

PhD Project - 1st Year

Privacy-Preserving and Scalable Occupant Tracking in Indoor Environments

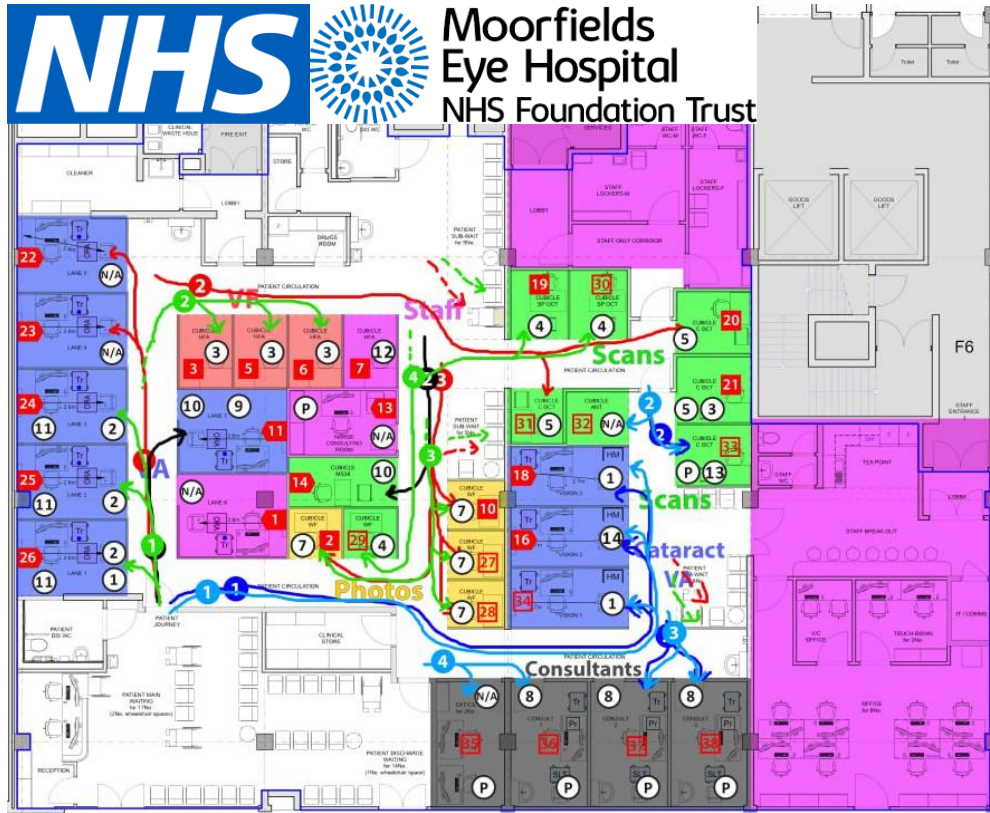
Yaman Rawas Kalaji

Supervised by:
Prof. Richard Mortier

Why occupant tracking?

- **Building optimisation & energy reduction**
(manual → reactive → predictive)
- **Shopper behaviour analysis and queue management.**
- **Patient flow optimisation in healthcare facilities**





● Cataract-post ● Cataract-pre ● Glaucoma ● Retina ● Kerataconus

Patient journeys by cases [3]

[3] <https://connected-environments.org/projects/hercules/>

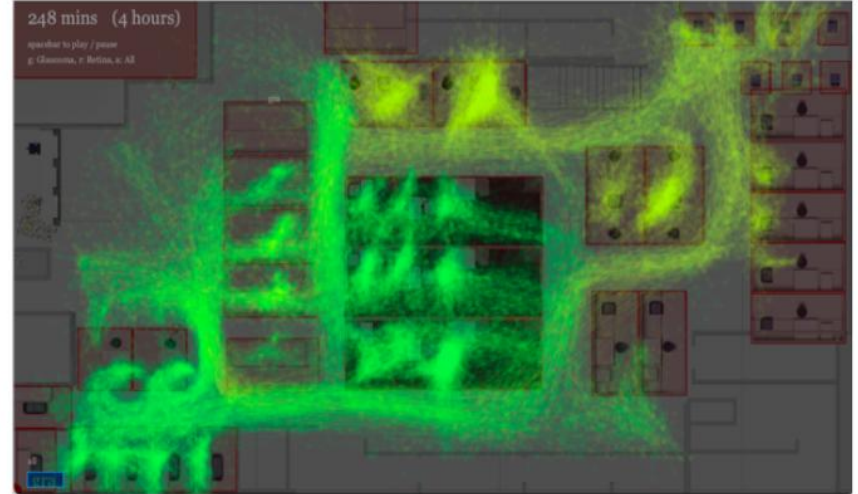


Diagnosis cubicles [3]



Ubisense Tracking tags [3]

(Ultra Wideband)

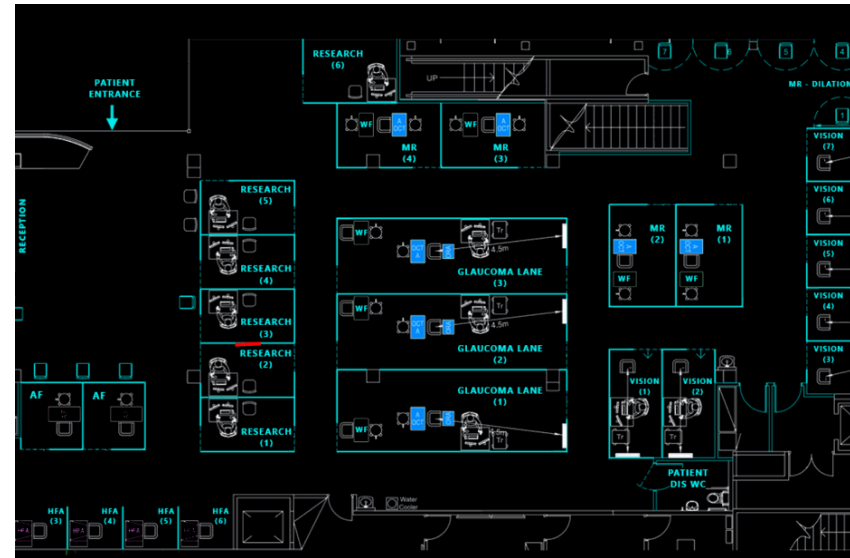


Spatiotemporal data of patient journeys [3]
(involving 4000 patients and 4 clinic layouts iterations)

Result: Recommended enhancements of clinic layout and process, resulting in a 9-minute decrease in mean patient visit length [3]



Collective patient journey



Single patient journey

(Journey visualisation platform – Opensource [4])

Handing tracking tags to patients...
Guess the acceptance percentage?

- Privacy concerns: **Only 50%** of patients accepted carrying a tracking tag
- Not a repeatable process, **hard to deploy** and **scale**

The research question

How to design an occupant tracking system that delivers spatiotemporal data while being:

- (1) Privacy preserving**
- (2) Scalable**
- (3) Easy to deploy**

Methodology

- Why mmWave Radar-Camera fusion?

Radar:

- High-privacy areas
- All lighting conditions
- Localisation (depth)

Camera:

- Low-privacy areas
- Better visual features
- Longer range

Best of two worlds!

- Why Private 5G (DECT NR+ 1.9 GHz)?

- **No interference**
- High theoretical node density (**1 million/km²**)
- **Longer range** than 2.4 GHz (Wi-Fi, Thread, Zigbee..)
- **Higher throughput** than 868 MHz (LoRa), **no duty cycle**

**DECT NR+
Sweet spot!**

Fisheye cameras

- 180° Field of View (FoV)
- Maximum coverage with lowest occlusion
- Best for ceiling setup
- High distorted edges



Fisheye cameras

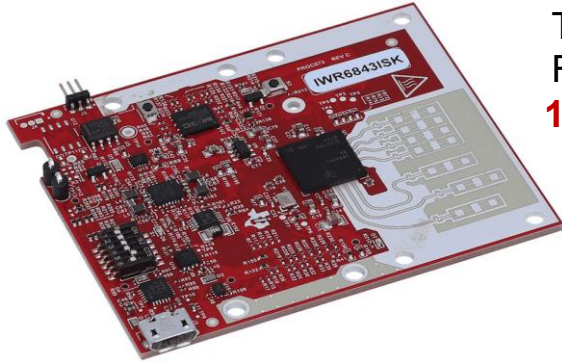


75° FoV



180° FoV

Indoor mmWave radars (60 GHz)

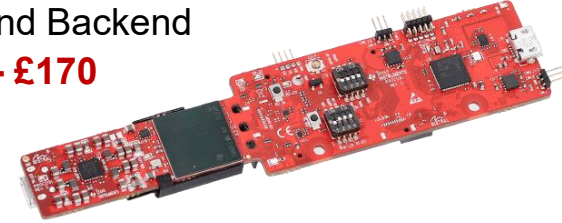


Texas Instruments IWR6843
Frontend and Backend
120° FoV – £230



Infineon BGT60TR13C
Only Frontend
120° FoV – £200

Texas Instruments IWR6843AOPEVM
Frontend and Backend
120° FoV – £170

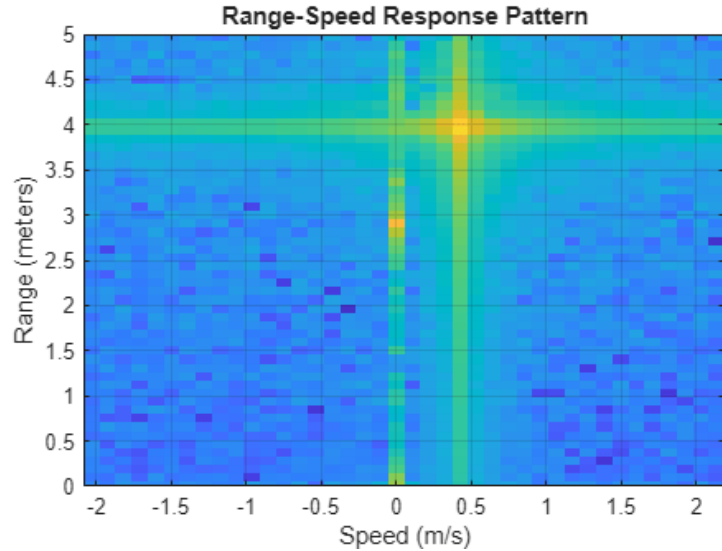


Acconeer XM123 – Low power
Frontend and Backend
65° FoV – £18

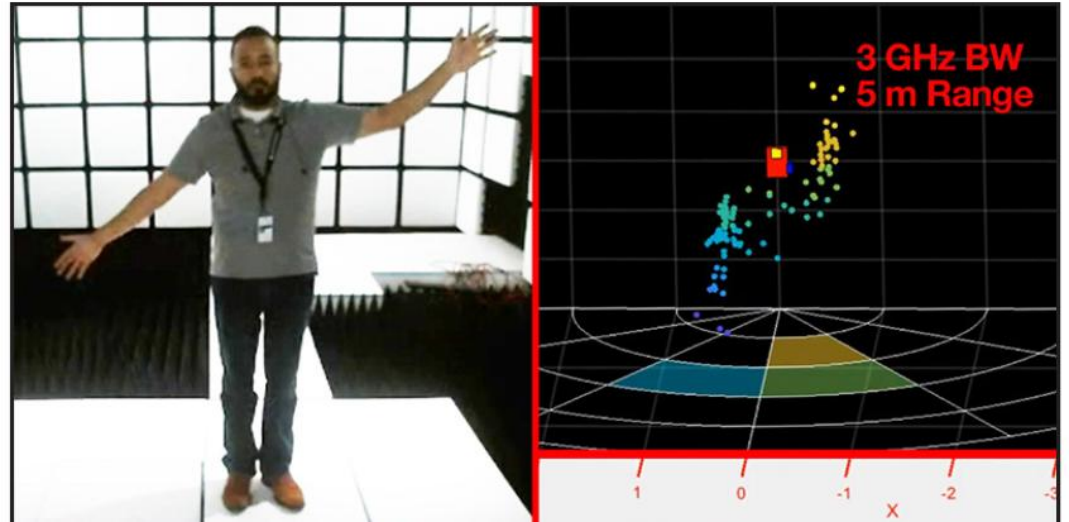


Indoor mmWave radars (60 GHz)

How radar data looks like?



Range-Doppler radar plot [7]



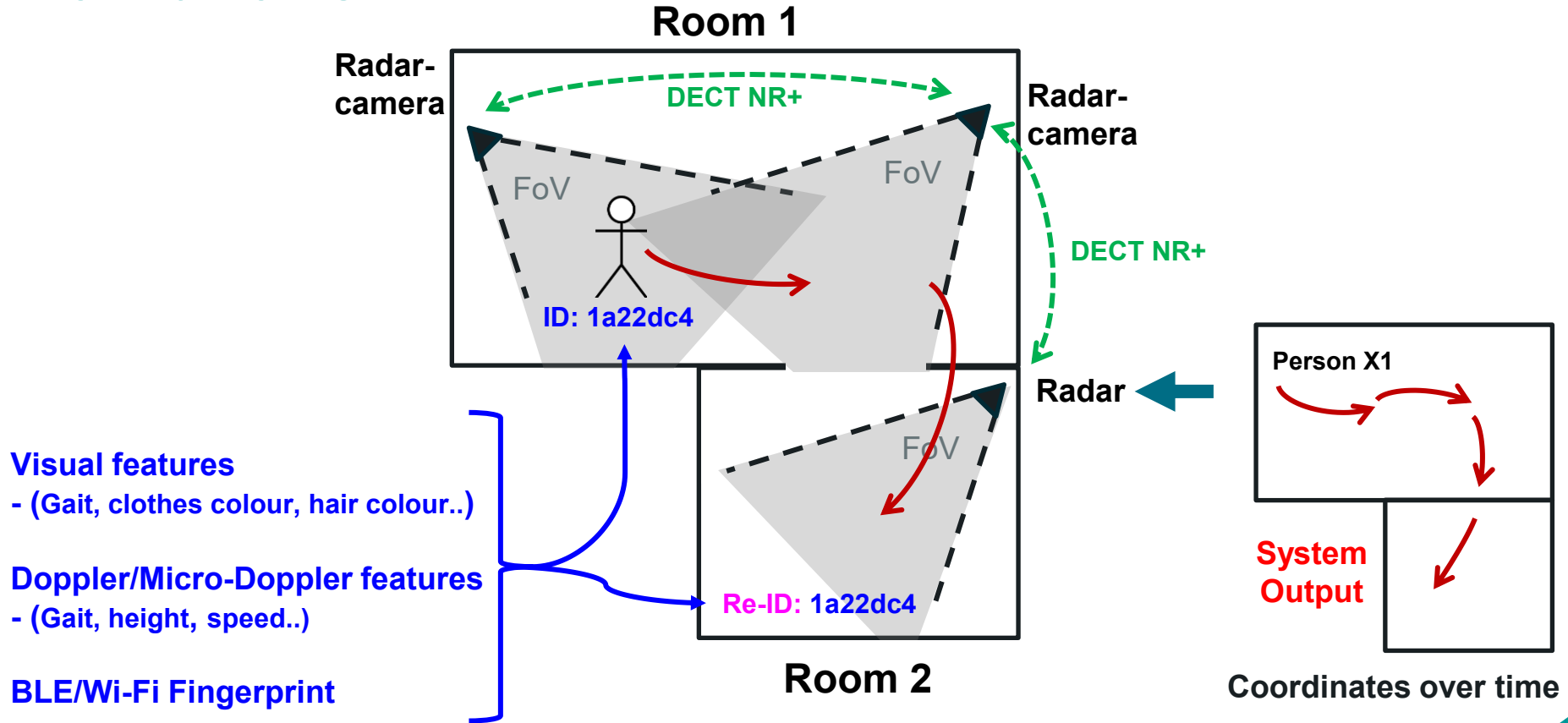
Radar point cloud (post processing) [8]

Indoor mmWave radars

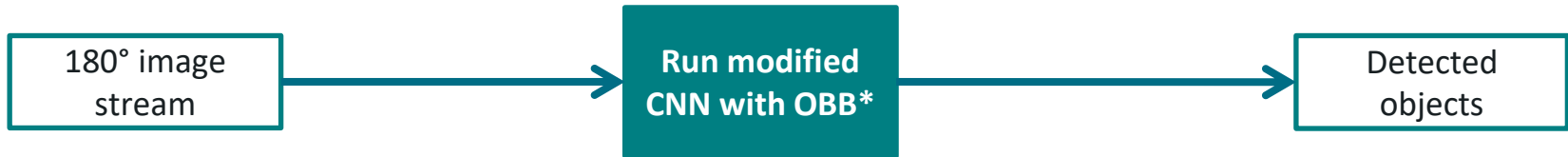
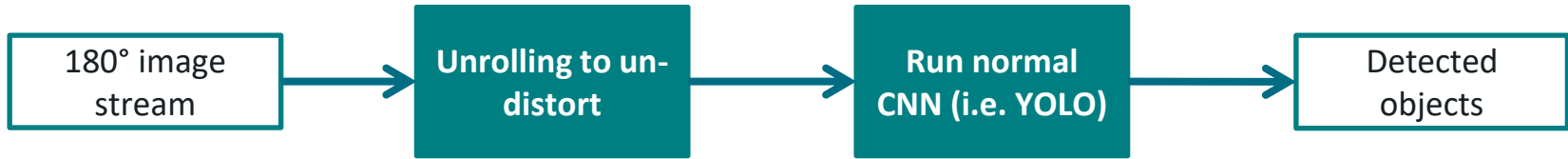


Example of mmWave radar in action
Infineon, 9m range, 120° FoV

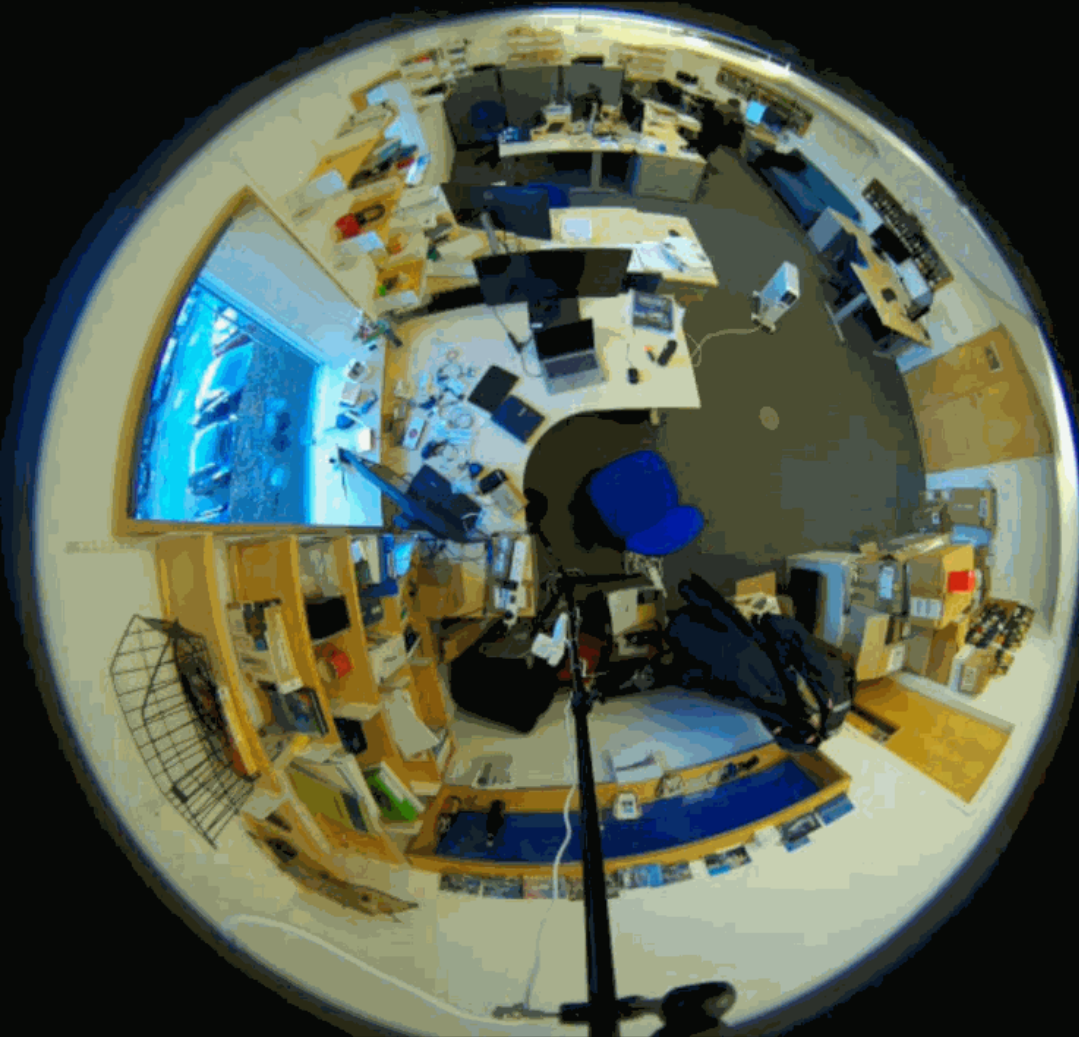
How it works?



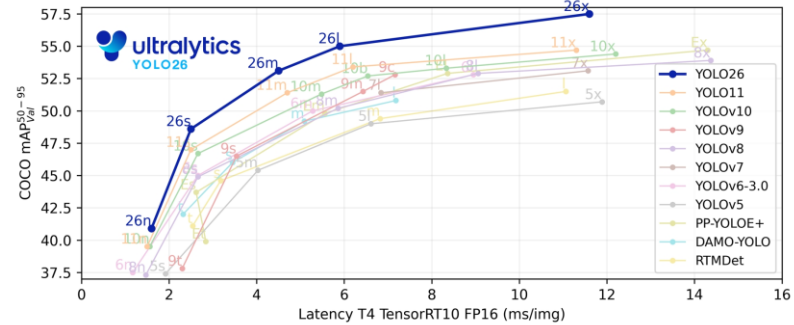
Fisheye cameras: Pipeline



*OBB: Oriented Bounding Boxes



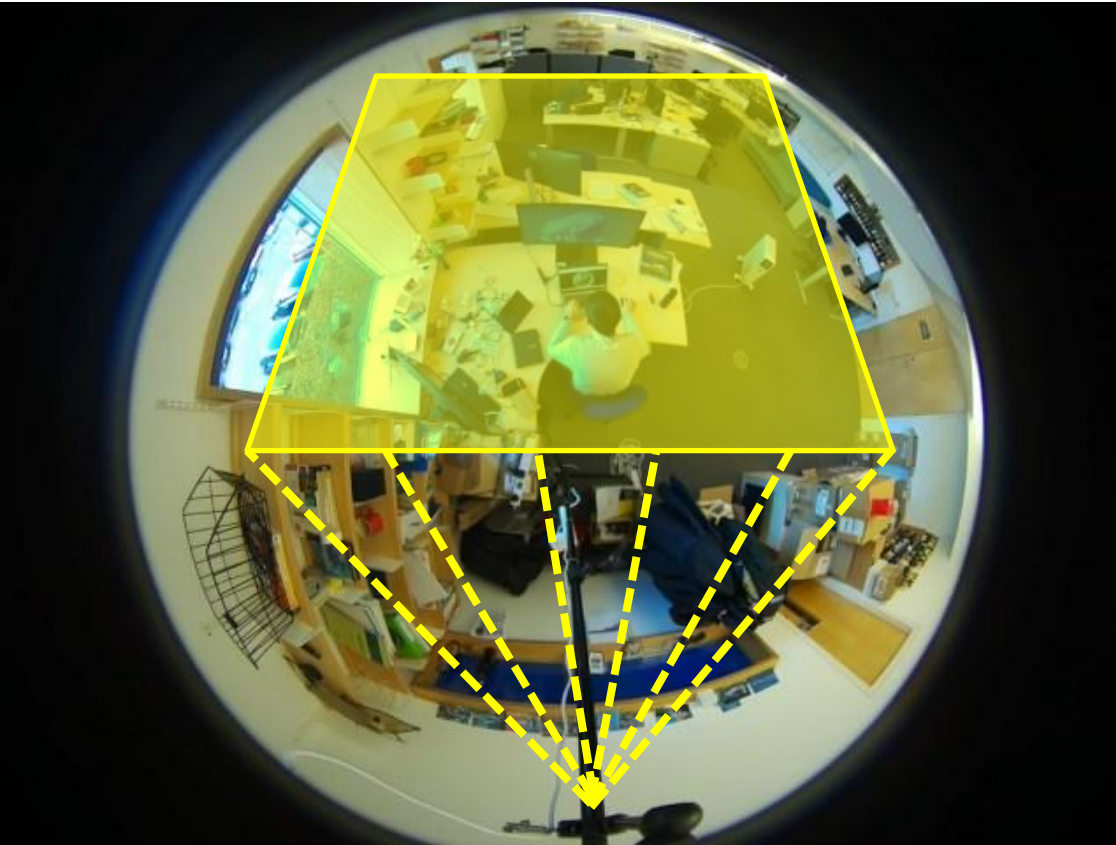
Example of OBB in action



YOLO26-OBB is selected [6]

Retraining and optimisation in progress

Radar-Camera Fusion Challenges



- Mapping radar depth to 2D optical images.
- Aligning spatial coordinates across overlapping FoVs.

DECT NR+ Mesh challenges

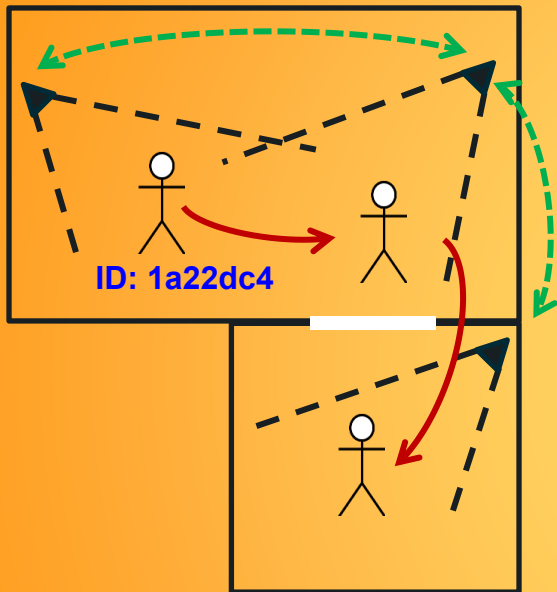


Based on Nordic nRF9151

- Using relatively new DECT NR+ (Mostly proprietary)
- Implementing custom mesh on the PHY layer.
- Working with OFDM (Orthogonal Frequency-Division Multiplexing) and OTA sync.

References:

- [1] <https://github.com/RizwanMunawar/yolov7-object-tracking?tab=readme-ov-file>
- [2] <https://www.retailsensing.com/people-counting/track-the-customer-journey-and-maximise-retail-store-sales/>
- [3] <https://connected-environments.org/projects/hercules/>
- [4] <https://github.com/ucl-casa-ce/hercules-web>
- [5] <https://github.com/duducosmos/defisheye>
- [6] <https://docs.ultralytics.com/models/yolo26/>
- [7] <https://www.mathworks.com/help/radar/ug/iq-data-collection-detection-application-example.html>
- [8] <https://www.ti.com/lit/pdf/spry328>



Thank you

Don't forget to check the poster :)

Yaman R.Kalaji myr22@cl.cam.ac.uk