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’.

\[
\begin{align*}
\text{Tx} &= \sin[w_1 t + \phi_1] \\
\text{IF} &= \sin[(w_1 - w_2)t + (\phi_1 - \phi_2)] \\
\text{Rx} &= \sin[w_2 t + \phi_2]
\end{align*}
\]

The fundamentals of millimeter wave sensors, [http://www.ti.com/lit/wp/spyy005/spyy005.pdf](http://www.ti.com/lit/wp/spyy005/spyy005.pdf)
By working with FFT on these IF signals to get **Range**, **Velocity**, **Angle** information of detecting object
Basics of FMCW (Velocity and Angle Measurement)

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

Multiple Transmission chirps separated in time

IF frequency = Tx frequency – Rx frequency

Multiple received chirps. Reflected Signal from moving object has different phase for two reflected chirps. (Intermediate frequency)

Multiple chirps for velocity detection

Multiple antennas for angle detection

Reception of chirps over different antennas separated in space (distance)
**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

RF Front-End → ADC

ADC Data

Pre-Processing (Interference Mitigation) → 1st Dim FFT (Range) → 2nd Dim FFT (Velocity) → 3rd Dim FFT (Angle Arrival) → Detection

Point Cloud (Range, Velocity, Angle)

Clustering → Tracking → Object Classification

Objects

IWR1443

IWR6843
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

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

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

TI.com Portal
White Papers & Videos
mmWave Experiments

OOB Demo + Visualizer
mmWave Labs
Chirp Database

Sensing Estimator
mmWave Studio

mmWave Sensors Forum (e2e)

mmWave SDK & LIB
IWR1xxxBOOST EVM
App Notes, TID & Training
## Object Range Detection

<table>
<thead>
<tr>
<th>Object</th>
<th>EVM measured range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Truck</td>
<td>✔</td>
</tr>
<tr>
<td>Car</td>
<td>✔</td>
</tr>
<tr>
<td>Motor bike</td>
<td>✔</td>
</tr>
<tr>
<td>Human</td>
<td>✔</td>
</tr>
<tr>
<td>Metal chair</td>
<td>✔</td>
</tr>
<tr>
<td>Large dog</td>
<td>✔</td>
</tr>
<tr>
<td>Coins (quarters)</td>
<td>✔</td>
</tr>
</tbody>
</table>
IWR mmWave Sensors

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

- **Level sensing**: Measure tank fluid level with unprecedented accuracy for inventory control and early leak detection.
- **Intelligent street lighting**: Sensing performance that improves pedestrian safety and provides power/cost savings through intelligent triggering of lighting.
- **Forklifts**: Detect objects in obstructed views for intelligent safety.
- **Robotics**: Unprecedented accuracy at the micrometer level.
- **Doors & Gates**: Intelligent perimeter detection.
- **Drones**: Enable autonomous flight for building, land surveying and delivering packages.
- **People counting**: Detect people in a zone of interest and trigger actions.
- **Perimeter security**: Enabling security systems with motion sensitive detection and tracking.
- **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

<table>
<thead>
<tr>
<th>Application</th>
<th>Occupancy Detection and Automated Doors and Gates</th>
<th>Motion Detectors and IP Network Cameras</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>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.</td>
<td>Robust detection and localization of slow moving people even in cluttered outdoor areas with lots of movement from clutter like trees and shrubs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardware (field of view)</th>
<th>IWR6843 ISK EVM</th>
<th>IWR6843 ODS EVM</th>
<th>IWR6843 ISK EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>(120° horizontal, 30° vertical)</td>
<td>(120° horizontal, 30° vertical)</td>
<td>(120° horizontal, 30° vertical)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example Environments</th>
<th>Conf Room</th>
<th>Open Office (ceiling mount)</th>
<th>Outdoors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example Coverage Area</td>
<td>6m x 6m</td>
<td>14m x 14m</td>
<td>16m x 16m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example Range (resolution)</th>
<th>6m (0.048m)</th>
<th>14m (0.12m)</th>
<th>8m (0.12m)</th>
<th>55m (0.5m)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Example Velocity (resolution)</th>
<th>5.17m/s (0.082m/s)</th>
<th>5.25m/s (0.082m/s)</th>
<th>5.25m/s (0.082m/s)</th>
<th>6.2m/s (0.1m/s)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Applicable Onboard Algorithms</th>
<th>Static Clutter Removal, Group Tracking/Counting</th>
<th>Static Clutter Removal, Group Tracking for Object filtering</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Provided Example Demonstrations</th>
<th>People Counting Lab</th>
<th>Indoor False Detection Mitigation Lab</th>
<th>Overhead People Counting Lab</th>
<th>50m Outdoor False Detection Filtering Lab</th>
</tr>
</thead>
</table>

### 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

### 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**

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

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

<table>
<thead>
<tr>
<th>HW / EVM</th>
<th>Short Range Configuration</th>
<th>Medium Range Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWR6483 ISK EVM</td>
<td>~1.5W</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Field of View</th>
<th>Static Clutter Removal, Group Tracking, False Detection Mitigation</th>
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<tr>
<td>120° Horizontal, 30° Vertical</td>
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</table>

<table>
<thead>
<tr>
<th>Max Range</th>
<th>6m</th>
<th>14m</th>
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<table>
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<tr>
<th>Example Area</th>
<th>6m x 6m</th>
<th>6m x 14m</th>
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<td>14m x 14m</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Range Resolution</th>
<th>4.8cm</th>
<th>12cm</th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Max Velocity</th>
<th>5.17 m/s</th>
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<tr>
<th>Velocity Resolution</th>
<th>0.082 m/s</th>
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<th>Algorithms Used</th>
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<th>Counting density</th>
<th>3 persons per square meter</th>
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<tr>
<th>Demonstrated accuracy</th>
<th>+/- 0 persons</th>
<th>+/- 1 persons</th>
<th>+/- 2 persons</th>
</tr>
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<tbody>
<tr>
<td>3 people in scene</td>
<td>&gt;95% of frames</td>
<td>100% of frames</td>
<td>100% of frames</td>
</tr>
<tr>
<td>5 people in scene</td>
<td>&gt;51% of frames</td>
<td>&gt;85% of frames</td>
<td>100% of frames</td>
</tr>
<tr>
<td>7 people in scene</td>
<td>&gt;59% of frames</td>
<td>&gt;85% of frames</td>
<td>&gt;98% of frames</td>
</tr>
<tr>
<td>9 people in scene</td>
<td>&gt;14% of frames</td>
<td>&gt;43% of frames</td>
<td>&gt;84% of frames</td>
</tr>
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1. Discover mmWave offering for people tracking and counting page [here](#).
2. Watch Video: People Counting Applications & Benefits
3. Watch Video: Intelligence at the Edge
4. Evaluate the performance
   1. Order IWR6843 EVM [here](#).
   2. Download People Counting Lab
   3. Download Indoor False Detection Mitigation Lab
5. Design custom boards with IWR6843 silicon
   1. Reference IWR6843 datasheet, errata and TRM
   2. Review IWR6843 EVM schematics and layout
6. 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

<table>
<thead>
<tr>
<th><strong>March 2019 (Release on TI REX)</strong></th>
<th></th>
</tr>
</thead>
</table>
| **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

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

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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
   2. Review IWR6843 EVM schematics and layout
4. Leverage turn-key or design custom solutions using 3rd Parties such as:
   1. Custom: Ainstein
   2. Turn-Key and Custom: RF Beam
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**

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**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

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**Example Configuration**

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

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**Windy day testing showing false detection filtering with Group Tracking algorithm**

1. Discover mmWave offering for people tracking and counting page [here](#)
2. Watch Video: Intelligence at the Edge
3. Evaluate the performance
   1. Order IWR6843 ISK EVM here
   2. Download 50m People Tracking and False Detection Mitigation Lab
4. Design custom boards with IWR6843 silicon
   1. Reference IWR6843 datasheet, errata and TRM
   2. Review IWR6843 EVM schematics and layout
5. 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)**

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**X-Y Scatterplot View**

See person starting at ~55m

**Cumulative Range vs Doppler View**

Person Tracked @ 50m

Moving Trees/Shrubs seen but filtered
Detecting Human Falls and Stance with IWR6843

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

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

## Active Infrared (3D ToF, LIDAR)

Measurement of infrared light time of flight

**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

## 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

## 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 Board Parameters

<table>
<thead>
<tr>
<th></th>
<th>IWR6843 ISK</th>
<th>IWR6843 ODS</th>
<th>IWR6843 AOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azimuth FOV</td>
<td>+/- 60 degree</td>
<td>+/- 60 degree</td>
<td>+/- 65 degree</td>
</tr>
<tr>
<td>Elevation FOV</td>
<td>+/- 20 degree</td>
<td>+/- 60 degree</td>
<td>+/- 65 degree</td>
</tr>
<tr>
<td>Azimuth Angle Resolution</td>
<td>15 degree</td>
<td>29 degree</td>
<td>29 degree</td>
</tr>
<tr>
<td>Elevation Angle Resolution</td>
<td>58 degree</td>
<td>29 degree</td>
<td>29 degree</td>
</tr>
<tr>
<td>Max Expected Distance (Human)</td>
<td>50m</td>
<td>20m</td>
<td>25m</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>3.5GHz (60.5 – 64GHz)</td>
<td>1.7GHz (61 – 62.7GHz)</td>
<td>4GHz (60 – 64GHz)</td>
</tr>
</tbody>
</table>
DCA1000 Raw Data Capture Solution

- 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