer vehicle (JLR) with interferer radars
- Reference corner reflector for calibration
- Additional road infrastructure in the form of brick wall facades around the road
- 3D infrastructure installed next to the facade wall

Figure 7 illustrates the scenarios for the relevant ACC use cases.



(a) (b)



(c) (d)

Figure 7: Adaptive Cruise Control (a) Without Facades. (b) Pedestrian in the field of view of victim radar. (c) Facades around the road. (d) Facades with 3D infrastructure.

Example of the post-processed results for an ACC scenario with facades around the road and dynamic victim and interferer vehicles is shown in Figure 8 along with the ground truth for scene visualization.

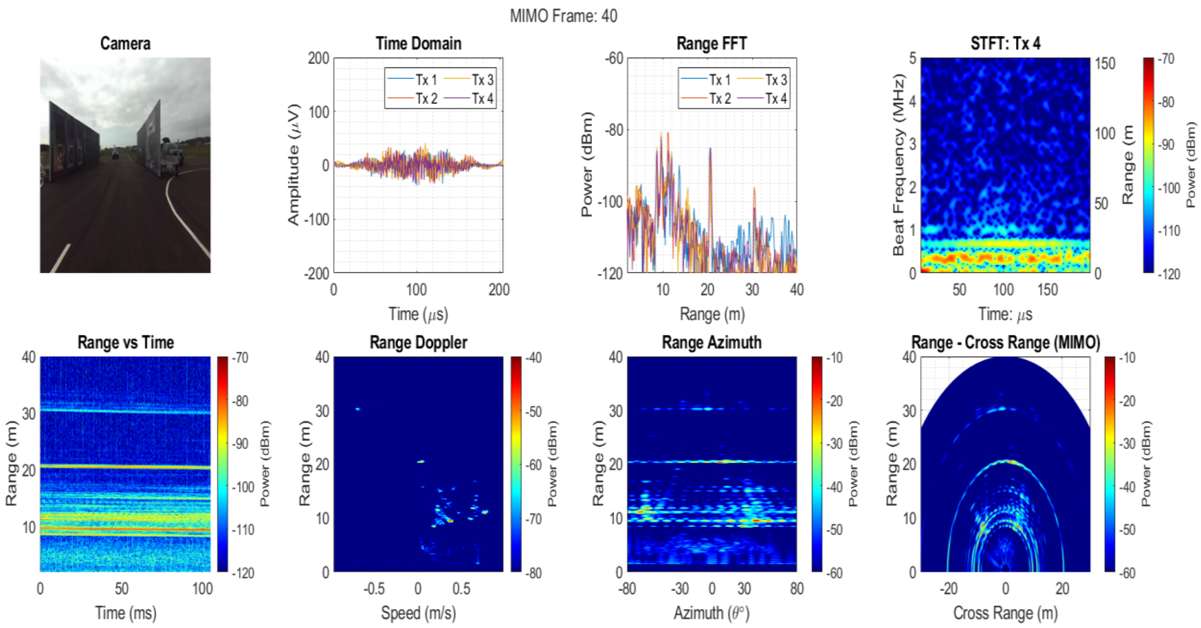


Figure 8: Adaptive Cruise Control scenario with dynamic victim and interferer vehicles and facades around the road.

3.3 Cross Traffic Alert

These measurements are performed to analyse the severity of interference in a cross traffic alert scenario. Serials 3a – 3e in Table 5 correspond to this use case.

The measurements were performed with static and dynamic scene in three sub-scenarios. For the dynamic measurements, the driving path of victim and interferer vehicles is indicated as a blue and red arrow in Figure 9 (a), respectively.

3.3.1 Without Facades

The measurements corresponding to this use case includes a victim vehicle (UoB) and interferer vehicle (JLR). No additional reflectors are included in the scene. Serials 3a – 3b in Table 5 correspond to this use case. The scene is illustrated in Figure 9 (a).

3.3.2 With Facades

The measurements corresponding to this use case includes a victim vehicle (UoB), interferer vehicle (JLR), and additional road infrastructure in the form of brick wall facades around the road as indicated in Figure 9 (b). The facades are included in the scene in order to estimate their effect in multipath interference contribution.

Serials 3c – 3e in Table 5 correspond to this use case.

(a) (b)

Figure 9: Cross Traffic Alert Scenario (a) Without Facades. (b) Facades around the road.

3.4 Blind Zone Estimation

These measurements are performed to estimate the blind zone created in the victim radar field of view due to the presence of facades, that blocks the radar signal.

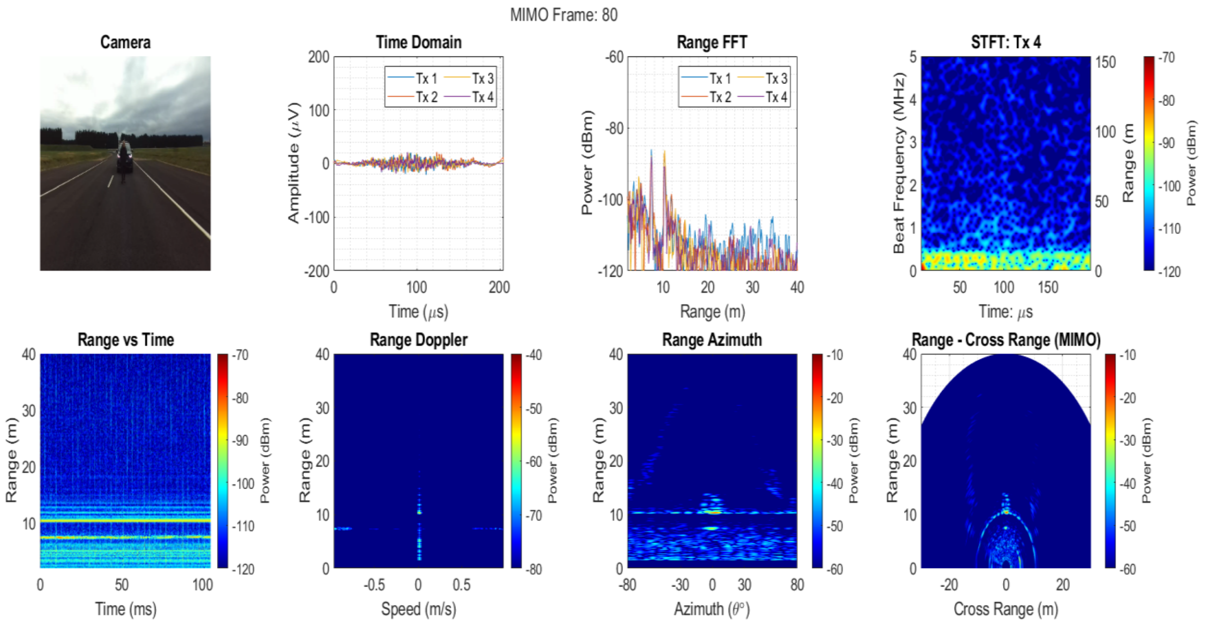
In the created blind zone, interference is expected to be received by the victim radar. Through this, the presence of a target vehicle can be expected, which is otherwise obscured (see Figure 9 (a) and 9 (b) for reference).

Serial 4a – 4b in Table 5 corresponds to this use case.

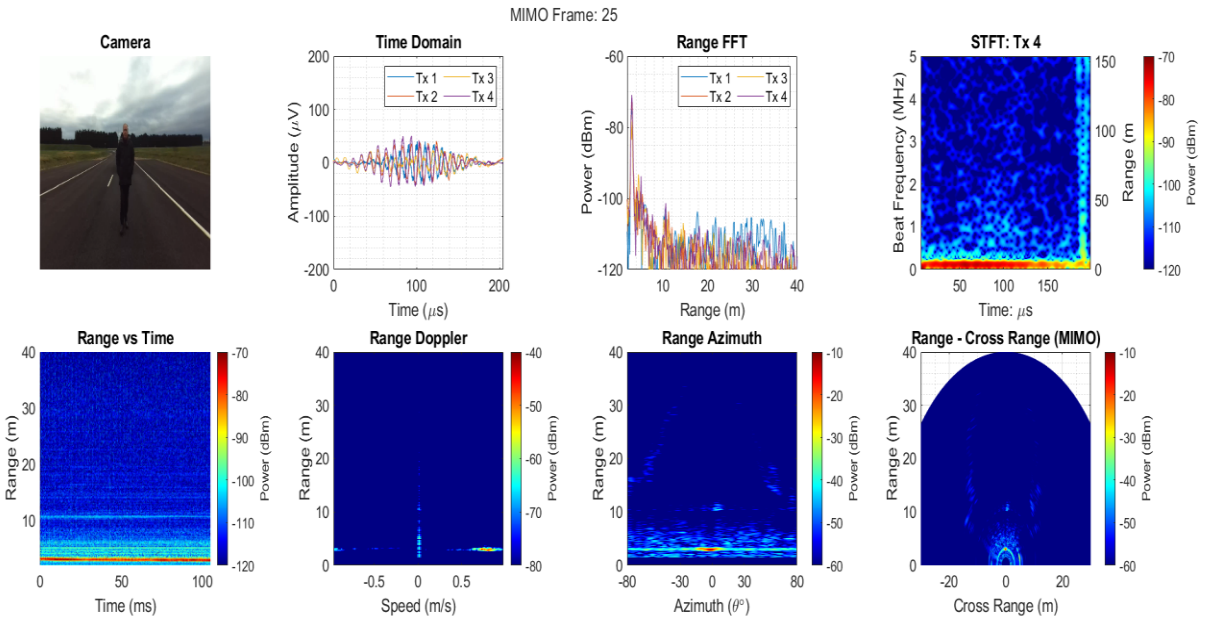
3.5 Beamfilling on Radar Signal Propagation

This measurement is performed to estimate the effect of target motion on the beamfilling on radar signal propagation. Serial 5 in Table 5 corresponds to the mentioned use case.

The post-processed result and ground truth for two different positions of the moving pedestrian are shown in Figure 10 (a) and 10 (b), respectively.



(a)



(b)

Figure 10: Beamfilling on the radar signal propagation due to a moving pedestrian in the radar's field of view.(a) Pedestrian at 7m from the radar. (b) Pedestrian at 3m from the radar.

Table 5: COSMOS Trials Data Repository Description

S. No.	Use Case	Description	Interferer Sensors	Road Actors	Radar Data		Video	GPS/ IMU	Timestamp	Purpose
					Radarlog	Radarbook				
1a	**Radar Calibration**	Radar absorbent material covering the sensor	NA	NA	C2_RLG_Cal_CR_RAM_Run1_211116_1000.h5	C2_RBK_Cal_CR_RAM_Run1_15-11-2021_11-41-36	RLG: C2_RLG_Cal_CR_RAM_Run1 RBK: C2_RBK_Cal_CR_RAM_Run1	RLG: C2_RLG_Cal_CR_RAM_Run1 (UoB) RBK: C2_RBK_Cal_CR_RAM_Run1 (UoB)	RLG: time211116_0958 RBK: time211115_1134	1. Estimating radar noise floor * Note: MIRA GPS Data not available
1b		The distance of corner reflector (RCS 17 dBsm) is dynamically changed with respect to the victim radar. • In the case of radarlog, vehicle is moving towards the static corner reflector • In the case of radarbook, a pedestrian is holding corner reflector and moving towards the radar. At all times, CR is in line of sight of victim radar and facing it.		• Radar under observation (Radarlog and Radarbook) • Corner Reflector	C2_RLG_Cal_CR_Dyn_Run3c_211116_1039	C2_RBK_Cal_CR_PedDyn_Run2_15-11-2021_11-56-29	RLG: C2_RLG_Cal_CR_Dyn_Run3 RBK: C2_RBK_Cal_CR_PedDyn_Run2	RLG: C2_RLG_Cal_CR_Dyn_Run3 (UoB) 8-C2_RLG_Cal_CR_Dyn_Run3\000400080001.txt (MIRA) RBK: C2_RBK_Cal_CR_PedDyn_Run2 (UoB)	RLG: time211116_0958 RBK: time211115_1134	1. Radar Calibration 2. Identifying Propagation Model 3. Estimating reflectivity from road 4. Identifying background clutter * Note: MIRA GPS Data not available for Radarbook calibration
1c		The corner reflector (RCS 17 dBsm) is placed at various azimuth angles with respect to the victim radar.			0^0: C2_RLG_Cal_CR10m_Run1_211116_1044.h5 15^0: C2_RLG_Cal_CR10m15Deg_Run2_211116_1049.h5 30^0: C2_RLG_Cal_CR10m30Deg_Run2_211116_1052.h5	0^0: C2_RBK_Cal_CR_10m_Run1_15-11-2021_12-23-55 15^0: C2_RBK_Cal_CR10m15Deg_Run1_15-11-2021_12-26-27 30^0: C2_RBK_Cal_CR10m30Deg_Run1_15-11-2021_12-27-59	RLG: C2_RLG_Cal_CR10m_Run1 C2_RLG_Cal_CR10m15Deg_Run2 C2_RLG_Cal_CR10m30Deg_Run2 RBK: C2_RBK_Cal_CR10m_Run1 C2_RBK_Cal_CR10m15Deg_Run1 C2_RBK_Cal_CR10m30Deg_Run1	RLG: C2_RLG_Cal_CR10m_Run1 (UoB) C2_RLG_Cal_CR10m15Deg_Run2 (UoB) C2_RLG_Cal_CR10m30Deg_Run2 (UoB) RBK: C2_RBK_Cal_CR10m_Run1 (UoB) C2_RBK_Cal_CR10m15Deg_Run1 (UoB) C2_RBK_Cal_CR10m30Deg_Run1 (UoB)	RLG: time211116_0958 RBK: time211115_1134	1. Radar calibration 2. Analysis of azimuth calibration * Note: MIRA GPS Data not available

* For calibration measurements, data from radarbook and radarlog is captured at different time.

S. No.	Use Case	Description	Interferer Sensors	Road Actors	Radar Data		Video	GPS/ IMU	Timestamp	Purpose
					Radarlog	Radarbook				
2a	**Adaptive Cruise Control**	Victim and interferer vehicles are static in adjacent lanes and facing each other. The distance between two vehicles is 10 m. Only TI interference is switched on.	TI AWR1243	• Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector	Reference: C2_RLG_ACC_TIInt10m_Ref2_Run1_211117_1008.h5 Interference: C2_RLG_ACC_TIInt10m_Run1_211117_1010.h5	Reference: C2_RBK_ACC_TIInt10m_Ref2_Run1_17-11-2021_10-08-38 Interference: C2_RBK_ACC_TIInt10m_Run1_17-11-2021_10-10-52	Reference: C2_RLG_ACC_TIInt10m_Ref2_Run1 Interference: C2_RLG_ACC_TIInt10m_Run1	Reference: C2_RLG_ACC_TIInt10m_Ref2_Run1 (UoB) 48-C2_RLG_ACC_TIInt10m_Ref2_Run1\000400480001 (MIRA) Interference: C2_RLG_ACC_TIInt10m_Run1 (UoB) 49-C2_RLG_ACC_TIInt10m_Run1\000400490001 (MIRA)	RLG: time211117_0943 RBK: timing211117_0939	1. Estimating interference level from corner looking radar 2. SINR improvement along the victim radar signal processing stages 3. Implementation of interference mitigation techniques 4. Strength of interference received at front and corner victim radars 5. Comparative analysis of interference from front and corner looking radars.
2b		Victim and interferer vehicles are static in adjacent lanes and facing each other. The distance between two vehicles is 12 m. Only NXP interference is switched on.	NXP Dolphin		Reference: C2_RLG_ACC_NXPInt10m_Ref_Run1_211116_1406.h5 Interference: C2_RLG_ACC_NXPInt10m_Run1_211116_1404.h5	Reference: C2_RBK_ACC_NXPInt10m_Ref_Run1_16-11-2021_14-06-22 Interference: C2_RBK_ACC_NXPInt10m_Run1_16-11-2021_14-04-04	Reference: C2_RLG_ACC_TIInt10m_Ref_Run1 Interference: C2_RLG_ACC_NXPInt10m_Run1	Reference: C2_RLG_ACC_TIInt10m_Ref_Run1 (UoB) 38-C2_RLG_ACC_TIInt10m_Ref_Run1\000400380002 (MIRA) Interference: C2_RLG_ACC_NXPInt10m_Run1 (UoB) 34-C2_RLG_ACC_NXPInt10m_Run1\000400340001 (MIRA)	RLG: time211116_1342 RBK: timing211116_1338	
2c		Victim and interferer vehicles are static in adjacent lanes and facing each other. Distance between vehicles is 12 m. Both TI and NXP interferers are switched on. Pedestrian is walking on the pavement, in same direction as victim vehicle.	TI AWR1243 and NXP Dolphin	• Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector • Pedestrian	Interference: C2_RLG_ACC_TINXPIntDyn_PedDyn_Run1_211116_1138.h5	Interference: C2_RBK_ACC_TINXPIntDyn_PedDyn_Run1_16-11-2021_11-38-34	Interference: C2_RLG_ACC_TINXPIntDyn_PedDyn_Run1	Interference: C2_RLG_ACC_TINXPIntDyn_PedDyn_Run1 (UoB) 16-C2_RLG_ACC_TINXPIntDyn_PedDyn_Run1\000400160001 (MIRA)	RLG: time211116_0958 RBK: timing211116_0949	1. Estimating interference level from front and corner looking radars 2. SINR improvement along VR signal processing stages 3. Implementation of interference mitigation techniques. 4. Interference intensit at front and corner VR 5. Pesdestiran detectabiltiy at the backgorund of interference
2d		Static victim and dynamic interferer radar. Both vehicles are facing each other. Interferer vehicle is driving towards the victim vehicles in adjacent lane.		• Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector	Reference: C2_RLG_ACC_TIIntDyn_Ref_Run1_211116_1103.h5 Interference: C2_RLG_ACC_TINXPIntDyn_Run2_211116_1133.h5	Reference: C2_RBK_ACC_TIIntDyn_Ref_Run116-11-2021_11-03-53 Interference: C2_RBK_ACC_TINXPIntDyn_Run2_16-11-2021_11-33-28	Reference: C2_RLG_ACC_TIIntDyn_Ref_Run1 Interference: C2_RLG_ACC_TINXPIntDyn_Run2	Reference: C2_RLG_ACC_TIIntDyn_Ref_Run1 (UoB) 9-C2_RLG_ACC_TIIntDyn_Ref_Run1\000400090001 (MIRA) 19-C2_TI_ACC_TIIntDyn_Ref_Run1\002100190002 (JLR) Interference: C2_RLG_ACC_TINXPIntDyn_Run2 (UoB) 15-C2_RLG_ACC_TINXPIntDyn_Run2\000400150001 (MIRA) 25-C2_TI_ACC_TINXPIntDyn_Run2\002100250001 (JLR)	RLG: time211116_0958 RBK: timing211116_0949	1. Estimating interference level if a dynamic scenario from front and corner looking radars 2. SINR improvement along victim radar processing stages 3. Implementation of interference mitigation techniques. 4. Strength of interference received at front and corner VR

2e		Dynamic victim and interferer vehicles. Both vehicles are in adjancent lanes, driving parallel to each other.	TI AWR1243 and NXP Dolphin	• Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector	Reference: C2_RLG_ACC_VRDyn_IntDyn_Parallel_Ref_Run1_211116_1457.h5 Interference: C2_RLG_ACC_VRDyn_TINXPIntDyn_Parallel_Run1_211116_1502.h5	Reference: C2_RBK_ACC_VRDyn_IntDyn_Parallel_Ref_Run1_16-11-2021_14-57-36 Interference: C2_RBK_ACC_VRDyn_TINXPIntDyn_Parallel_Run1_16-11-2021_15-02-04	Reference: C2_RLG_ACC_VRDyn_IntDyn_Parallel_Ref_Run1 Interference: C2_RLG_ACC_VRDyn_TINXPIntDyn_Parallel_Run1	Reference: C2_RLG_ACC_VRDyn_IntDyn_Parallel_Ref_Run1 (UoB) 39- C2_RLG_ACC_VRDyn_IntDyn_Parallel_Ref_Run1\000400390001 (MIRA) Interference: C2_RLG_ACC_VRDyn_TINXPIntDyn_Parallel_Run1 (UoB) 40- C2_RLG_ACC_VRDyn_TINXPIntDyn_Parallel_Run1\000400400001 (MIRA)	RLG: time211116_1342 RBK: timing211116_1338	1. Estimating interference level if a dynamic scenario from front and corner looking radars 2. SINR improvement along the victim radar processing stages 3. Implementation of interference mitigation techniques. 4. Interference intensity at front and corner VR
2f	**Adaptive Cruise Control** **(With Facades)**	Dynamic victim and interferer radars driving in adjacent lanes but facing each other.	TI AWR1243 and NXP Dolphin	• Facades around the road • Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector	Reference: C2_RLG_ACC_Fac_VRDyn_Ref_Run2_211117_1042.h5 TI Interference: C2_RLG_ACC_Fac_VRDyn_TIIntDyn_Run1_211117_1058.h5 NXP Interference: C2_RLG_ACC_Fac_VRDyn_NXPIntDyn_Run1_211117_1101.h5 TI and NXP Interference: C2_RLG_ACC_Fac_VRDyn_TINXPIntDyn_Run3_211117_1110.h5	Reference: C2_RBK_ACC_Fac_VRDyn_Ref_Run2_17-11-2021_10-42-57 TI Interference: C2_RBK_ACC_Fac_VRDyn_TIIntDyn_Run1_17-11-2021_10-58-41 NXP Interference: C2_RBK_ACC_Fac_VRDyn_NXPIntDyn_Run1_17-11-2021_11-01-18 TI + NXP Interference: C2_RBK_ACC_Fac_VRDyn_TINXPIntDyn_Run3_17-11-2021_11-10-36	Reference: C2_RLG_ACC_Fac_VRDyn_Ref_Run2 TI Interference: C2_RLG_ACC_Fac_VRDyn_TIIntDyn_Run1 NXP Interference: C2_RLG_ACC_Fac_VRDyn_NXPIntDyn_Run1 TI + NXP Interference: C2_RLG_ACC_Fac_VRDyn_TINXPIntDyn_Run3	Reference: C2_RLG_ACC_Fac_VRDyn_Ref_Run2 (UoB) 53- C2_RLG_ACC_Fac_VRDyn_Ref_Run2\000400530001 (MIRA) TI Interference: C2_RLG_ACC_Fac_VRDyn_TIIntDyn_Run1 (UoB) 56- C2_RLG_ACC_Fac_VRDyn_TIIntDyn_Run1\000400560001 (MIRA) 60- C2_TI_ACC_Fac_VRDyn_TIDyn_Run1\002100600001 (JLR) NXP Interference: C2_RLG_ACC_Fac_VRDyn_NXPIntDyn_Run1 (UoB) 57- C2_RLG_ACC_Fac_VRDyn_NXPIntDyn_Run1\000400570001 (MIRA) TI + NXP Interference: C2_RLG_ACC_Fac_VRDyn_TINXPIntDyn_Run3 (UoB) 60- C2_RLG_ACC_Fac_VRDyn_TINXPIntDyn_Run3\000400600001 (MIRA)	RLG: time211117_0943 RBK: timing211117_0939	1. Multipath analysis 2. Inerference from multipath 3. Appearance of ghost targets 4. Interference level in a reflective scenario
2g		Static interferer vehicle (radar) and dynamic victim vehicle (radar). Victim vehicle driving towards the interferer vehicle in adjacent lane.			Interferer Position 9m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Ref_Run1_211117_1121.h5 Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Run2_211117_1139.h5	Interferer Position 9m Reference: C2_RBK_ACC_Fac_VRDyn_TINXPInt9m_Ref_Run1_17-11-2021_11-21-30 Interference: C2_RBK_ACC_Fac_VRDyn_TINXPInt9m_Run2_17-11-2021_11-39-26	Interferer Position 9m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Ref_Run1 Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Run2	Interferer Position 9m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Ref_Run1 (UoB) 64- C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Ref_Run1\000400640001 (MIRA) Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Run2 (UoB) 66- C2_RLG_ACC_Fac_VRDyn_TINXPInt9m_Run2\000400660002 (MIRA)	RLG: time211117_0943 RBK: timing211117_0939	

					Interferer position 15m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Ref_Run1_211117_1114.h5 Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Run2_211117_1118.h5	Interferer Position 15m Reference: C2_RBK_ACC_Fac_VRDyn_TINXPInt15m_Ref_Run1_17-11-2021_11-14-37 Interference: C2_RBK_ACC_Fac_VRDyn_TINXPInt15m_Run2_17-11-2021_11-18-39	Interferer Position 15m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Ref_Run1 Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Run2	Interferer Position 15m Reference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Ref_Run1 (UoB) 61-C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Ref_Run1\000400610001 (MIRA) Interference: C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Run2 (UoB) 63-C2_RLG_ACC_Fac_VRDyn_TINXPInt15m_Run2\000400630001 (MIRA)		
2h	**Adaptive Cruise Control (Facades with 3D Infrastructure)**	Dynamic victim and interferer radars	TI AWR1243 and NXP Dolphin	• Facades around the road • 3D infrastructure next to the facades • Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Corner Reflector	Reference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Ref_Run1_211117_1540.h5 Interference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Run1_211117_1536.h5	Reference: C2_RBK_ACC_3Fac_VRDyn_TINXPIntDyn_Ref_Run1_17-11-2021_15-40-06 Interference: C2_RBK_ACC_3Fac_VRDyn_TINXPIntDyn_Run1_17-11-2021_15-36-48	Reference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Ref_Run1 Interference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Run1	Reference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Ref_Run1 (UoB) 81-C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Ref_Run1\000400810001 (MIRA) Interference: C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Run1 (UoB) 80-C2_RLG_ACC_3Fac_VRDyn_TINXPIntDyn_Run1\000400800001 (MIRA)	RLG: time211117_1419 RBK: timing211117_1439	1. Multipath analysis 2. Inerference from multipath 3. Appearance of ghost targets 4. Interference level in a reflective scenario 5. Effect of additional infrastructure on the radar return.

* Notes:
For all the measurements corresponding to ACC use case, data from radarlog and radarbook is captured simultaneously. However, from different laptops.

S. No.	Use Case	Description	Interferer Sensors	Road Actors	Radar Data		Video	GPS/ IMU	Timestamp	Purpose
					Radarlog	Radarbook				
3a	**Cross Traffic Alert**	Static Victim, Static Interference.	TI AWR1243 and NXP Dolphin	• Victim vehicle • Interferer vehicle	Reference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Ref_Run1_211115_1547.h5 C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Ref_Run1_211115_1549.h5 Interference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Run1_211115_1545.h5 C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Run1_211115_1540.h5	Reference: C2_RBK_CTA_NFac_VR5m_TINXP0m_Ref_Run1_15-11-2021_15-47-06 C2_RBK_CTA_NFac_VR5m_TINXP5.4m_Ref_Run1_15-11-2021_15-49-39 Interference: C2_RBK_CTA_NFac_VR5m_TINXP0m_Run1_15-11-2021_15-45-09 C2_RBK_CTA_NFac_VR5m_TINXP5.4m_Run1_15-11-2021_15-40-39	Reference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Ref_Run1 C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Ref_Run1 Interference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Run1 C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Run1	Reference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Ref_Run1 (UoB) C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Ref_Run1 (UoB) Interference: C2_RLG_CTA_NFac_VR5m_TINXPInt0m_Run1 (UoB) C2_RLG_CTA_NFac_VR5m_TINXPInt5.4m_Run1 (UoB)	RLG: time211115_1437 RBK: time211115_1453	1. Strength of interference received from front and corner interferer radars 2. Comparative analysis of interference received at front and corner victim radars.
3b		Static Victim, Dynamic Interference Victim radar is placed at 5 m from the start of junction		• Victim vehicle • Interferer vehicle	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1_211115_1532.h5 Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run2_211115_1537.h5	Reference: C2_RBK_CTA_NFac_VR5m_TINXPDyn_Ref_Run1_15-11-2021_15-32-10 Interference: C2_RBK_CTA_NFac_VR5m_TINXPDyn_Run2_15-11-2021_15-37-13	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1 Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run2	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1 (UoB) 99- C2_TI_CTA_Fac_VR5m_TINXPIntDyn_Run2\002100990001 (MIRA) Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run2 (UoB) 99- C2_TI_CTA_Fac_VR5m_TINXPIntDyn_Run2\002100990001 (MIRA) 8- C2_TI_CTA_NFac_VR5m_TINXPInDyn_Run2\002100080001 (JLR)	RLG: time211115_1437 RBK: time211115_1453	
3c	**Cross Traffic Alert** **(With Facades)**	Static Victim, Static Interference.	TI AWR1243 and NXP Dolphin		Reference: C2_RLG_CTA_Fac_VR5m_TIInt0m_Ref_Run1_211118_1145.h5 C2_RLG_CTA_Fac_VR5m_TIInt5.4m_Ref_Run1_211118_1159.h5	Reference: C2_RBK_CTA_Fac_VR5m_TIInt0m_Ref_Run1_18-11-2021_11-45-57 C2_RBK_CTA_Fac_VR5m_TIInt5.4m_Ref_Run1_18-11-2021_11-59-06	Reference: C2_RLG_CTA_Fac_VR5m_TIInt0m_Ref_Run1 C2_RLG_CTA_Fac_VR5m_TIInt5.4m_Ref_Run1	Reference: C2_RLG_CTA_Fac_VR5m_TIInt0m_Ref_Run1 (UoB) 119- C2_RLG_CTA_Fac_VR5m_TIInt0m_Ref_Run1\000401190001 (MIRA) C2_RLG_CTA_Fac_VR5m_TIInt5.4m_Ref_Run1 (UoB) 125- C2_RLG_CTA_Fac_VR5m_TIInt5.4m_Ref_Run1\000401250001 (MIRA)	RLG: time211118_0938 RBK: timing211118_0939	

				• Facades around the road • Victim vehicle • Interferer vehicle	Interference: C2_RLG_CTA_Fac_VR5m_TINXPInt0m_Run1_211118_1152.h5 C2_RLG_CTA_Fac_VR5m_TINXPInt5.4m_Run1_211118_1204.h5	Interference: C2_RBK_CTA_Fac_VR5m_TINXPInt0m_Run1_18-11-2021_11-52-41 C2_RBK_CTA_Fac_VR5m_TINXPInt5.4m_Run1_18-11-2021_12-04-52	Interference: C2_RLG_CTA_Fac_VR5m_TINXPInt0m_Run1 C2_RLG_CTA_Fac_VR5m_TINXPInt5.4m_Run1	Interference: C2_RLG_CTA_Fac_VR5m_TINXPInt0m_Run1 (UoB) 123-C2_RLG_CTA_Fac_VR5m_TINXPInt0m_Run1\000401230001 (MIRA) C2_RLG_CTA_Fac_VR5m_TINXPInt5.4m_Run1 (UoB) 128-C2_RLG_CTA_Fac_VR5m_TINXPInt5.4m_Run1\000401280001 (MIRA)		1. Strength of interference received from front and corner interferer radars 2. Comparative analysis of interference received at front and corner victim radars. 3. Multipath analysis 4. Inerference from multipath 5. Appearance of ghost targets 6. Interference level in a reflective scenario 7. Effect of additional infrastructure on the radar return.
3d		Static Victim Dynamic Interferer	TI AWR1243 and NXP Dolphin		Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1_211118_1053.h5 Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1_211118_1101	Reference: C2_RBK_CTA_Fac_VR5m_TIIntDyn_Ref_Run1_18-11-2021_10-53-53 Interference: C2_RBK_CTA_Fac_VR5m_TINXPIntDyn_Run1_18-11-2021_11-01-44	Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1 Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1	Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1 (UoB) 103-C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1\000401030001 (MIRA) Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1 (UoB) 106-C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1\000401060001 (MIRA) 98-C2_TI_CTA_Fac_VR5m_TINXPIntDyn_Run1\002100980001 (JLR)	RLG: time211118_0938 RBK: timing211118_0939	
3e		Dynamic Victim Static Interferer	TI AWR1243 and NXP Dolphin		Reference: C2_RLG_CTA_Fac_VRDyn_TIInt2.5m_Ref_Run1_211118_1130.h5 Interference: C2_RLG_CTA_Fac_VRDyn_TINXPInt2.5m_Run1_211118_1136.h5	Reference: C2_RBK_CTA_Fac_VRDyn_TIInt2.5m_Ref_Run1_18-11-2021_11-30-27 Interference: C2_RBK_CTA_Fac_VRDyn_TINXPInt2.5m_Run1_18-11-2021_11-36-15	Reference: C2_RLG_CTA_Fac_VRDyn_TIInt2.5m_Ref_Run1 Interference: C2_RLG_CTA_Fac_VRDyn_TINXPInt2.5m_Run1	Reference: C2_RLG_CTA_Fac_VRDyn_TIInt2.5m_Ref_Run1 (UoB) 114-C2_RLG_CTA_Fac_VRDyn_TIInt2.5m_Ref_Run1\000401140001 (MIRA) Interference: C2_RLG_CTA_Fac_VRDyn_TINXPInt2.5m_Run1 (UoB) 115-C2_RLG_CTA_Fac_VRDyn_TIInt2.5m_Run1\000401150001 (MIRA)	RLG: time211118_0938 RBK: timing211118_0939	

* Notes:
For all the measurements corresponding to ACC use case, data from radarlog and radarbook is captured simultaneously. However, from different laptops.

S. No.	Use Case	Description	Interferer Sensors	Road Actors	Radar Data		Video	GPS/ IMU	Timestamp	Purpose
					Radarlog	Radarbook				
4a	**Blind Region Estimation**	Static Victim radar and dynamic interference. Interference driving along the straight road and crossing the victim vehicle	TI AWR1243 and NXP Dolphin	• Victim Radar/ Vehicle • Interferer Radar/ Vehicle	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1_211115_1532.h5 Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run1_211115_1535.h5	Reference: C2_RBK_CTA_NFac_VR5m_TINXPDyn_Ref_Run1_15-11-2021_15-32-10 Interference: C2_RBK_CTA_NFac_VR5m_TINXPDyn_Run1_15-11-2021_15-35-22	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1 Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run1	Reference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Ref_Run1 (UoB) Interference: C2_RLG_CTA_NFac_VR5m_TINXPIntDyn_Run1 (UoB)	RLG: time211115_1437 RBK: time211115_1453	1. Blind Region estimation due to the presence of reflectors in the radar signal path. 2. Identification of a possible target in the radar's blind field of view from received interference.
4b		Facades arranged in the form of a cross traffic alert scenario Static Victim radar and dynamic interference. Interference driving along the straight road and crossing the victim vehicle		• Facades around the road • Victim Radar/ Vehicle • Interferer Radar/ Vehicle	Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1_211118_1053.h5 Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1_211118_1101.h5	Reference: C2_RBK_CTA_Fac_VR5m_TIIntDyn_Ref_Run1_18-11-2021_10-53-53 Interference: C2_RBK_CTA_Fac_VR5m_TINXPIntDyn_Run1_18-11-2021_11-01-44	Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1 Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1	Reference: C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1 (UoB) 103- C2_RLG_CTA_Fac_VR5m_TIIntDyn_Ref_Run1\000401030001 (MIRA) Interference: C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1 (UoB) 106- C2_RLG_CTA_Fac_VR5m_TINXPIntDyn_Run1\000401060001 (MIRA)	RLG: time211118_0938 RBK: timing211118_0939	
5	**Beamfilling on Radar Signal Propagation**	Static interferer vehicle (radar) at 11 m from the static victim vehicle (radar). Pedestrian walking between the two vehicles	TI AWR1243	• Victim Radar/ Vehicle • Interferer Radar/ Vehicle • Pedestrian	C2_RLG_ACC_VR10m_TIInt_PedDyn_2_Run1_211118_1232.h5	NA	C2_RLG_ACC_TIInt_PedDyn_2_Run1.mp4	C2_RLG_ACC_TIInt_PedDyn_2_Run1 (UoB) 137- C2_RLG_ACC_TIInt_PedDyn_2_Run1\000401370001.txt (MIRA)	time211118_0938.dat	1. Beamfiling on the radar propagation due to the movement of pedestrian

N.B.

1) It is to be noted that in the case of corner radar (Radarbook), the video for ground truth is captured from the forward facing camera.

2) Victim vehicle velocity and GPS information from MIRA not available for 15th November, 2021.

4. Appendix

4.1 Data Structure

This section describes the structure of the data collected from the radars by the project team at the University of Birmingham. The structure of the important variables in this file are described within this section, with the variable name given in brackets.

NOTE: Only those variables used in the signal processing are described. There are other variables in the file that are used for checks during testing, but these are not used during processing and so will not be described here.

4.1.1 INRAS Radarlog

This sub-section gives the configuration of the Inras Radarlog, used to collect the data within the file. The parameters are stored as structure with the following fields. Most of the values are either calculated from the FMCW parameters described previous, or are set explicitly.

- fStart: Start frequency of the FMCW signal in Hz
- fStop: Stop frequency of the FMCW signal in Hz
- TrampUp: Ramp-up time of the FMCW signal in sec
- TrampDo: Ramp-down time of the FMCW signal in sec
- Tint: Frame interval time in secs
- Tp: Chirp interval time in sec
- N: Requested number of samples to be read per chirp
- TxSeq: TDMA ordering of Tx sequence in MIMO mode

Correct MIMO beamforming requires the application of calibration data in order to account for the fixed phase deviations which can be expected to occur due to the manufacturing variations. This calibration data is based on our measured data and is provided in the form of complex exponential which must be multiplied across the virtual phase array prior to beamforming (i.e. second matrix dimension).

Note that the raw data captured from radarlog is real and NOT complex.

4.1.2 INRAS Radarbook

This sub-section gives the configuration of the Inras Radarbook, used to collect the data within the file. The parameters are stored as a .mat files. Most of the values are either calculated from the FMCW parameters described previous, or are set explicitly.

Radarlog collected ADC Data (rawData): This is the raw (uncalibrated) ADC data collected from the radarbook stored as a matrix with the following dimensions.

- Dimension1 – Number of samples
- Dimension2 – Number of physical receive channels
- Dimension3 – Number of chirps

Note that this data is real and NOT complex.

- Read Sampling Frequency (fsRead): This is the actual sampling frequency as was used by the radarbook in the collection of rawData. It's unit is in Hz.
- FMCW Frequency Bandwidth (fBandwidth) The specified bandwidth of the FMCW chirp signal in Hz.
- FMCW Centre Frequency (fCentre) The specified centre frequency of the FMCW signal in Hz
- FMCW Ramp us time (tRampUp): The specified ramp-up time of the FMCW signal in secs
- FMCW Chirp interval time (tChirpInt): The specified time interval between chirps of the same MIMO frame in secs.
- FMCW MIMO frame interval time (tMIMOFrameInt): The specified time interval between MIMO frame in secs.
- Inras Calibration Data (CalData): This gives the calibration data this is read from the Inras Radarbook. It has the following size in MIMO mode.

  Array of 32 complex values for each of the virtual elements as follows:

  1 Tx1 to Rx1
  2 Tx1 to Rx2
  :
  8 Tx1 to Rx8
  9 Tx2 to Rx1
  10 Tx3 to Rx2
  :
  32 Tx4 to Rx8

Correct MIMO beamforming requires the application of calibration data in order to account for the fixed phase deviations which can be expected to occur due to the manufacturing variations. This calibration data is based on our measured data and is provided in the form of complex exponential which must be multiplied across the virtual phase array prior to beamforming (i.e. second matrix dimension, as described above).

4.1.3 Video

Video.mp4: Video file containing the left camera image from stereo camera

4.1.1 Timestamp

RLG_Time: Text file containing timestamp when each radarlog frame is received by the laptop (not entirely accurate due to latency)

RBK_Time: Text file containing timestamps when each radarbook frame is received by the laptop (i.e. not entirely accurate due to latency)

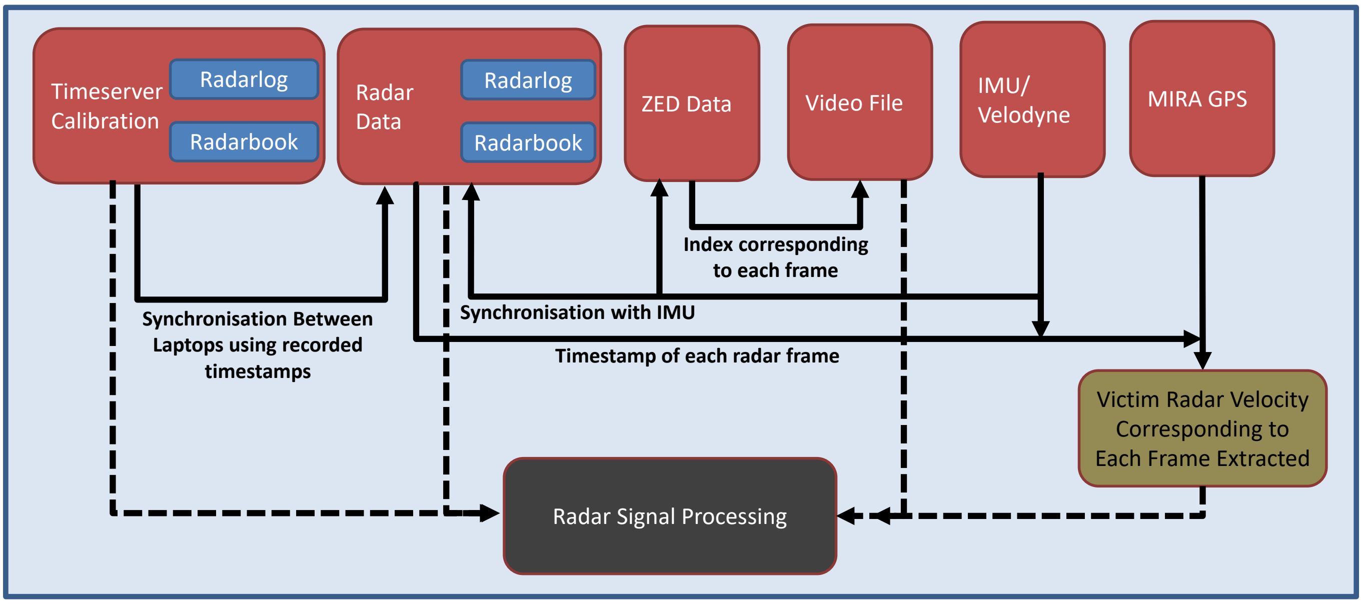
4.2 Signal Processing Steps

The basic signal processing steps involved in generating the post-processed results shown in the document are:

1) Reshaping the data according to correct frame structure (MIMO mode)
2) Perform real to complex FFT across the first dimension for range. Since only one half of the real DFT is redundant, it can be discarded
3) Perform complex to complex FFT across the third dimension for Doppler.
4) Apply phase calibration across the MIMO elements due to platform motion.
5) Perform calibration across the antenna elements
6) Perform complex to complex FFT across the second dimension for beamforming

4.3 Data Integration

The integration of data from all the sensors is performed in the following way:



4.4 Repository Folder Structure

Folder Structure	Description
COSMOS UOB Repository	Main Folder
01_Radar_Calibration	Use Case
02_Adaptive_Cruise_Control	Use Case
1_Without_Facades	Scenario variation per use case
Case_2a	Experiments performed for each scenario (From Table 5)
Interference	Condition of Radars: Interferer radar transmitting
GPS_IMU	GPS data
MIRA	GPS data from MIRA
UoB	GPS data from UoB
Radar	Radar raw data
Radarbook	Raw data from INRAS Radarbook
Radarlog	Raw data from INRAS Radarlog
TimeStamp	Timestamps captured from laptops operating the radar
Radarbook	Timestamps from the laptop operating radarbook
Radarlog	Timestamps from the laptop operating radarlog
Video	Video for ground truth
Reference	Condition of Radars: Interfer radar not transmitting
Case_2b	Cases from Table 5
Case_2c	
Case_2d	
Case_2e	
2_With_Facades	Scenario variation per use case
3_Facades_With_3D_Infrastructure	

4.5 MATLAB Sample Codes

Minimal MATLAB codes for signal processing are described below.

4.5.1 Reshaping Data for MIMO mode

In MIMO mode, chirps are transmitted by a single active transmitter at a time. The active transmitters cycles from chirp to chirp. Therefore, a simple additional processing step must be performed in order to reshape the matrix prior to the beamforming. If the number of available chirps is not divisible by the number of transmit elements, the remaining chirps should be discarded. For MIMO mode, it is useful to have data in matrix with following dimensions:

- Dimension 1: Number of Fast Time samples
- Dimension 2: Number of Virtual MIMO channels
- Dimension 3: Number of MIMO frames

To reshape the data into a MIMO format, the following MATLAB code sample is useful.

```
%N_Tx:      Number of Transmit Elements
%N_Rx:      Number of Receive Elements
%RawData:   Collected Raw Data from Radar
%N_Samples: Number of Fast Time Samples

N_Samples     = size(RawData,1);
N_MIMO_Frames = floor(size(RawData,3)/N_Tx);
Rx_Data       = zeros(N_Samples, N_Rx*N_Tx,N_MIMO_Frames);

% Reshape Data
  RawData = RawData(:,:,1:N_MIMO_Frames*N_Tx);
  for Idx_Frame = 1:N_MIMO_Frames
      Idx_Start              = Idx_Frame*N_Tx - N_Tx + 1;
      Idx_End                = Idx_Frame*N_Tx;
      Rx_Data(:,:,Idx_Frame) = reshape(RawData_MIMO(:,:,Idx_Start:Idx_End),N_Samples,N_Tx*N_Rx);
  end
```

4.5.2 Selecting $\lambda/2$ spaced Virtual Channels

The MIMO virtual channels formed by Inras Radarlog and radarbook have three overlapping channels. For beamforming by FFT, it is required to have all virtual channels that are $\lambda/2$ spaced with no overlaps. Therefore, only the set of channels are selected where there is no overlap, maintaining $\lambda/2$ spacing. This is done with the code sample below:

```
% Index of Virtual Channels
  Vir_Idx_Radarlog  = [1:15, 17:31, 33:47, 49:64];
  Vir_Idx_Radarbook = [1:7, 9:15, 17:23, 25:32];

% Reshaping Radar Data
  Rx_Data = Rx_Data(:,Vir_Idx_Radarlog,:); % For Radarlog
```

4.5.3 Reading .h5 file from Radarlog

The following lines of code can be used as a reference to read a single frame from Radarlog.

```
%N_FastSamples = Number of fast time samples
%NRead         = Number of chirps to read
%N_Rx          = Number of receive channels
%Filename_RLG  = Radarlog .h5 format filename
%NLoop         = Number of Chirps in 1 frame (4 for Radarlog)
%Frame         = Frame to read

RLGData = zeros(N_FastSamples, N_Rx, NRead);
for iCh = 1:N_Rx
    RLGData(:, iCh, :) = double(h5read(Filename_RLG, sprintf('/Chn%d', iCh), ...
                             [1,NLoop*(Frame - 1) + 1],[N_FastSamples,NRead]));
end
```

4.5.4 Radarlog Data Format/ Antenna Calibration

The Radarlog data/ parameters stored in H5 file are in an unsigned integer data type. Therefore, all data/ parameters needs to be converted into 'double' data type before processing.

```
Cal_Real      = typecast(h5readatt(Radarlog_File_Name, '/', 'CalRe'),'double');
% To read the real part of antenna calibration in double format
Cal_Imag      = typecast(h5readatt(Radarlog_File_Name, '/', 'CalIm'),'double');
% To read the imaginary part of antenna calibration in double format
Cal_Default   = complex(Cal_Real, Cal_Imag); % Calibration vector to be used
%typecast ensures that data is not changed when it is read in 'double' datatype.
```

It is to be noted that during the trials, Radarlog was operated in MIMO configuration. Therefore, calibration file contains 64 elements, corresponding to each virtual antenna element of the radar.

4.5.5 Data Synchronisation

The sample code to synchronise data from all the sensors is attached in the repository.