TI mmWave in Building Automation

For 2019/11/13 Seminar

End Equipment Overview

IP Network Camera
Motion Detectors
Automated Doors & Gates
People Counting

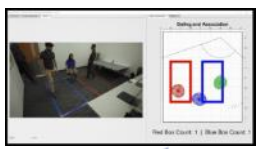
mmWave Sensors – Technology Overview

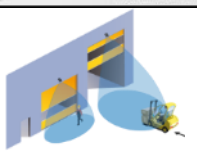
What is mmWave sensing

- mmWave is the band of spectrum between 30GHz and 300GHz
- Electromagnetic waves used for sensing, imaging and communications
- mmWave sensors measure with high accuracy **range**, **velocity** and **angle** of remote objects

When to use mmWave sensing?

- **Motion Detection** – Indoor detection of breathing, talking, typing for lighting control and security. Outdoor detection at extended distances (50m+) for security. Motion classification of people vs animals vs background.
- **People Counting** – Counting and location tracking of multiple people for security, retail, elevators, factories.
- **Automated Doors** – Tracking of objects approaching automatic door. Classification of object direction, size.
- **IPNC Surveillance** – Augmenting security cameras for enhanced motion detection or point-tilt-zoom (PTZ) control

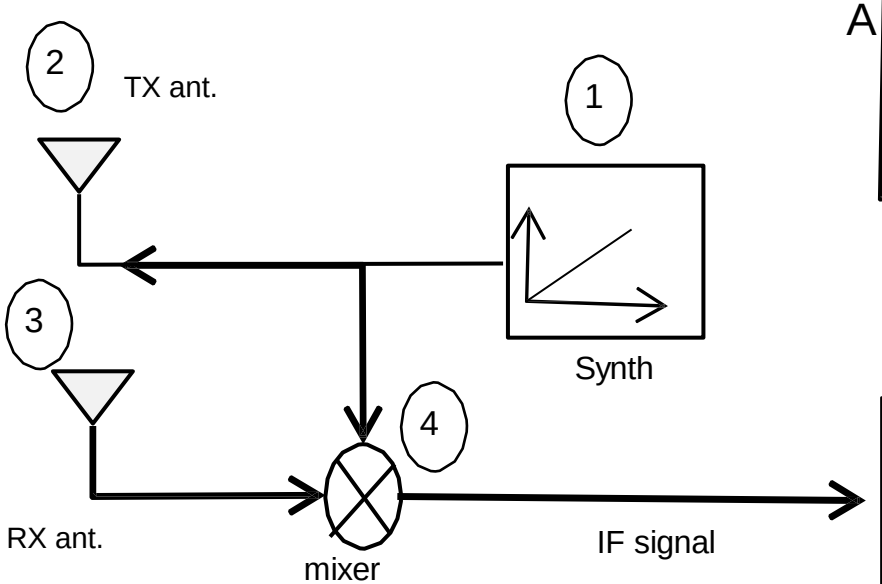



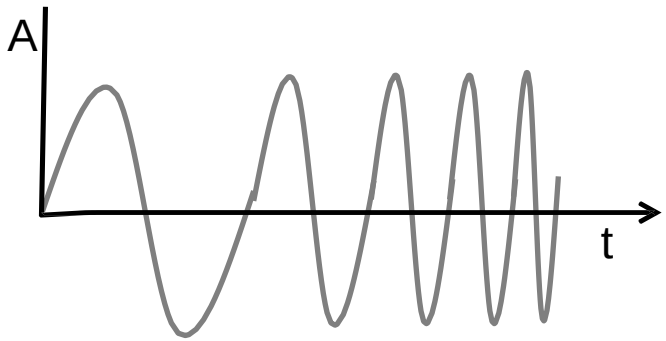


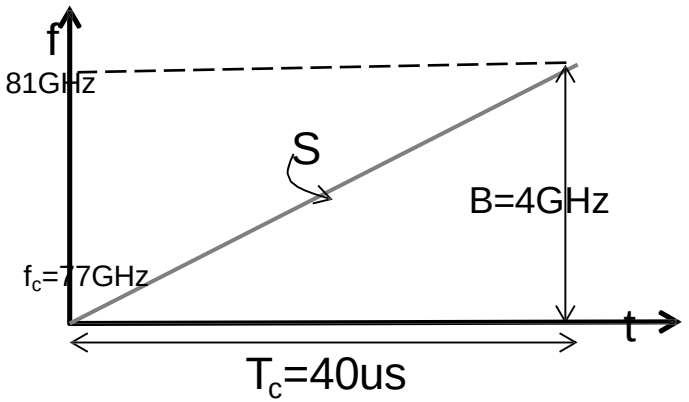

Why Now?

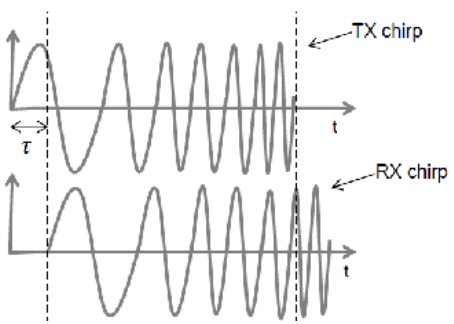
- mmWave technology is robust against environmental influences such as dazzling sunlight, no light, weather conditions like rain and fog and changes in temperature
- Detect very fine motions, RF technology for penetration through materials like plastic, fabric, and drywall. Use in privacy conscious applications
- RFCMOS technology enables analog/digital integration in a single low-power, small, single-chip solution

Basics of FMCW (Frequency Modulation Continue Wave)









1. A synthesizer (synth) generates a "**chirp**"
2. The chirp is transmitted by the TX antenna
3. The chirp is reflected off an object and the reflected chirp is received at the RX antenna.
4. The RX signal and TX signal are 'mixed' and the resulting signal is called an 'IF signal'.

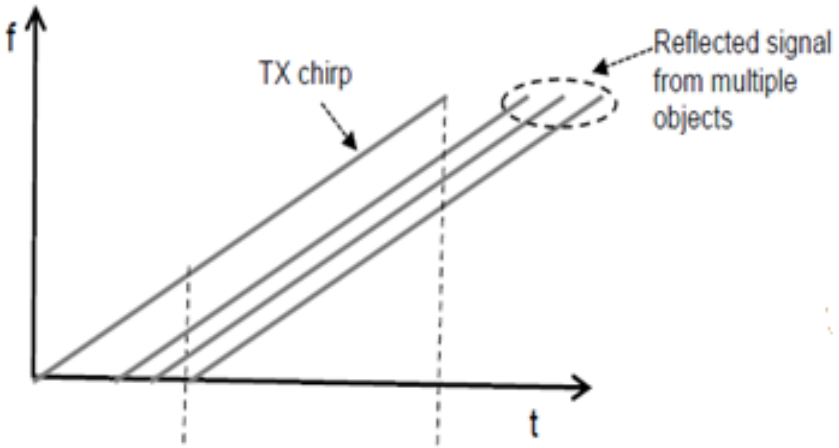
$$\mathrm{Tx} = \sin[w_1 t + \phi_1)\ ]$$

$$\mathrm{Rx} = \sin[w_2 t + \phi_2)\ ]$$

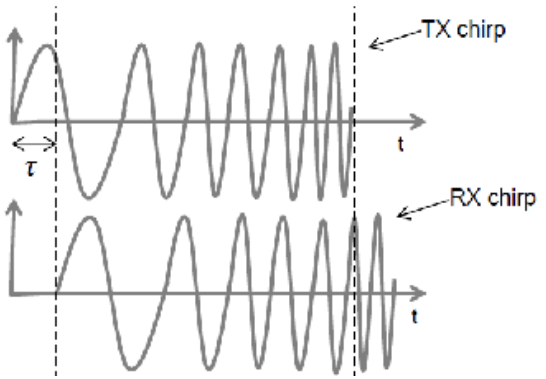
$$\mathrm{IF} = \sin\ \ [(w_1 - w_2)t + (\phi_1 - \phi_2)\ ]$$

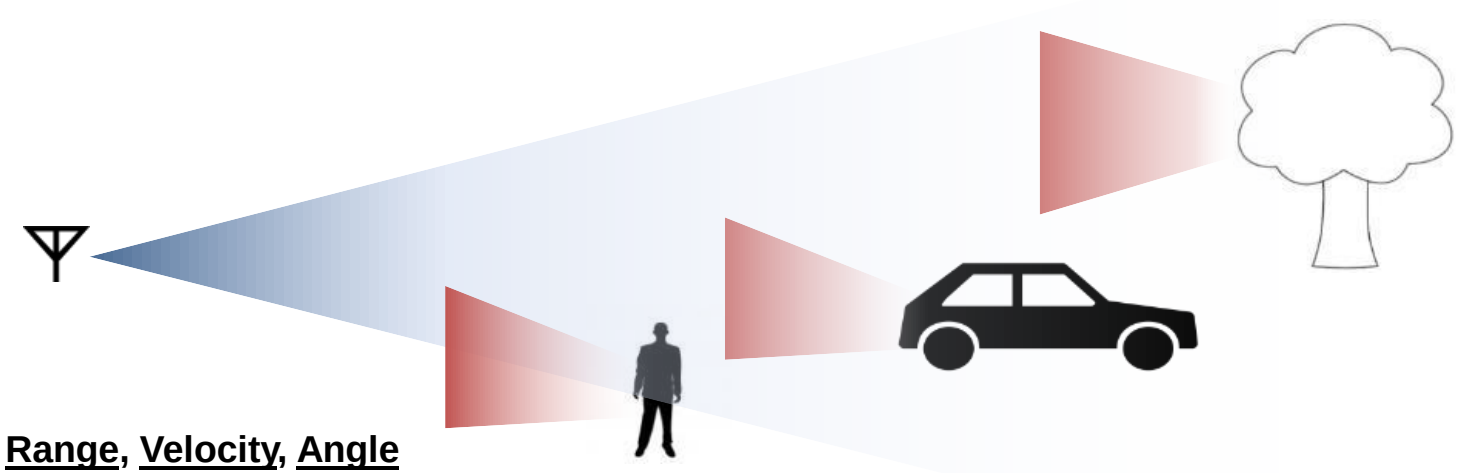
The fundamentals of millimeter wave sensors, http://www.ti.com/lit/wp/spyy005/spyy005.pdf

Basics of FMCW (Range Measurement)



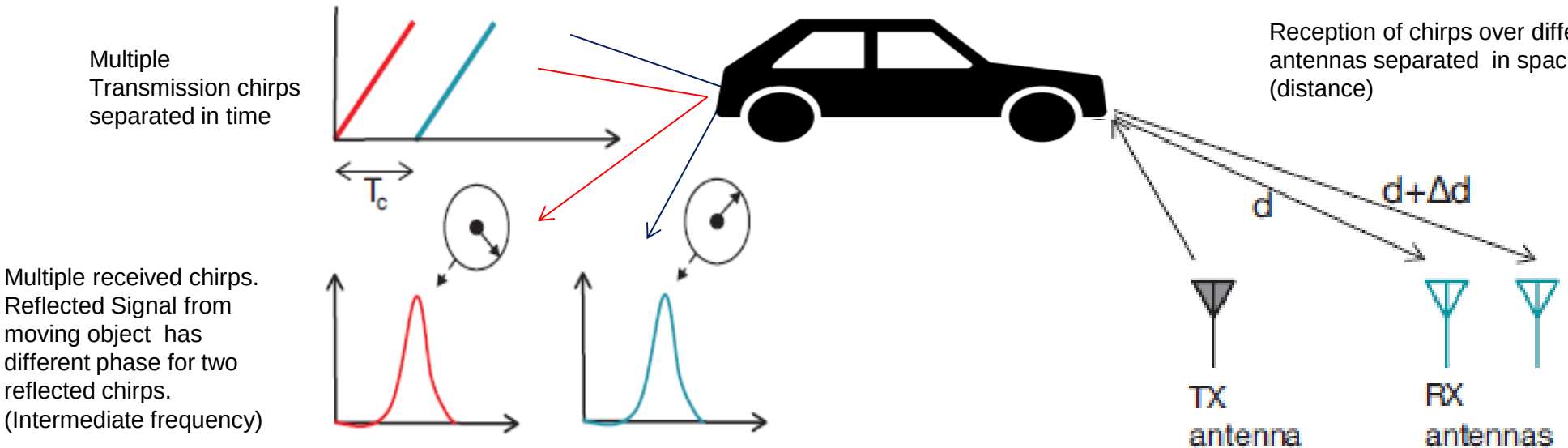
IF frequency = Tx frequency – Rx frequency





By working with FFT on these IF signals to get **Range**, **Velocity**, **Angle** information of detecting object

Basics of FMCW (Velocity and Angle Measurement)



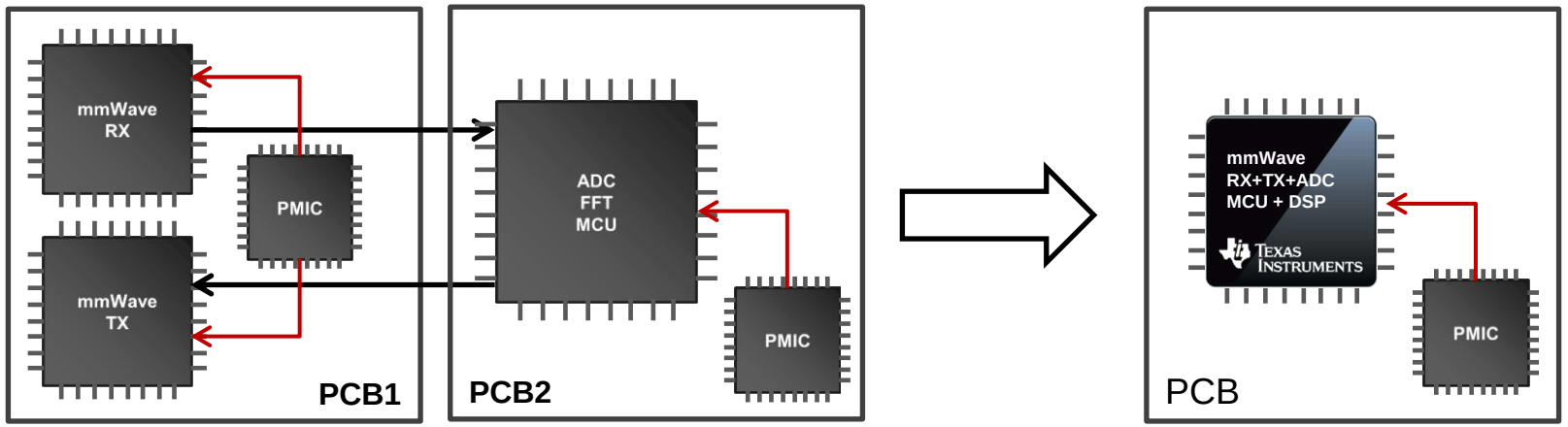
Multiple chirps for velocity detection

IF frequency = Tx frequency – Rx frequency

Multiple antennas for angle detection

Velocity and Angle of object reflects in phase difference of IF signal.

TI Innovation – Single-Chip CMOS



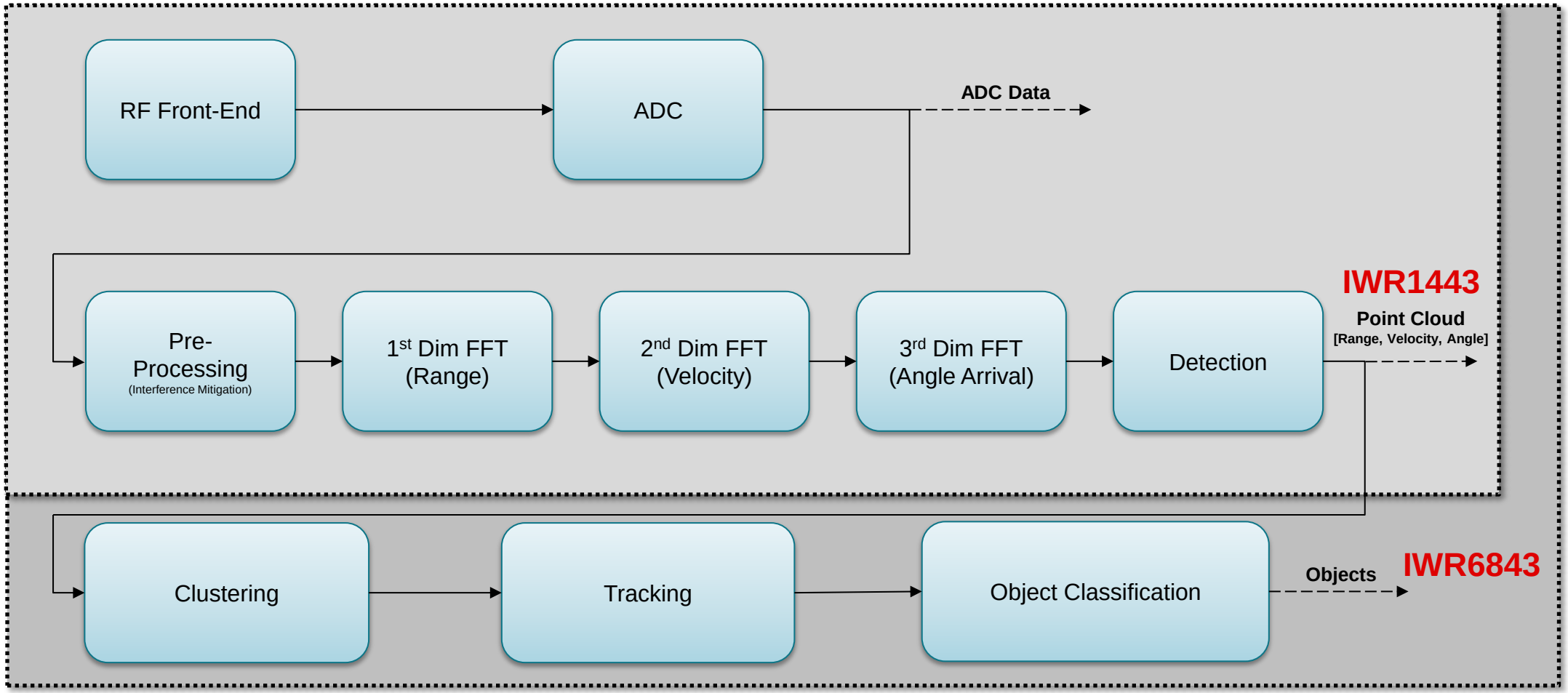
Discrete Multi-Chip mmWave Sensor

- Discrete solution – expensive
- Complex and critical signal routes
- Unconventional packaging
- Prone to noise
- Lack of system level monitoring
- Crude implementation of RF and Baseband safety

TI Single-Chip mmWave Sensor

- Smaller in size
- Simpler design
- Built in monitoring and calibration (SIL)
- High Resolution, less false positives
- Programmable core
- Lower Power

IWR1xxx mmWave Signal Processing



Industrial Radar – Path of Development

Discover

"I am looking for a new sensor for my project"

- Tools focused on showcasing mmWave sensor capabilities and potential
- Enable Proof of Concept validation of use cases

TI.com Portal

White Papers & Videos

mmWave Experiments

Evaluate

"I have purchased an EVM to evaluate mmWave sensors"

- Tools & SW focused on shortening evaluation time by simplifying getting started and providing reference software to start with

OOB Demo + Visualizer

mmWave Labs

Chirp Database

Design

"I have selected mmWave sensors for my project"

- Tools & SW that provide building blocks to develop unique mmWave sensor applications
- Enable rapid development, test and deployment

mmWave SDK & LIB

IWR1xxxBOOST EVM

App Notes, TID & Training

Sensing Estimator

mmWave Studio

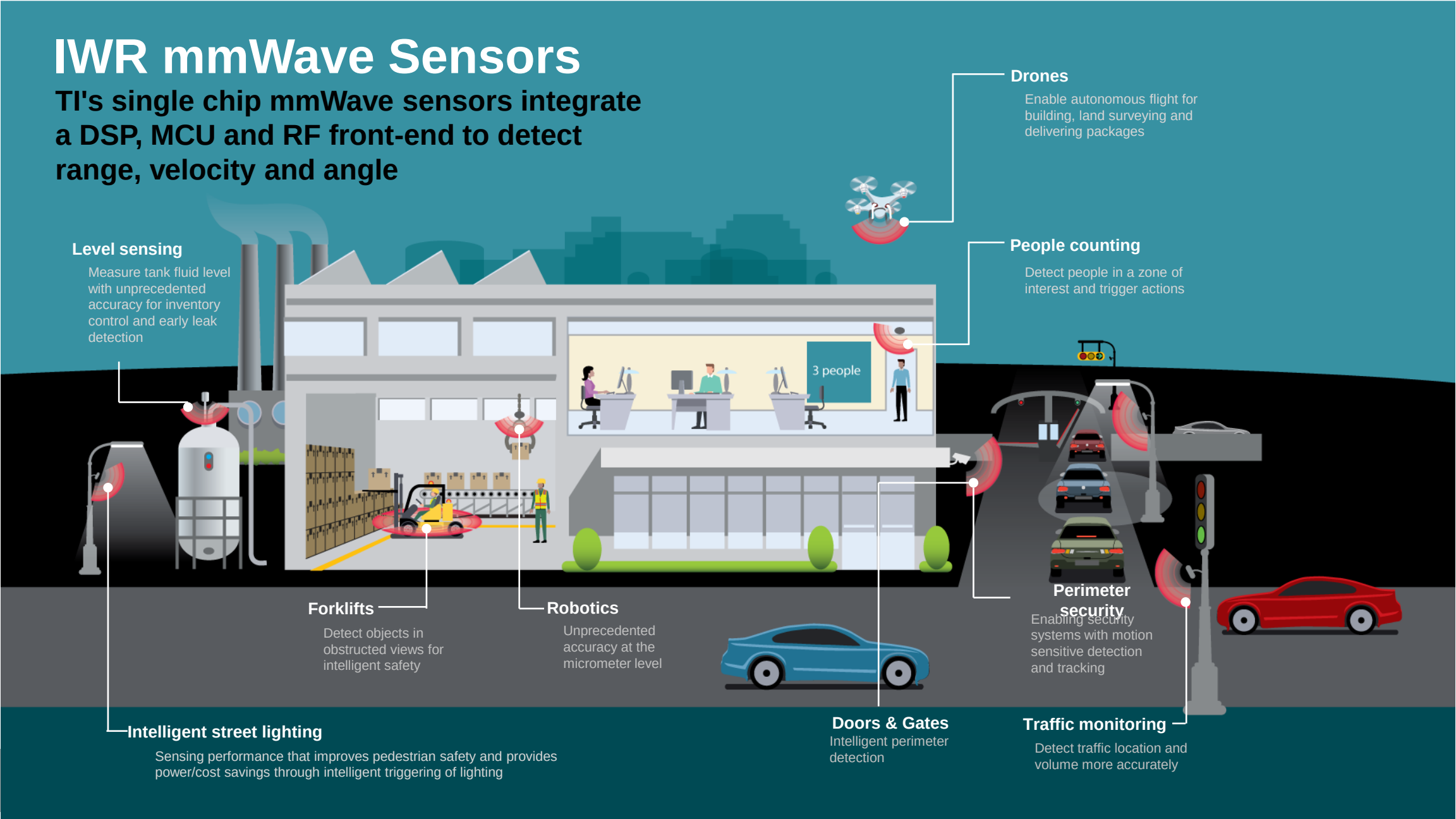
mmWave Sensors Forum (e2e)

Object Range Detection

Object	EVM measured range (m)								
	1	10	20	30	40	60	80	120	160
Truck	✓	✓	✓	✓	✓	✓	✓	✓	✓
Car	✓	✓	✓	✓	✓	✓	✓	✓	
Motor bike	✓	✓	✓	✓	✓	✓	✓		
Human	✓	✓	✓	✓	✓				
Metal chair	✓	✓	✓	✓					
Large dog	✓	✓							
Coins (quarters)	✓								

IWR mmWave Sensors

TI's single chip mmWave sensors integrate a DSP, MCU and RF front-end to detect range, velocity and angle



Drones

Enable autonomous flight for building, land surveying and delivering packages

People counting

Detect people in a zone of interest and trigger actions

Level sensing

Measure tank fluid level with unprecedented accuracy for inventory control and early leak detection

Forklifts

Detect objects in obstructed views for intelligent safety

Robotics

Unprecedented accuracy at the micrometer level

Perimeter security

Enabling security systems with motion sensitive detection and tracking

Intelligent street lighting

Sensing performance that improves pedestrian safety and provides power/cost savings through intelligent triggering of lighting

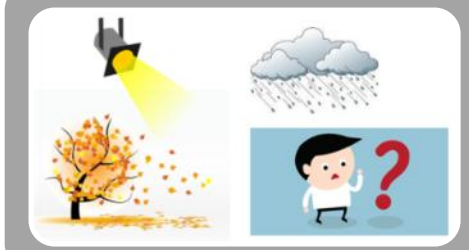
Doors & Gates

Intelligent perimeter detection

Traffic monitoring

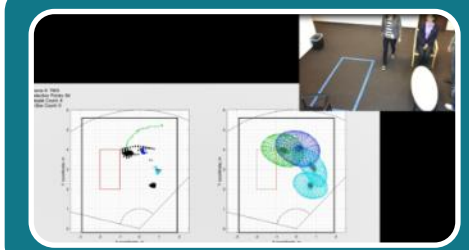
Detect traffic location and volume more accurately

Building Automation – Problems to Solve using mmWave



False Detection – Fine Motion

- Sensing systems to detect occupancy today are prone to false detection
- In security, all detection events must be responded to by a person (camera, guard, police)
- Costs $$$, false detection desensitize responders to real threats
- Need sensing systems that can ignore common false detection sources (environment, objects, movement outside ROI)



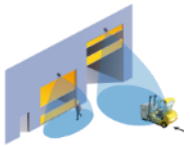
People Localization and Counting

- Locating and counting people can be done today, but requires complex and expensive technologies like stereo vision and 3D ToF
- Doing this accurately requires expensive processing and complex SW.
- Need for less expensive, higher accuracy solutions
- **TI mmWave on-board processing enables counting and tracking of multiple people in single-chip**

Motion Classification

- Classification of objects and motion such as determining if John, a forklift, or a dog has just moved into a ROI
- Can be done today, but requires complex and expensive technologies like vision processors.
- Need for less expensive solutions that require less complex SW implementations
- **TI mmWave range, velocity, angle, data along with point cloud size can be used for classification**

mmWave Sensors for Building Automation – Offering Summary

Application	Occupancy Detection and Automated Doors and Gates			Motion Detectors and IP Network Cameras
Benefits	Track and separate multiple people simultaneously with a single chip sensor. Simplify solution by ignoring non-moving (static) objects like chairs and tables and filtering moving objects such as fans, curtains, or blinds.			Robust detection and localization of slow moving people even in cluttered outdoor areas with lots of movement from clutter like trees and shrubs
Hardware (field of view)	IWR6843 ISK EVM (120° horizontal, 30° vertical)		IWR6843 ODS EVM (120° horizontal, 120° vertical)	IWR6843 ISK EVM (120° horizontal, 30° vertical)
Example Environments	**Conf Room**	**Open Office**	**Open Office (ceiling mount)**	**Outdoors**
Example Coverage Area	6m x 6m	14m x 14m	16m x 16m	25m x 50m
Example Range (resolution)	6m (0.048m)	14m (0.12m)	8m (0.12m)	55m (0.5m)
Example Velocity (resolution)	5.17m/s (0.082m/s)	5.25m/s (0.082m/s	5.25m/s (0.082m/s)	6.2m/s (0.1m/s)
Applicable Onboard Algorithms	Static Clutter Removal, Group Tracking/Counting			Static Clutter Removal, Group Tracking for Object filtering
Provided Example Demonstrations	• People Counting Lab • Indoor False Detection Mitigation Lab		• Overhead People Counting Lab	50m Outdoor False Detection Filtering Lab

Follow the links below for where to go on **ti.com**

Discover	ti.com and videos	1. Review mmWave Building Automation Applications page 2. Watch the People Counting Video 3. Watch the People Counting Applications Video 4. Watch the Intelligence at the Edge Video
Evaluate	Evaluation Kits	1. Order IWR6843ISK + MMWAVEICBOOST EVM 2. Order IWR6843 ODS Antenna Board 3. Order mmWave POE Board
	Experiments	1. Fine Motion Detection vs PIR Experiment 2. People Counting through drywall, glass, wood Experiment 3. Response of radar to rain Experiment **4. *NEW*** Fall Detection with IWR6843
	Labs	1. People Counting Lab 2. Indoor False Detection Mitigation Lab 3. 50m Outdoor False Detection Filtering Lab 4. Overhead People Counting Lab
	Reference Designs	1. People Counting and Tracking Reference Design using IWR6843
Design	Explore Device	1. Product Folder IWR6843 2. Reference IWR6843 datasheet, errata and TRM 3. Review IWR6843 EVM schematics and layout

Wall Mounted People Tracking and Counting Reference Design using mmWave Radar Sensor

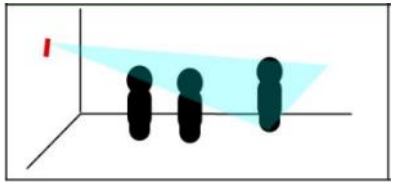
TIDEP-01000, **Design Status: On ti.com**

TIDesigns

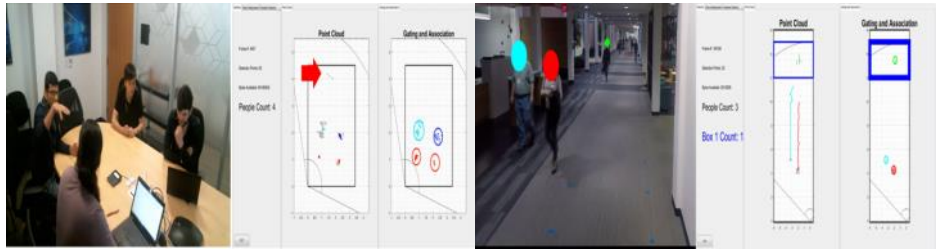
Base configurations of people counting TI Design support 6m and 14m operation.

Tuning of parameters in TI Design enables variety of applications and environments

	Short Range Configuration	Medium Range Configuration	
HW / EVM	IWR6483 ISK EVM		
Field of View	120° Horizontal, 30° Vertical		
Max Range	6m	14m	
Example Area	6m x 6m	6m x 14m 14m x 14m	
Range Resolution	4.8cm	12cm	
Max Velocity	5.17 m/s	5.25 m/s	
Velocity Resolution	0.082 m/s	0.082 m/s	
Algorithms Used	Static Clutter Removal, Group Tracking, False Detection Mitigation	Static Clutter Removal, Group Tracking, False Detection Mitigation	
System Power	~1.5W		
Location accuracy	Person location within <16cm		
Counting density	3 persons per square meter		
Demonstrated accuracy	+/- 0 persons	+/- 1 persons	+/- 2 persons
3 people in scene	>95% of frames	100% of frames	100% of frames
5 people in scene	>51% of frames	>85% of frames	100% of frames
7 people in scene	>59% of frames	>85% of frames	>98% of frames
9 people in scene	>14% of frames	>43% of frames	>84% of frames



Mounting assumes 1.5-2.5m elevation, with 10 degree downtilt



L: Conference Room with **Static Clutter Removal** for chairs and table
R: Hallway Scene person in GREEN tracked at **14m** with **Medium Range Configuration** and **Group Tracking**

1. Discover mmWave offering for people tracking and counting page here
    1. Watch Video: People Counting Applications & Benefits
    2. Watch Video: Intelligence at the Edge
2. Evaluate the performance
    1. Order IWR6843 EVM here
    2. Download People Counting Lab
    3. Download Indoor False Detection Mitigation Lab
3. Design custom boards with IWR6843 silicon
    1. Reference IWR6843 datasheet, errata and TRM
    2. Review IWR6843 EVM schematics and layout
4. Leverage turn-key or design custom solutions using 3rd Parties such as:
    1. Turn-Key and Custom: Ainstein
    2. Turn-Key and Custom: D3 Engineering
    3. Turn-Key and Custom: Smart Radar Systems (SRS)

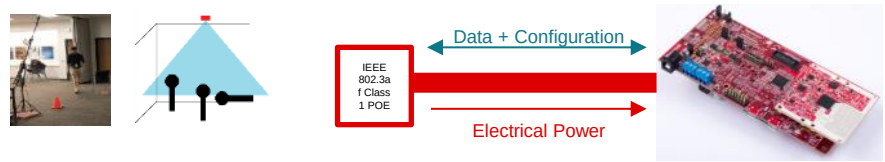
Ceiling Mounted People Tracking and Counting Reference Design using mmWave Radar Sensor and POE

Design Status: Available on TI REX

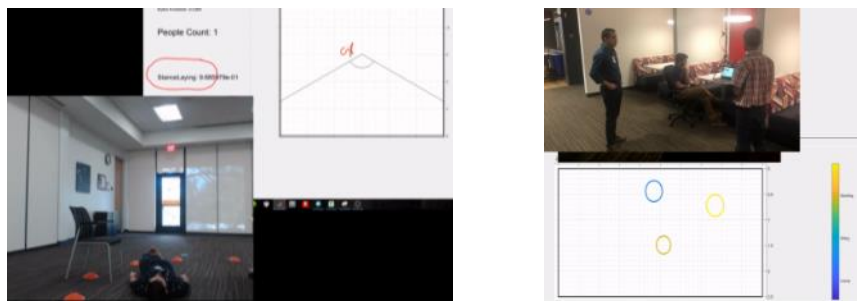
Base configurations of ceiling mounted people counting TI Design support 360° radial operation.

Tuning of parameters in TI Design enables variety of applications and environments

	March 2019 (Release on TI REX)
HW / EVM	IWR6843 ODS EVM IWR6843 Power Over Ethernet Adaptor
Field of View	120° Horizontal, 120° Vertical
Max Range	4m – radial
Example Area	6m x 6m
Range Resolution	12cm
Max Velocity	5.25m/s
Velocity Resolution	0.082m/s
Algorithms Used	Static Clutter Removal, Group Tracking, Stance Detection
System Power	~1.5W
Performance Details	Max count: 3 people Stances detected: standing / sitting



Mounting and sensing distance assumes 3m elevation
POE enables simplified integration with existing infrastructure



Ability to detect height of people and classify as standing/sitting/laying down (YELLOW – standing, BLUE – sitting)

1. Discover mmWave offering for people tracking and counting page here
   1. CES 2019 : Video Standing / Sitting detection
   2. CES 2019 : Video Conference Room Implementation with 3P Ainstein
2. Evaluate the performance
   1. Order IWR6843 ODS EVM + MMWAVEICBOOST
   2. Order mmWave POE Board
   3. Download Overhead People Counting Lab
3. Design custom boards with IWR6843 silicon
   1. Reference IWR6843 datasheet, errata and TRM
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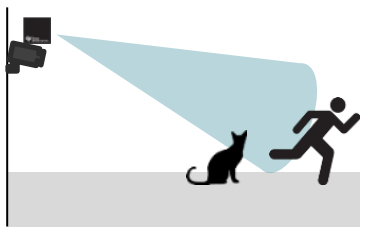
4. Leverage turn-key or design custom solutions using 3rd Parties such as:
   1. Custom: Ainstein
   2. Turn-Key and Custom: RF Beam

Outdoor 50m People Tracking and False Detection Mitigation
Application Usage



Radar ON: Low Power State → Motion Detected and classified by Radar → Video Stream Turned ON

Intelligent Motion Detection

- Only turn on camera if radar **detects and verifies** motion
- Reduce false detection, less false alarms
- Result is system resource conservation:
  - Reduce Power Consumption
  - Reduce Network Bandwidth – more cameras in system
  - Reduce Video Storage – less server storage required

Vision Fusion / PTZ Control

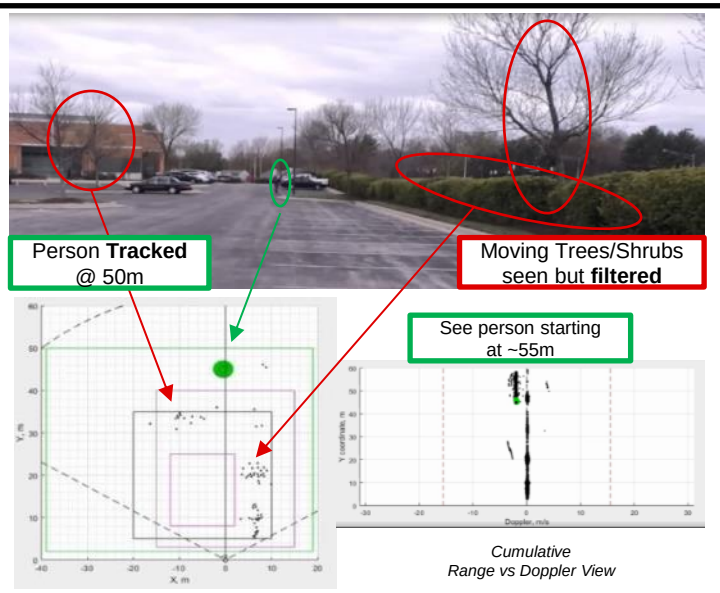
- Use of both camera vision and radar combined to determine position and velocity of people
- Use radar to identify targets even in rain, fog, dust, and other extreme conditions
- Locate and track targets for PTZ and focus control

Outdoor 50m People Tracking and False Detection Mitigation

Detects slow moving people even in cluttered outdoor areas with lots of motion

- Robust sensing regardless of environment, uses integrated DSP on IWR6843 and algorithms to ignore point cloud from dynamic clutter like trees and shrubs
- Use with **IP Network Cameras** to turn cameras on or send alerts when a moving person is detected only

	Example Configuration	
HW / EVM	IWR6843 ISK EVM (ES2.0)	
Max Field of View / Coverage Area	120° Horizontal, 30° Vertical	
Max Range	**56m**	
Range Resolution	50cm	
Max Velocity	6.2m/s	
Velocity Resolution	0.10m/s	
Algorithms Used	Static Clutter Removal, Group Tracking (configured for outdoor, false detection filtering)	
System Power	~1.5W (not duty cycled) 100mW-500mW (duty cycled, 1 frame to 5 frames)	
Performance Metrics	• Max range: 56 m departing, 56 m approaching • Sneaking person (Crouched) detected @56m departing and @42m approaching	
Field of View (horizontal) at measured distance	55m	+/- 45°
	40m	+/- 60°
	30m	+/- 60°
	20m	+/- 60°
	10m	+/- 60°



Windy day testing showing false detection filtering with Group Tracking algorithm

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2. Evaluate the performance
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    2. Download 50m People Tracking and False Detection Mitigation Lab
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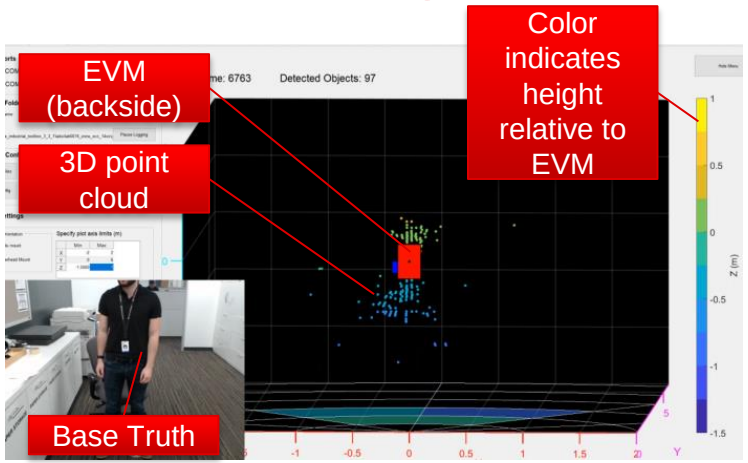
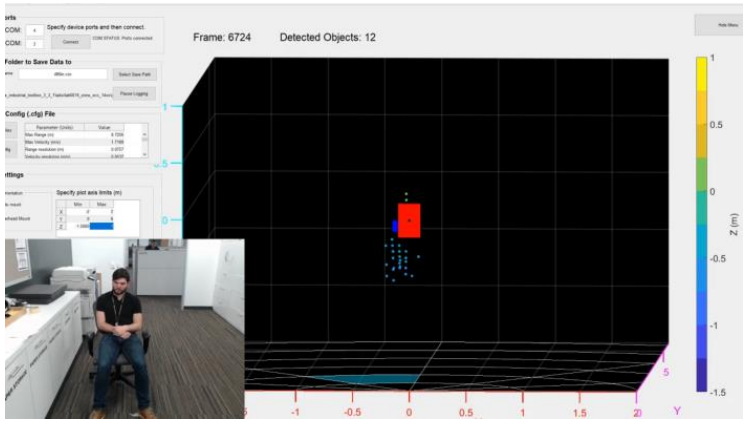
4. Leverage turn-key or design custom solutions using 3rd Parties such as
    1. ODM: Alpha Networks
    2. ODM: Primax
    3. Custom: Smart Radar Systems (SRS)
    4. Custom: Colorado Engineering (CEI)

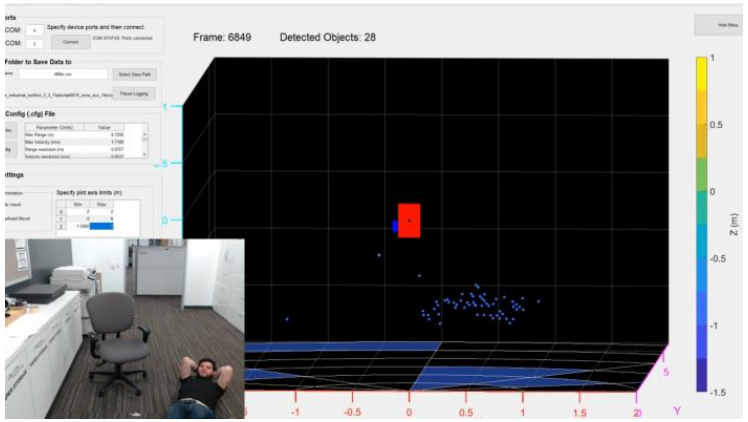
Detecting Human Falls and Stance with IWR6843



Standing



Sitting



Laying Down

Shows the change in shape and height of mmWave 3D point cloud when person stands, sits, or lays down

- Uses wide-angle antenna on IWR6843 ODS EVM to visualize the point cloud of person standing, sitting, or laying down
- Point cloud and velocity information could be used to create algorithm to determine if person has fallen down for applications such as **elderly monitoring**
- Visualization of stance was demonstrated at **ranges of 2m** and **5m**

Evaluate today!

More information: including Documentation and Software	Available on TI Resource Explorer
Hardware	IWR6843 ODS EVM

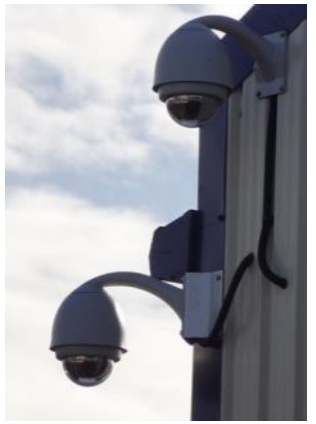
Building Automation – Technology Comparison

Passive Infrared

Measures change in infrared light to detect motion

Pros:
- Simple, low power consumption (uA-mA)

Cons:
- Low sensitivity to motion
- False detection outdoors from sunlight, temperature
- Limited range (5-10m), no position/range information



Cameras

Video image processor analyzes imagery to determine people movement and behavior

Pros:
- Algorithms applied for variety of applications
- Video for recording and monitoring

Cons:
- False detection from shadows, occlusion, day/night cycles, changing environment.
- No position/range information
- Privacy considerations

Active Infrared (3D ToF, LIDAR)

Measurement of infrared light time of flight

Pros:
- High angular resolution provides rich dataset similar to camera

Cons:
- Limited range in presence of sunlight (5-10m)
- Requires substantial processing to separate and classify relevant objects
- System complexity (optics, illumination, processing)

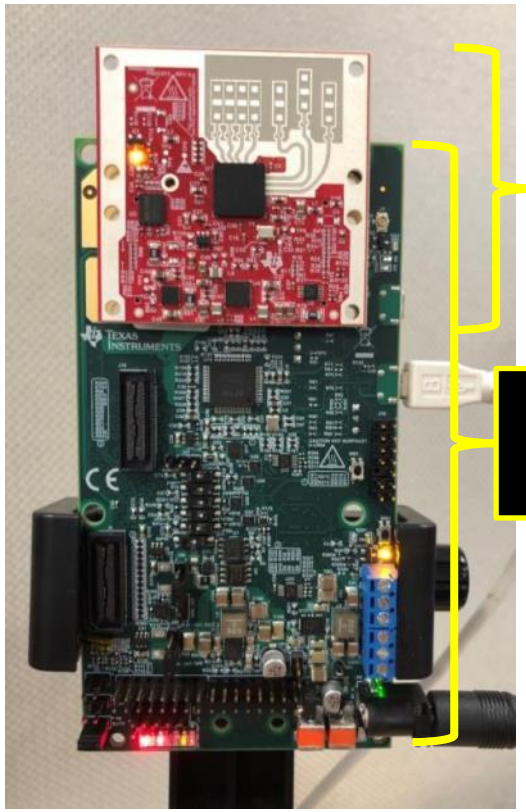
TI mmWave Radar

TI's fully-integrated, single-chip 77GHz and 60GHz mmWave radar

Pros:
- High sensitivity to motion (breathing, typing)
- Simple static and dynamic object separation
- Onboard DSP processing for single-chip tracking, classification of objects
- Extended range for person detection (50m+)
- Insensitive to weather, changing environments

Cons:
- Lower angular resolution than camera or active infrared

IWR6843 Industrial Starter Kit



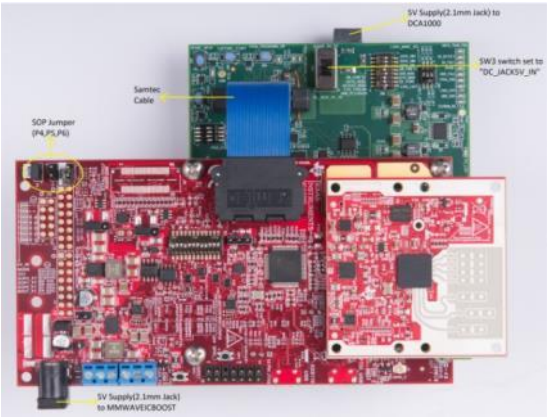
- Carrier board with swappable antenna boards
- Swappable antenna boards support different antenna designs

Antenna Parameters	 IWR6843 ISK	 IWR6843 ODS	 IWR6843 AOP
Azimuth FOV	+/- 60 degree	+/- 60 degree	+/- 65 degree
Elevation FOV	+/- 20 degree	+/- 60 degree	+/- 65 degree
Azimuth Angle Resolution	15 degree	29 degree	29 degree
Elevation Angle Resolution	58 degree	29 degree	29 degree
Max Expected Distance (Human)	50m	20m	25m
Bandwidth	3.5GHz (60.5 – 64GHz)	1.7GHz (61 – 62.7GHz)	4GHz (60 – 64GHz)

DCA1000 Raw Data Capture Solution

xWR1x + DCA1000

or



- Enables RF performance evaluation with PC environment
- mmWave ADC data can be captured and brought onto PC for advanced algorithm development and prototyping
- Data capture (recording) via Ethernet interface at high speed (ADC, User data, debug data)
- mmWave Studio software tool used to visualize object range/velocity/angle