mmWave Radar – IWR1642 People Counting Demonstration
Presenters

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mmWave Webinar Series

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mmWave Sensors:

http://www.ti.com/sensing-products/mmwave/overview.html
http://www.ti.com/sensing-products/mmwave/iwr/overview.html
http://www.ti.com/sensing-products/mmwave/awr/overview.html
Agenda

• Demonstration Introduction
• Implementation
  – Signal Processing Chain
  – Tracking Module
• Demo and Run
  – Demo Setup
  – Live Demo Show
• Q&A
People Counting Demonstration using IWR1642

**Platform**
- IWR1642 – TI’s FMCW mmWave (76-81GHz) **Single chip Radar** with 2Tx/4Rx RF front End, ADC, DSP(C674x) and MCU(Cortex-R4F)

**Features**
- Single chip solution.
- Device outputs point cloud and object tracking information
- Demonstration is locating and tracking moving objects

**Benefits**
- Count and track the people with mmWave Radar, especially in privacy-conscience applications or in challenging environments such as nighttime, fog, smoke

**Applications**
- People Counting
- Motion Detector
- IPNC Video Camera
- Lighting Sensors
- HVAC Control
- Factory Safety Sensors
Implementation

Hardware

- IWR1642
  - 4 RX, 2TX

Software

- mmwave_industrial_toolbox_2_1_2
- Check the latest version in TI-REX
  - [http://dev.ti.com/tirex/#/](http://dev.ti.com/tirex/#/)
  - TI-Design coming soon.

### Key Performance Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Short Range</th>
<th>Long Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max range</td>
<td>5 m</td>
<td>12m</td>
</tr>
<tr>
<td>Max velocity</td>
<td>18.64 Km/h</td>
<td>18.9 Km/h</td>
</tr>
<tr>
<td>Range resolution</td>
<td>4.9 cm</td>
<td>12 cm</td>
</tr>
<tr>
<td>Velocity resolution</td>
<td>0.297 Km/h</td>
<td>0.297 Km/h</td>
</tr>
<tr>
<td>Field of View</td>
<td>120° horizontal 30° vertical</td>
<td>120° horizontal 30° vertical</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>2 watt</td>
<td>2 watt</td>
</tr>
</tbody>
</table>
• Low level signal processing chain is implemented on DSP (C674x) of IWR16xx
• Low level signal processing chain outputs detected point cloud with information of range, Doppler, angle, and detection SNR.
• Output point cloud information are shared with R4/tracker in L3 memory for the current implementation.
• ADC samples are EDMAed into local scratch buffers in PING-PONG fashion.
• Range processing performs FFT per antenna per chirp.
• Range processing results in local scratch buffers are EDMAed to L3 with transpose.
• **Static clutter removal** is performed removing DC components per range bin.

• Per range bin, calculate the Capon BF solution and store the angle spectrum in memory to construct the range-azimuth heatmap.
• 2-pass CFAR is performed on the range-azimuth heatmap.
• First pass is cell averaging smallest of (CFAR-CASO) in the range domain.
• Second pass is cell averaging smallest of (CFAR-CASO) in angle domain.
After detection, per detected point, estimate Doppler by filtering the range bin using Capon beamweights and then FFT with peak searching.
Point cloud, tracking and grouping

Tracking and Grouping
Tracking Module

- Implements **Object Localization**
  - Example: “I am consistently observing an array of objects. Each object has a set of following properties”
  - Uses Detection Layer Data
  - Is a State-full Layer
  - Does not Classify at object
- **Input:** Point Cloud
  - ~1000s of measurements (detection points)/frame
  - Each point has range/angle/radial velocity with associated variances
- **Output:** Target List
  - ~100s of targets/frame
  - Each target properties may include
    - Cartesian position
    - Cartesian velocity
    - Additional Features
      » Number of points/reflections
      » Dispersion/Sizes/Density
      » Timing/History
      » Velocity spread

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**Classification**

**Localization**

**Tracking Module**

**Point Cloud**

**Detection**

**Range/Doppler FFT**

**Digital FE**

**Analog FE**

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**Texas Instruments**
• **Point cloud** input is first tagged based on scene boundaries. Points outside the boundary are ignored.

• **Predict function** estimates tracking group centroid for time n based on state and process covariance matrices estimated at time n-1. *a-priori* state and error covariance estimations for each trackable object are computed. At this step we also compute measurement vector estimations.

• **Association** function allows each tracking unit to indicate whether each measurement point is “close enough” (gating), and if it is, to provide the bidding value (scoring). Point is assigned to a highest bidder.

• **Allocation**: Points not assigned, are going through an Allocate function. During the Allocation process, points are first joined into a sets based on their proximity in measurement coordinates. Each set becomes a candidate for allocation decision. It has to pass multiple tests to become a new track. Once passed, the new tracking unit is allocated.

• **Update**: During Update step, tracks are updated based on the set of associated points.

• The **Report function** queries each tracking unit and produces the algorithm output.
### Implementation Details – Tracking Config

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>maxNumPoints</td>
<td>250</td>
<td>Max # of detection points per frame</td>
</tr>
<tr>
<td>maxNumTracks</td>
<td>20</td>
<td>Max # of targets to track at any given time</td>
</tr>
<tr>
<td>initialRadialVelocity</td>
<td>0 m/s</td>
<td>Expected target radial velocity at moment of detection</td>
</tr>
<tr>
<td>maxURadialVelocity</td>
<td>20 m/s</td>
<td>Max unambiguous radial velocity; sets valid rates from –max to +max</td>
</tr>
<tr>
<td>maxAcceleration</td>
<td>5 m/s²</td>
<td>Max target acceleration; used to compute processing noise matrix</td>
</tr>
<tr>
<td>deltaT</td>
<td>50 ms</td>
<td>Frame Rate</td>
</tr>
</tbody>
</table>
TI Resource Explorer (TIREX)
Locate the Demo and Run
Demo Customization
Demo Setup and Customization

There are 3 major steps involved to get to a desired People counting Demo.

Chirp configuration design

For the area of interest like the conference room, hallway etc where the demo is being setup, working with the 5m/12m chirp configuration examples, chirp configuration needs to be designed with max range, range resolution, Max velocity and Velocity resolution in mind.

EVM installation

The EVM needs to be installed at a proper height and with a Elevation tilt to maximize the energy reflection from the objects and hence to get to a rich point cloud. This means directing the majority of transmitted energy towards the area of interest for better reflected energy reception.

GUI and Tracking Parameter Customization

Demo customization is done in GUI matlab code for setting up the Demo visualization

The Group tracker needs to be configured for various parameters in task_app.c file under the project pplcount_16xx_mss, to work on the input point cloud data for localization and tracking via. These parameters include

Scenery Parameters
Allocation Parameters
State Transition Parameters

and the Demo needs to be recompiled & built after any change to the above said tracking parameters
Steps for Demo setup

**Step-1**
EVM Setup

- EVM setup to get to a better detection resulting in rich point cloud

**Step-2**
Set the Scenery parameters

- Change scenery parameters for tracker according to area of Interest

**Step-3**

- Run the Demo, Observe the artifacts, if any

**Step-4**

- Based on the artifacts seen further customize the tracker using State transition and allocation parameters

- No artifacts → Desired Demo

- Repeat until artifacts exists
EVM installation

- **Height:**
  EVM needs to be installed at least 2-2.5mtrs above ground

- **Tilt in Elevation**
  EVM needs to be tilted as shown in the picture with an angle \(x\) deg where \(10 < x < 45\) deg.

  \(X=10\) deg works better for conference/meeting rooms

  The elevation tilt helps focus the transmitted energy towards the area of interest and achieve better reflection which results in a good detection thus a rich point cloud.
Steps for Demo setup

Step-1: EVM Setup
- EVM setup to get to a better detection resulting in rich point cloud

Step-2: Set the Scenery parameters
- Change scenery parameters for tracker according to area of Interest

Step-3: Run the Demo, Observe the artifacts, if any
- Based on the artifacts seen further customize the tracker using State transition and allocation parameters

Step-4: No artifacts
- Desired Demo

Repeat until artifacts exists
Tracking Parameter Customization

Run the demo once with the test scenarios in the area of Interest
Observe the performance and note down the artifacts seen.
Steps for Demo setup

Step-1
EVM Setup
EVM setup to get to a better detection resulting in rich point cloud

Step-2
Set the Scenery parameters
Change scenery parameters for tracker according to area of Interest

Step-3
Run the Demo, Observe the artifacts, if any

Step-4
Based on the artifacts seen further customize the tracker using State transition and allocation parameters

Repeat until artifacts exists

No artifacts

Desired Demo
Tracking Parameter Customization

Allocation Parameters

The reflection points reported in point cloud are associated with existing tracking instances. Points that don’t get associated are subjects for the allocation decision. Each candidate point is clustered into an allocation set. To join the set, each point needs to be within maxDistance and maxVelThre from the set’s centroid. Once the set is formed, it has to have more than setPointsThre members, and pass the minimal velocity and SNR thresholds to start tracking.

\[
\text{appAllocationParamTable}[2] = \{\text{SNRThreshold, VelocityThreshold, Pointsthreshold, MaxDistanceThre, MaxVelThre}\}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SNR Threshold</strong></td>
<td>250</td>
<td>Minimum total SNR for the allocation set, linear sum of power ratios</td>
</tr>
<tr>
<td><strong>Velocity Threshold</strong></td>
<td>0.1 m/s</td>
<td>Minimum radial velocity of the allocation set centroid</td>
</tr>
<tr>
<td><strong>Points Threshold</strong></td>
<td>5</td>
<td>Minimum number of points in the allocation set</td>
</tr>
<tr>
<td><strong>maxDistanceThre</strong></td>
<td>1 m²</td>
<td>Maximum squared distance between candidate and centroid to be part of the allocation set</td>
</tr>
<tr>
<td><strong>maxVelThre</strong></td>
<td>2 m/s</td>
<td>Maximum velocity difference between candidate and centroid to be part of the allocation set</td>
</tr>
</tbody>
</table>
Steps for Demo setup

Step-1: EVM Setup
- EVM setup to get to a better detection resulting in rich point cloud

Step-2: Set the Scenery parameters
- Change scenery parameters for tracker according to area of Interest

Step-3: Step-3
- Run the Demo, Observe the artifacts, if any

Step-4: Step-4
- Based on the artifacts seen further customize the tracker using State transition and allocation parameters

Repeat until artifacts exist

No artifacts → Desired Demo
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