Project Closure Report

Feasibility study on radio frequency enabled 4D imaging for in-vehicle occupancy/ human detection (IVOD)

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Contents

1. Company Request

The company is interested to engage the consultant to design and study the **feasibility** of using a radio frequency (RF) based system-on-chip (SOC) development kit to detect in-vehicle occupancy detection (IVOD) of human obscured from view.

2. Project Scope

The scope of work is as follows:

2.1 Acquire Vayyar system-on-chip (SOC) development kit or similar technology.

2.2 Design indoor and outdoor housing unit suitable for local environment.

2.3 Conduct sensitivity test between objects, humans and other interference in an indoor controlled environment.

2.4 Conduct sensitivity test between objects, humans and other interference in a controlled outdoor environment.

2.5 Live trial at vehicular gateway into NP - Conduct sensitivity test between objects, humans and other interference in an uncontrolled outdoor environment.

2.5 Evaluate feasibility for use in local environment.

3. Project Deliverables

3.1 Complete purchase of Vayyar SOC or similar technology.

3.2 Establish test protocol(s) for using the SOC to detect objects in unimpeded environment. (collaborate with client's expertise)

3.3 Complete acquiring data output from SOC of different objects (less than 10 common objects).

3.4 Complete prototyping of indoor and outdoor housing for downstream indoor and outdoor testing.

3.5 Complete counting of objects on a screen onsite. (collaborate with client's expertise)

3.6 Complete classification of objects onsite. (collaborate with client's expertise)

3.7 Complete live visualisation of objects on a screen onsite. (collaborate with client's expertise)

3.8 Complete sensitivity testing and fine-tuning the detection algorithm in a controlled indoor environment with impediment such as wall and metal interference to target for 95% accuracy.

3.9 Complete sensitivity testing and fine-tune the detection algorithm in a controlled outdoor environment with impediment such as wall and metal interference to target for 90% accuracy.

3.10 Complete sensitivity test between objects, humans and other interference in an uncontrolled outdoor environment in a live trial to target 80% accuracy.

3.11 Complete evaluate feasibility for use in local environment.

4. Project Schedule and Completion

The schedule of works was completed as follows:

No.	Deliverables	Completed on	Accepted by Toppan
1	3.1	-	Yes
2	3.2	-	Yes
3	3.3	-	Yes
4	3.4	Demo #01 on 7 Sept 2021	Yes
5	3.5	-	Yes
6	3.6	-	Yes
7	3.7	Demo #02 on 2 Nov 2021	Yes
8	3.8	-	Yes
9	3.9	Demo #03 on 18 Jan 2022	Yes
10	3.10	Not required	N.A.
11	3.11	Not required	N.A
12	Project closing	To be completed by 30 Oct 2022	Yes

Table 4.1 – Deliverable completion

No.	Deliverables	Completed on	Accepted by Toppan
1	Design of Test Matrix for AI	Feb 2022	Yes
2	Development of AI model for testing part 1	Aug 2022	Yes (by 2 Interns)
3	Development of AI model for testing part 2	Mar 2023	In Progress (by 2 Interns)

Table 4.2 – Additional collaborative work

5. Project expenses for the project

The total consultancy fee for this project is **S$69,550** (included GST of S$4,550).

As deliverables 3.10 and 3.11 were not required, $20,000 was waived.

Deliverables 3.1 to 3.9 has been completed and paid. See table 5.1

The breakdown of the material budget and expenses for material is summarized as follows:

A material budget of **$5917 (with GST)** was set aside for material cost.

The total expenses for material was **$2057.97 (with GST)**. See Table 5.3.
The remaining material budget at the end of the project was **$3859.13 (with GST).** See Table 5.4

The cost of project closing is **$4000 (without GST)/ $4280 (with GST**). After subtracting the cost of project closing and the remaining material budget, the final bill is **$420.87(with GST).** See Table 5.4.

No.	**Deliverables**	**Payable S$ (before GST)**	**Remarks**
1	On signing of consulting agreement	1000	Completed, Payment received
2	3.1		Completed
3	3.2	5,000	Completed, Payment received
4	3.3		Completed
5	3.4	10,000	Completed, Payment received
6	3.5		Completed
7	3.6	10,000	Completed, Payment received
8	3.7		Completed
9	3.8		Completed
10	3.9	15,000	Completed, Payment received
11	3.10		Not required
12	3.11	20,000	Not required, Payment waived
13	Project closing	4,000	On receipt of project report
	Total	65,000	

Table 5.1 – Deliverables completion status

No.	**Items Purchased**	**Payable S$ (with GST)**	**Remarks**
1	Mini-circuit 40 antenna radar	3927.51	Paid directly by Toppan LF

Table 5.2 – Direct expenditure by Toppan LF

No.	**Items Purchased**	**Payable S$ (with GST)**	**Remarks**
1	uRAD 60 GHz radar (1 unit)	608.95	Deducted from Budget
2	uRAD 24 GHz (1 unit) and 66 GHz radar (1 unit)	849.02	Deducted from Budget
3	Accessories - cables, PCB, boxes, 3D filaments)	600.00	Deducted from Budget
		2057.97	

Table 5.3 – Direct expenditures by NP (to be deducted from material budget)

No.	Items	Cost S$ (with GST)
1	Material Budget	5917.10
2	Expenses for material	(2057.97)
3	Remaining material budget at the end of project	**3859.13**

No.	Items	Cost S$ (with GST)
4	Project closing & Final report	4280.00
5	Remaining material budget at the end of project	(3859.13)
6	**Final bill**	**420.87**

Table 5.4 – Final bill (to be deducted from Material budget)

6. Material Transfer

The following set of radars have been collected by Toppan LF via Mr Cassidy Goh.

No.	Items transferred	Date of receipt
1	Mini-circuit 40 antenna radar (1 unit)	5 October 2022
2	uRAD 60 GHz radar (2 units)	2 September 2022
3	uRAD 24 GHz (1 unit)	2 September 2022

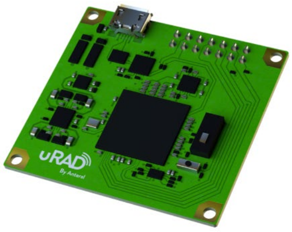
Table 6.1 – List of material transfer

7. Methods and Materials

7.1 Deliverables 3.1,3.2, 3.3, 3.4

A 60GHz mmWave radar was purchased from uRAD (Spain) from www.uRAD.es.

The product specifications and cost are as follows. The datasheet is available at https://uRAD.es/wp-content/descargables/uRAD%20-%20Datasheet%20-%20Industrial%20v2.0%20-%20EN.pdf



uRAD Industrial

FROM: 225,00€ tax for EU not incl.

Main features:

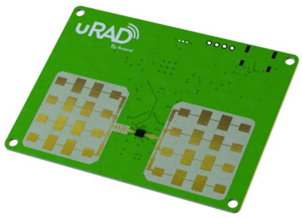
- 60 - 64 GHz regulated frequency band for industry
- Velocity and 3D positioning of multiple targets
- Ultrawide field of view of 160 x 160 deg
- Superior detection accuracy
- USB, serial port and Raspberry Pi adaptor

Our product includes:

- uRAD Hardware
- User Manual
- Graphical User Interface
- Example of use in Python

A 24GHz radar was purchased from uRAD (Spain)

The product specifications and cost are as follows. The datasheet is available at https://uRAD.es/wp-content/descargables/uRAD%20-%20Datasheet%20-%20USB%20v1.2%20-%20EN.pdf



uRAD USB

FROM: 199,00€ tax for EU not incl.

Main features:

- Free emission 24 GHz frequency band
- Ideal for frontal detection (FoV 30x30 deg)
- Velocity, 1D distance and presence
- Raw signal data

Our product includes:

- uRAD Hardware
- User Manual
- Graphical User Interface
- Python Libraries
- Examples of use
- Android Application for mobile phones

Deliverables 3.2 established test protocols to evaluate the mmWave radar for the ability to discern humans from inanimate objects.

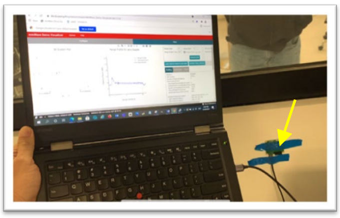
Test protocol (using the demo visualizer in an open environment)

- Adjust range to between 0.4 to 1m for unobstructed detection
- Adjust Field of view (Elevation and Azimuth) to 15 degrees
- Adjust velocity to 1m/s
- Turn on clutter reduction algorithm to reduce noise from static object but it uses more power
- The radar must be placed on stable surface
- The radar was placed directly on the object or directed towards the object.
- A subject sat behind the object to be detected and counted.

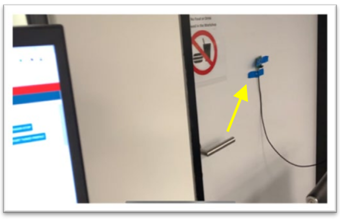
Deliverables 3.3 determined responses of 12 common objects.

12 common objects were tested and checked for response to radio wave

- Plastic chair (Ikea) with 0.5cm thickness, opaque, no perforation
- 80GSM single sheet A4 size paper
- Car fabric Cushion pillow (15 cm thick with polyester fillings)
- 1cm tempered glass
- Water barrier via water bottle
- Clothing (t-shirt, school uniform, thick jacket, jeans)
- Ceiling fan (radar was directed toward the fan)
- Human
- Wooden table (Ikea, chipboard)
- Car window
- Partition board
- Wooden door (10cm thickness)



Partition board



Wooden door

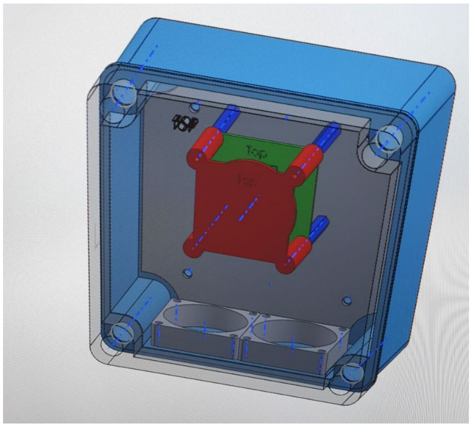
Glass

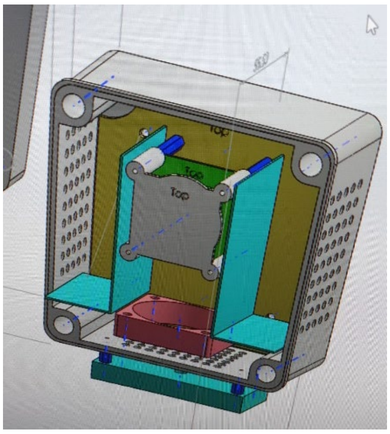
Yellow arrows depict placement of radar

Deliverables 3.4 creates an enclosure to improve the deployment capability, to protect the radar from overheating damage and from light splash conditions.

Design features

- Fan to cool the radar Battery
- Housing for fan
- Sunshade
- Splash proof box
- Ease of mounting on any camera tripod with universal screw-in attachment



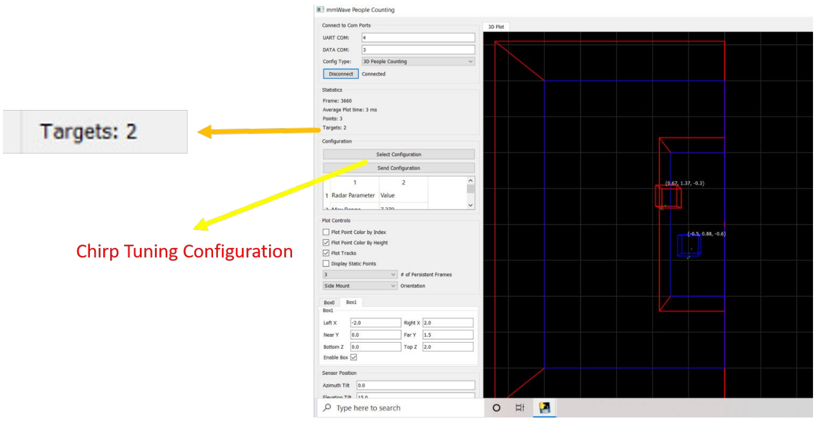


7.2 Deliverables 3.5, 3.6 and 3.7

Radar setup to determine occupant in an open room and to determine minimal distance between 2 subjects.

2 human subjects were positioned side by side to determine the sensitivity and counting capability of the radar. This shows a unobstructed set up in an empty room.

Design of Radar software configuration

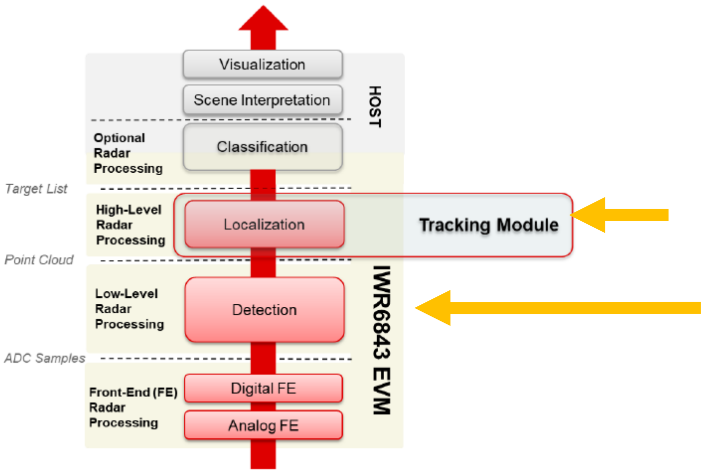


Initial test setup for detecting occupant inside a car (Mercedes Benz S350L)

Test protocol

- Two subjects sat 1m, 0.8m, 0.6m, 0.4, 0.2, 0.0m apart un-obstructed
- Adjust range to 0.4m to 8m for obstructed detection in the software configuration.
- Adjust Field of view (Elevation and Azimuth) to 15 degrees
- Adjust detection velocity between 10m/s to 0.07m/s.
- Turn on clutter reduction algorithm to reduce noise from static object.
- The radar was loaded with the chirp tuning configuration shown below.
- The radar was placed on stable surface.

Tuning the radar for accuracy in detecting subjects



2nd Tracking/ counting Tuning
E.g. velocity of movement, size of point clouds

1st Detection Tuning
E.g. field of view, range, physical radar setup

The radar (consisting of Texus Instrument IWR6843 EVM core radar component) is tuned to optimised to detect and count occupants by tuning the detection and tracking/ counting parameters in the chirp tuning configuration file. The detection layer produces a point cloud output and is used by the tracking/ counting layer to produce the visualisation of occupants counted.

1St detection and 2nd tracking tuning with the sample chirp tuning configuration file (affect sensitivity of detection)

```
frameCfg 0 2  96  0 55.00 1 0
dynamicRACfarCfg -1 4 4 2 2 8 12 4 8 5.00 8.00 0.40 1 1
staticRACfarCfg -1 6 2 2 2 8 8 6 4 8.00 15.00 0.30 0 0
dynamicRangeAngleCfg -1 0.75 0.0010 1 0
dynamic2DAngleCfg -1 1.5 0.0300 1 0 1 0.30 0.85 8.00
staticRangeAngleCfg -1 0 8 8
antGeometry0 -1 -1 0 0 -3 -3 -2 -2 -1 -1 0 0
antGeometry1 -1 0 -1 0 -3 -2 -3 -2 -3 -2 -3 -2
antPhaseRot 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1
fovCfg -1 70.0 20.0
compRangeBiasAndRxChanPhase 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0

% Tracker Layer Parameters
% See the Tracking Layer Tuning Guide for more information
% "C:\ti\mmwave_industrial_toolbox_[VER]\labs\people_counting\docs\3D_people_counti
boundaryBox -4 4 0 5 0 2.5
staticBoundaryBox -2 2 0.5 2 0 2
presenceBoundaryBox -2 2 0.5 2 0 2
#leftX, rightX, NearY, FarY, BottomZ, TopZ Realworld coordinates
sensorPosition 1.6 0 15
gatingParam 3 1.1 1.1 1.1 2
stateParam 2 3 25 500 5 500
allocationParam 40 100 0.01 20 0.1 5
maxAcceleration 0.1 0.1 0.1
trackingCfg 1 2 800 3 37 46 96 55
sensorStart
```

1st Detection layer tuning

2nd Tracking/ counting layer tuning

Optimised chirp tuning configuration (with balance detection and counting sensitivity)

```
sensorStop
flushCfg
dfeDataOutputMode 1
channelCfg 15 7 0
adcCfg 2 1
adcbufCfg -1 0 1 1 1
lowPower 0 0

%Detection Layer Parameters
profileCfg 0 60.75 30.00 25.00 59.10 394758 0 54.71 1   96 2950.00 2 1 36
chirpCfg 0 0 0 0 0 0 0 1
chirpCfg 1 1 0 0 0 0 0 2
chirpCfg 2 2 0 0 0 0 0 4

%chirpStartIdx, chirpEndIdx, numLoops, numFrames, framePeriodicity,
triggerSelect, frameTriggerDelay
frameCfg 0 2  96  0 55.00 1 0

%do not change this configuration
dynamicRACfarCfg -1 4 4 2 2 8 12 4 8 5.00 8.00 0.40 1 1
staticRACfarCfg -1 6 2 2 2 8 8 6 4 8.00 15.00 0.30 0 0
dynamicRangeAngleCfg -1 0.75 0.0010 1 0
dynamic2DAngleCfg -1 1.5 0.0300 1 0 1 0.30 0.85 8.00
staticRangeAngleCfg -1 0 8 8
antGeometry0 -1 -1 0 0 -3 -3 -2 -2 -1 -1 0 0
antGeometry1 -1 0 -1 0 -3 -2 -3 -2 -3 -2 -3 -2
antPhaseRot 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1

%subFrameIdx, azimuthFoV, elevationFoV
fovCfg -1 50.0 20.0

compRangeBiasAndRxChanPhase 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0

% Tracker Layer Parameters
% LEFT X, RIGHT X, NEAR Y, FAR Y, BOTTOM Z, TOP Z
staticBoundaryBox -2 2 1 3.5 -2 2

% LEFT X, RIGHT X, NEAR Y, FAR Y, BOTTOM Z, TOP Z
boundaryBox -2 2 0.8 3.5 -2 2

% x, y, WIDTH, HEIGHT
cubicleOneBox 0 2 1 1.5
cubicleTwoBox 1 2 1 1.5

% HEIGHT, AZIMUTH TILT, ELEVATION TILT
%chirp_config/config.cfg --> sensorPosition 1.65 0 12
sensorPosition 1.2 0 0
gatingParam 3 1 1 2 4
%gatingParam 3 1 1 1 4
```

stateParam 3 3 6 200 5 1000
allocationParam 40 200 0.1 12 0.5 20
maxAcceleration 0.1 0.1 0.1
trackingCfg 1 2 500 2 46 96 55
presenceBoundaryBox -4 4 0.5 6 0 3
sensorStart

7.3 Deliverables 3.8 and 3.9

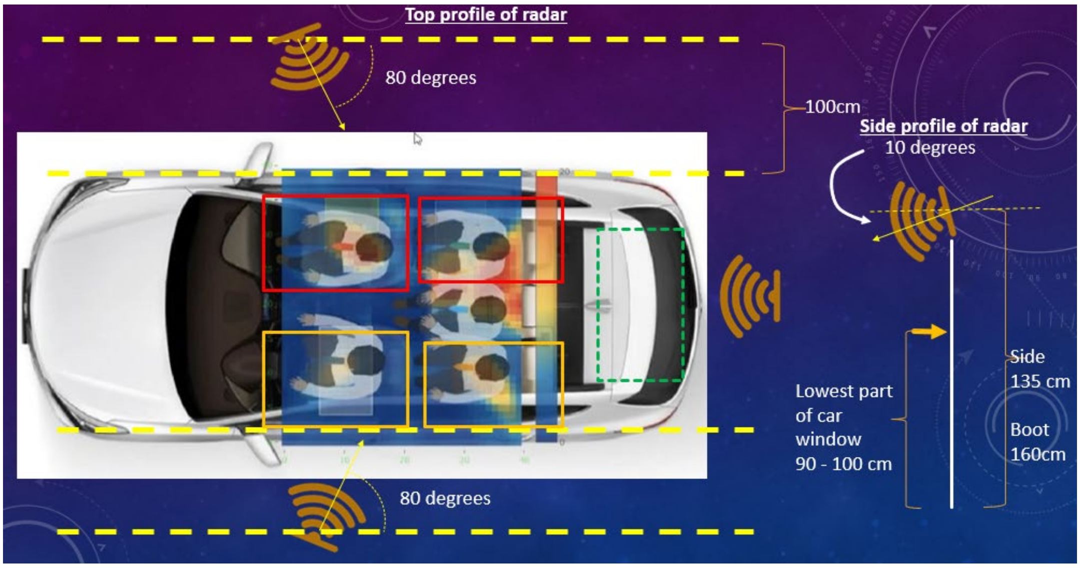
Indoor Test condition

- IT01 1 x Barebone mock car seat setup using plastic chairs
- IT02 1 x Radar was set up 1m on one side of car (Hyundai IoniQ 1.5L)
- IT03 1 x Radar was set up 0.5m from the car boot
- IT04 2 x Radar was set up 1m on one side of the car (2 radar on 1 side)
- IT05 1 x Radar was set up 1 m on each of the car (1 radar on each side)

Outdoor Test condition

- OT01 1 x Radar was set up 1m on one side of car (Nissan Note)

Basic setup of radar position in an indoor/ outdoor environment



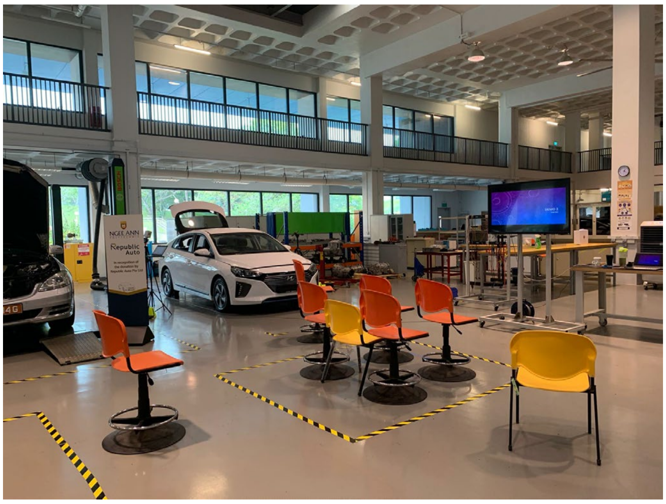
Test protocol

- One of two subjects sat in the barebone mock car seat setup unobstructed.
- One of two subjects sat in the car with windows up or windows down.
- One subject lies inside the car booth with boot lid up or down.
- Turn on clutter reduction algorithm to reduce noise from static object.
- The radar was loaded with the chirp tuning configuration as per deliverable 3.7.
- The radar was placed on stable surface.
- Each presence detection set is be completed and scored once every 5 min.
- 1 or 2 subjects enter the car and sit on designated seat.
- Upon subject being seated, wait for 10 sec for ghost (if any) from earlier

entry track.
- The test subject is to remain as still as possible with normal breathing.
- Repeat 10 sets of presence detection

To score as failed or successful detection
- If radar detects subject(s) for at least 5 sec, this is counted as 1 successful detection.
- If radar detects subject(s) for less 5 sec, this is counted as 1 failed detection.
- If radar detects ghosting or nothing, this is counted as 1 failed detection.

IT01 - Barebone mock car seat setup using plastic chairs

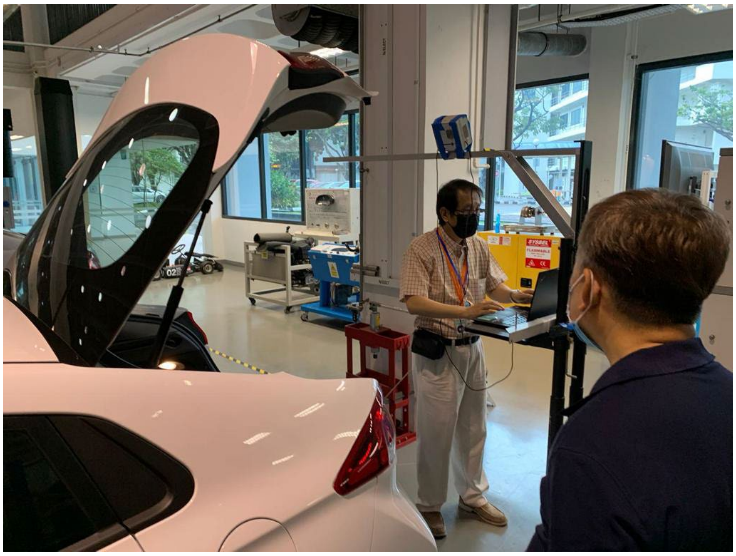


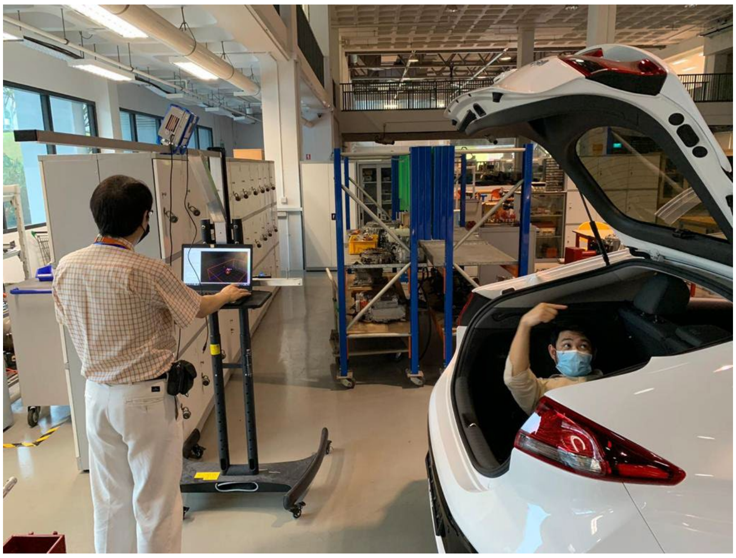
IT02 - 1 sided 1 radar setup

Perspective from the driver seat

IT03 - Car boot/trunk radar detection

- Objective(s): To determine detection accuracy with/ without boot/trunk lid.



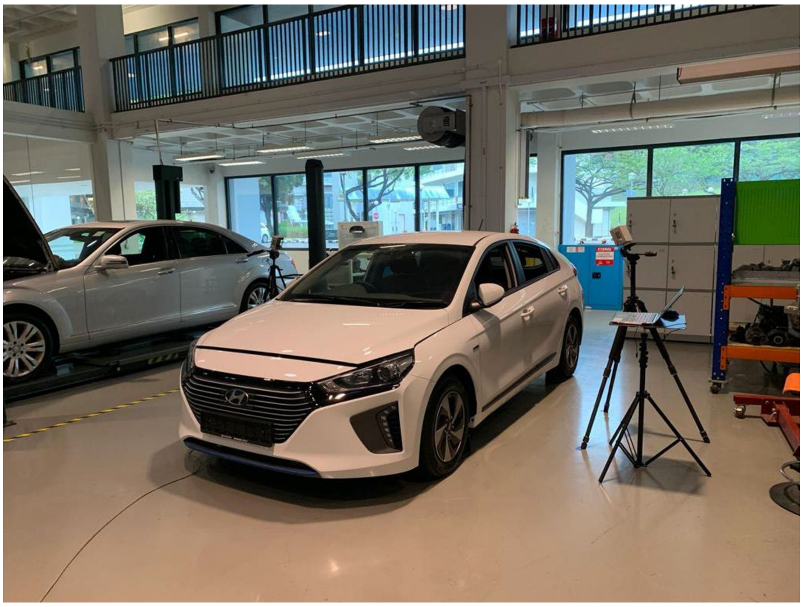


IT04 - 2 radar on 1 side setup

- Objective(s): To determine cross interference and accuracy

IT05 - 2 sided 1 radar on each side setup

- Objective(s): To determine cross interference and accuracy



OT01 - Outdoor testing with 1 radar on 1 side

- Objective(s): To check for interference from engine block, vibration and to determine challenges encounter for parking

8. Results

Deliverable 3.1

- One 24GHz radar and one 60GHz radar were purchased for testing. These were purchased from uRAD (Spain).

Deliverable 3.2

- Various test protocols were completed.

Deliverable 3.3

- Materials such as plastic, fabric, gypsum partition wall, wood, cotton does not interfere with detection.

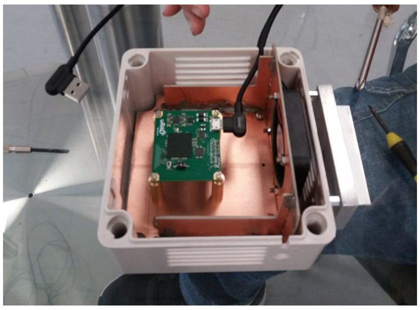
No	Object	Detected subject behind object	Remarks
1	Plastic chair (Ikea) with 0.5cm thickness, opaque, no perforation	Yes	
2	80GSM single sheet A4 size paper	Yes	
3	Car fabric Cushion (15 cm thick with polyester fillings)	Yes	
4	Water barrier via water bottle	No	
5	Clothing (t-shirt, school uniform, thick jacket, jeans)	Yes	
6	Metal Ceiling fan		
7	Human	No	
8	Wooden table (Ikea, chipboard)	Yes	
9	Car window	Yes	Non-reflective solar film
10	Partition board	Yes	
11	Wooden door (10cm)	Yes	

No	Object	Detected	Remarks
12	Metal Ceiling fan	Yes	Fan was spinning; to determine velocity of a metallic object affects detection

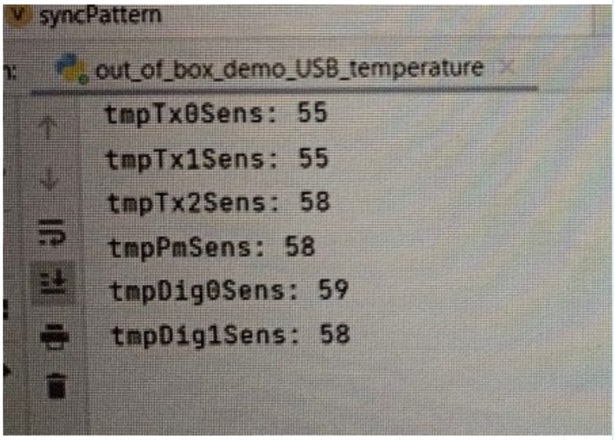
Deliverable 3.4

- The radar was fitted to a square PVC enclosure with an in-built fan, vents, attachment for mobile deployment. The radar can be mounted on any camera tripods with screw size standard of 1/4-20 UNC thread.





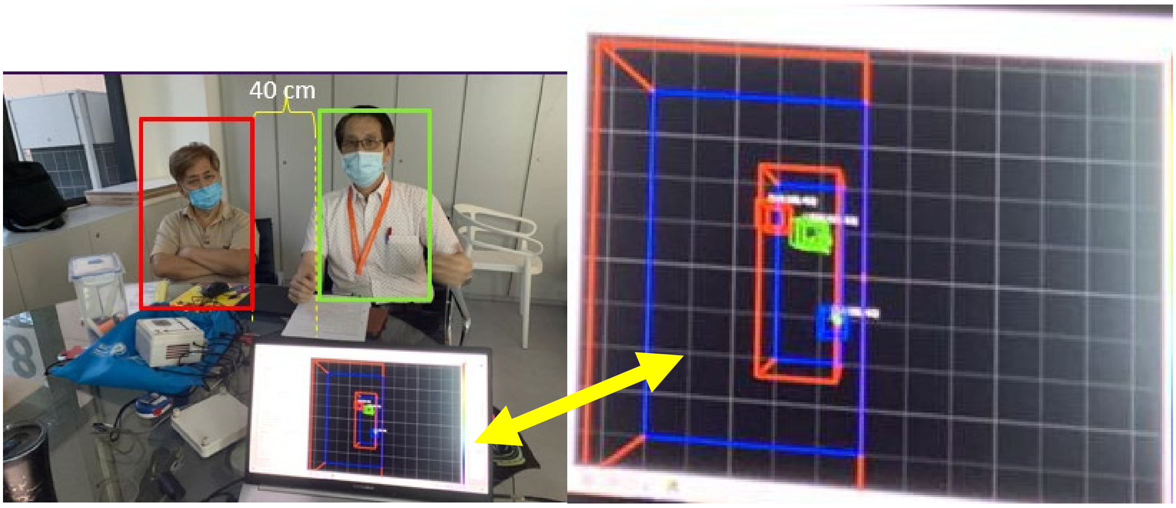
- The radar temperature was at 59 °C at a shaded ambience temperature of 30 °C shown below.



- The radar temperature was reduced by 10 – 12°C at the shaded ambience temperature of 30°C . (from 58 °C to 48 °C) in a 12 hour stress test setup.

Deliverable 3.5 and 3.6

- Radar is most accurate in open spaces (classroom, meeting room).
- Small gestures such as finger typing on keyboard, turning of head, leg movement, minor breathing movement can be detected and counted.
- Higher detection velocity at 10m/s increase sensitivity; lowest of 0.07m is achieved for lowest sensitivity.
- When sensitivity of the radar is tuned up, ghost/ artefacts may appear causing false positive and produced an increase in the number of occupants counted.
- When sensitivity of the radar is tuned down, subjects are not counted producing false negative and produced a decrease in the number of occupant counted.
- Radar can be easily concealed.
- Heat signature from the radar is between 45 degrees Celsius to 60 degrees Celsius.
- Minimal power requirements - DC 5V, 1A power source.
- Radar station is highly mobile and easily deployed within 15 – 30 min.
- Radar can detect, distinguish and count when the subjects are at least 40cm apart 100% of the time.
- If the subjects are closer than 40cm, the radar will count both subject as one.



- For the 24GHz radar, the unit was able to detect vital signs such as breathing and heart beat when placed in front of an individual. It can be used together with 60GHz to enhance detection.

Deliverable 3.7

- 2 Occupants who sat adjacent to each other were count as one.
- Detection of occupants who remains static reduced accuracy.

Deliverable 3.8

- When occupant stopped moving, radar was able to count correctly 80% of the time.
- Reflections from glass can create false positives , leading to increase number of occupants.
- Accuracy of detecting and counting occupants of the radar was 80% based on the 2 tuned chirp config was loaded to demonstrate the sensitivity of the uRAD radar (one being more sensitive and one being less sensitive)
- Different occupants appeared to reflect the radio wave very differently.
- The structure and pillar of a car poses a challenge to good detection and counting
- Due to the presence of obstruction and shielding in the car, the tuned chirp config is either too

sensitive (results in ghosting/ false positives) or not sensitive enough.

Deliverable 3.9

- Accuracy of detecting and counting occupants was 80% based on the 1 tuned chirp config was loaded to demonstrate the sensitivity of the uRAD radar (one being more sensitive and one being less sensitive)
- Individuals were detected and counted in the outdoor test environment. The car needs to park accurately in the detection zone for the radar to optimally detect the occupants.

9. Discussion

Radar from uRAD proved to be useful for detecting humans over many objects except for metal, concrete, glass and reflective UV solar film.

To detect human effectively, the subject of interest needs to maintain micro movement such as moving their hand, turning their head and deep chest breathing. Blinking of the eye and mouth gestures can be detected by the radar in an open and unobstructed space.

Using the uRAD radar, it cannot detect person that are sitting shoulder to shoulder. There need to be at least 40cm separation between the shoulder. However, mini-circuit radar specification (minimum angle resolution) appears to have the ability to alleviate this problem. For e.g., uRAD radar states a maximum azimuthal angle resolution of 30 degrees while mini-circuit radar states a maximum azimuthal angle resolution (max. angular resolution) of 6.7 degrees.

Several radars will be needed to count and confirm the presence of people in the vehicle. Two transmitting and receiving radars placed side by side or opposite each other do not affect the detection of people.

Key points to note

- Metal, concrete and glass are hindrance to accurate detection
- Current uRAD radar has problem detecting human sitting close together (within 40cm proximity)
- Spatial placement of radar must be very precise to detect humans accurately
- Lack of movement and gesturing from human subjects reduce the radar effectiveness

There are challenges when the occupants are sitting in the car and interference from the metallic component (such as doors) and glass windows with reflective UV/ solar films are present. Therefore, windows and metallic structures such as in the car front, side and rear pillars can interfere with radio wave.

The radar needs to be placed strategically to detect a person that may be obstructed by another person ahead or adjacent to the person in an open or unobstructed space.

Occupants can also block or interfere with radio waves within the car. For e.g., 2 occupants sitting too close together may be counted as 1 occupant. An occupant sitting near the window may block the other occupant sitting adjacent to him. Therefore, the radar must be carefully positioned so that this situation never occurs. To solve this problem, multiple radars should be used so that occupants cannot intentionally or unintentionally obstruct the line of transmission of radio waves.

Future work should consider whether the radar can detect a person, living object of smaller build (e.g. a child, dog).

We have determined that mmWave radars alone will not be able to meet deliverable 3.8 and 3.9 (to detect and count accurately up to 90% of the time, As such we proposed that the radar be augmented by artificial intelligence to determine the probabilistic presence based on the movement detection, size of the point clouds based on known human figurine dimension and additional sensors (such as infra-red, image recognition) collected from the spaces within the car.

10. Conclusion

The project set out to determine how mmWave interacts with different materials in the local environment. Materials such as glass while permissible for mmWave radio frequency to pass through can create problems for detection. Automotive glass with heat reduction film/ solar film with metallic components (continental cars such as the Mercedes-Benz S350L may use reflective solar films) proved to be most problematic. Side windows should be wound down for the radio waves to fully interact with occupants within the car. Other non-metallic materials such as plastic, cotton, leather, gypsum, fabric, thin piece of wood does not interfere with radio wave penetration.

The advantage of using mmWave radar is the ability to detect an occupant who consistently displays micro movements. Such movement can be breathing, blinking of the eyes, turning of heads, finger movement and facial expression. Therefore, there needs to be a mean to encourage the driver and passengers in the car to wave in the direction of the radar.

The radar is best used with a fan to circulate air and cooled continuously. The radar is designed performs between -20 to +85 ºC. An enclosure to house the radar has been designed and produced to maintain the operating temperature below 85 ºC in a shaded area with maximum ambient temperature of 30 ºC.

The radar housed in the enclosure has been proven to be easily deployed with any non-proprietary camera tripod. The cooling fan can be powered using a 10000 mAh powerbank that runs for up to 3 hours. The radar can be connected to a laptop for power and the application for detection and counting. The physical footprint is 1.5m (L) x 0.6m (B) for deployment setup. It requires 2 tripod, 1 laptop (or microcontroller – Raspberry Pi 4) and a laptop tray. The radar is mounted on 1 tripod and the laptop is positioned on the tray on the second tripod. To reduce the physical footprint from 1.5m to 0.8m, the laptop tray can be mounted in a single tripod. The footprint will be 0.8m (L) x 0.6m (B)

The radar should be positioned around the vehicle of interest for best transmission. For e.g., the radar can be positioned about 1m away from the passenger or driver seat. Multiple radars can be used together with no observable degradation in the detection. However, windows should be wound down to receive direct radar wave. Do not place radar at the front of the car or behind the car as the windscreens of the car cannot be removed or wound down for the radio wave to reach the occupants.

To detect occupants in the car boot, trunk or at the third row of the car (MPV type of car), the boot lid or tailgate door must be lifted.

The radar position around the car should be optimised to send radio wave towards the occupants that may be blocked by another occupant along the line of transmission.

The tilt angle of the radar should be adjusted so that radio wave can be directed inside of the car. The radar was tilted 15 degrees for optimum detection but angles between 10 to 20 degrees (in research literatures) can be explored to improve getting the radio wave reaching multiple occupants along the line of transmission.

MmWave radar system with more antennae (Mini-circuit radar with 40 antennae) can be used to detect occupants that are sitting too close to each other.

Combustion engine and hybrid engine (electric/ combustion) of a car does not interfere with occupant detection. Detection of occupants within a fully electric vehicle need to be tested.

Lastly, there appears to be a challenge with directing the driver to position their car to meet the most optimal position in the outdoor setting. The car may be driven further away from the radar or too close to the radar. The car my also be too positioned ahead or way behind the radar position. This can cause delays in detection and counting the occupants. The user must determine a way to direct the driver or move the car to a specific position for rapid count of the occupants in a real world setting. Detecting occupants hidden in the car boot/ trunk, floor of the first or second and third row of the car remains a challenge. The car boot/ trunk lid must be lifted for the radar to determine occupants hidden in the boot/ trunk.

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