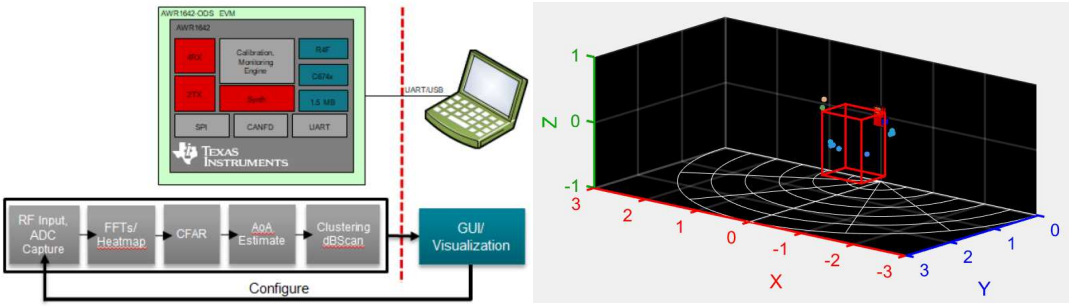
Overview

This lab demonstrates the use of TI mmWave sensors to detect objects that are within close proximity of a vehicle. Using the AWR1642-ODS EVM, algorithms run onboard the single-chip device to create Range-Azimuth and Range-Elevation heatmaps, then performs object detection with CFAR, angle of arrival estimation and clustering on configured range rows in the heatmaps.



Quickstart

The quickstart contains:

- Precompiled binaries for flashing the device using Uniflash
- Visualizer as .exe

1. Hardware and Software Requirements

Hardware

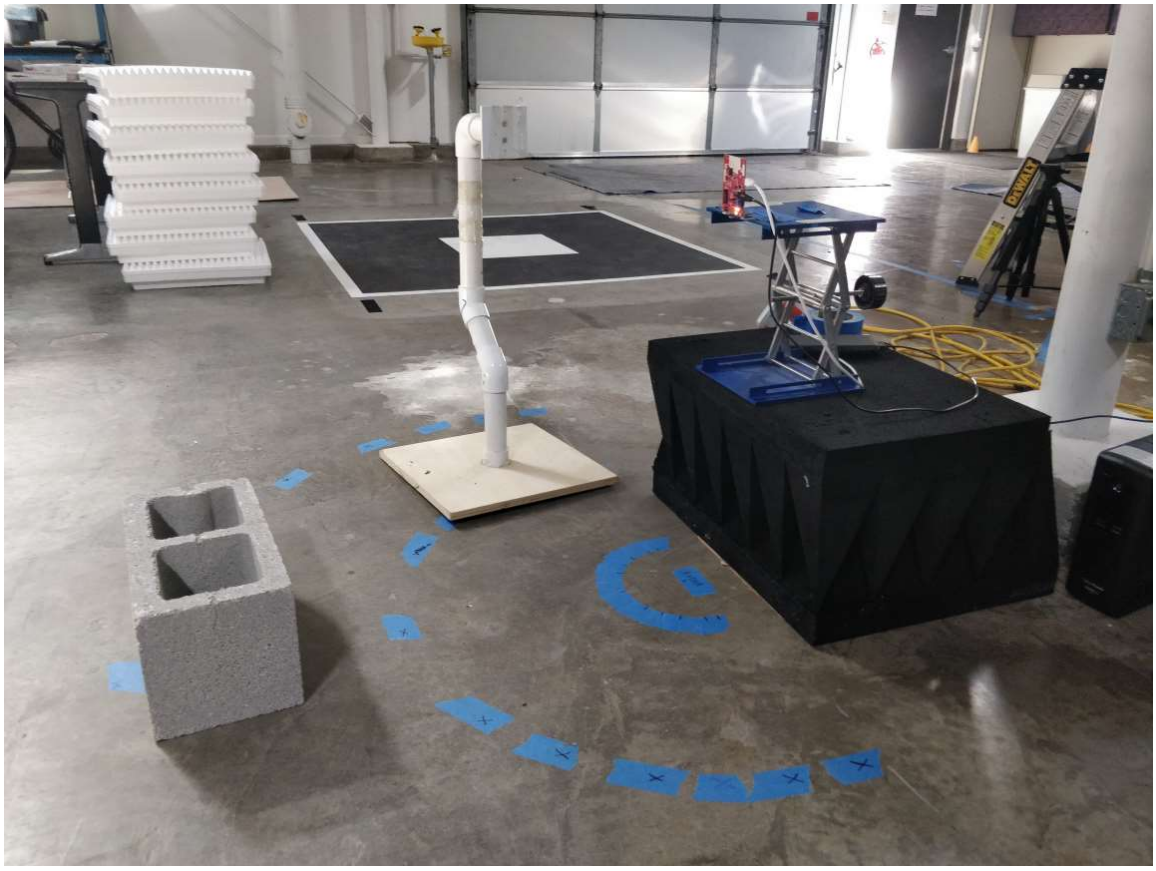
Item	Details
Device	AWR1642 ODS EVM (http://www.ti.com/tool/AWR1642BOOST-ODS)
Computer	PC with Windows 7 or 10. If a laptop is used, please use the 'High Performance' power plan in Windows. 2.4Ghz processor, 8GB RAM recommended.
Micro USB Cable	USB 2.0 to Micro USB.
Power Supply	5V, >2.5A with 2.1-mm barrel jack (center positive). The power supply can be wall adapter style or a battery pack with a USB to barrel jack cable.

Software

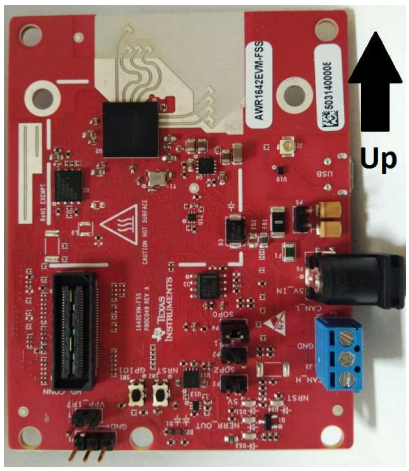
Tool	Version	Required For	Details
mmWave Automotive Toolbox	2.0.0+	ES2.0 silicon	Contains all files (quickstart, visualizer and firmware source files) related to mmWave Obstacle Detection Lab
MATLAB Runtime	2017a (9.2)	GUI Visualizer	To run the quickstart visualizer the runtime (https://www.mathworks.com/products/compiler/matlab-runtime.html) is sufficient.
TI mmWave SDK	2.0.0.4	Firmware Source Code	The latest TI mmWave SDK (http://dev.ti.com/tirex/#/?link=Software%2FmmWave%20SDK) and all the related tools are required to be installed as specified in the mmWave SDK release notes
TI Emulators package	6.0.0576.0 or later	-	Upgrade to the latest using CCS update process (see SDK user guide for more details)
ODS Design Document	n/a	More Details /Info	Find it here: http://www.ti.com/tool/TIDEP-0104 (http://www.ti.com/tool/TIDEP-0104)

2. Physical Setup

For best results, the EVM should be positioned at car door height, with no objects in the configured range of the sensor except those objects that are under test:



In order to provide +/-70deg FOV in azimuth and +/-40deg FOV in elevation, the AWR1642BOOST-ODS EVM must be placed with antenna at the top as shown in this picture.



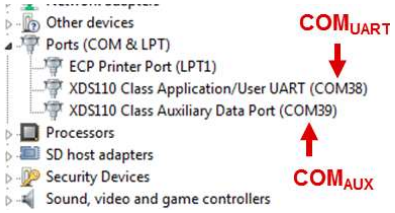
3. Flash the Device

- Power on the EVM using a 5V/2.5A power supply.
- Flash the following image using **Uniflash**

Image	Location
Meta Image 1/RadarSS	`C:<install_dir>\lab0002_obstacle_detection\prebuilt_binaries\odsdemo_16xx.bin`

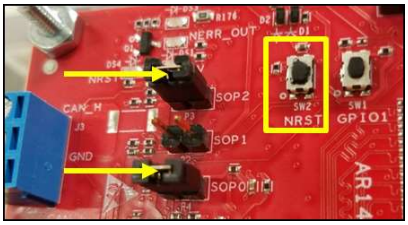
Expand for help using Uniflash

- Connect the EVM to your PC and check the COM ports in **Windows Device Manager**
  - The EVM exports two virtual COM ports as shown below:
    - XDS110 Class Application/User UART (COM UART): Used for passing configuration data to the EVM
    - XDS110 Class Auxiliary Data Port (COM AUX): Used to send processed radar data output to the PC

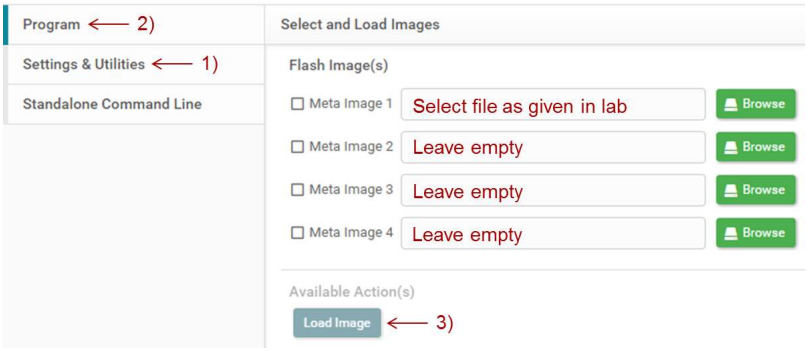


> Note the COM UART and COM AUX port numbers, as they will be used later for flashing and running the lab.

- Put the EVM in flashing mode by connecting jumpers on **SOP0** and **SOP2** as shown in the image. Then power cycle the EVM with **SW2**.



- Open the **UniFlash tool** (Download offline tool (http://www.ti.com/tool/UNIFLASH) or use cloud version (https://dev.ti.com/uniflash/#!/))
  - In the New Configuration section, locate and select the appropriate device (AWR1642)
  - Click Start to proceed
- Click the **Settings & Utilities** tab. Under setup, fill the **COM Port** text box with the Application/User UART COM port number (COM UART) noted earlier.
- In the **Program** tab, browse and locate the images (.bin file) as specified in the lab directions.



- **Power cycle** the device and click on **Load Images**

> **Successful Flash Procedure**
> UniFlash's console should indicate: [SUCCESS] Program Load completed successfully

- Power off the board and **remove only SOP2 jumper**

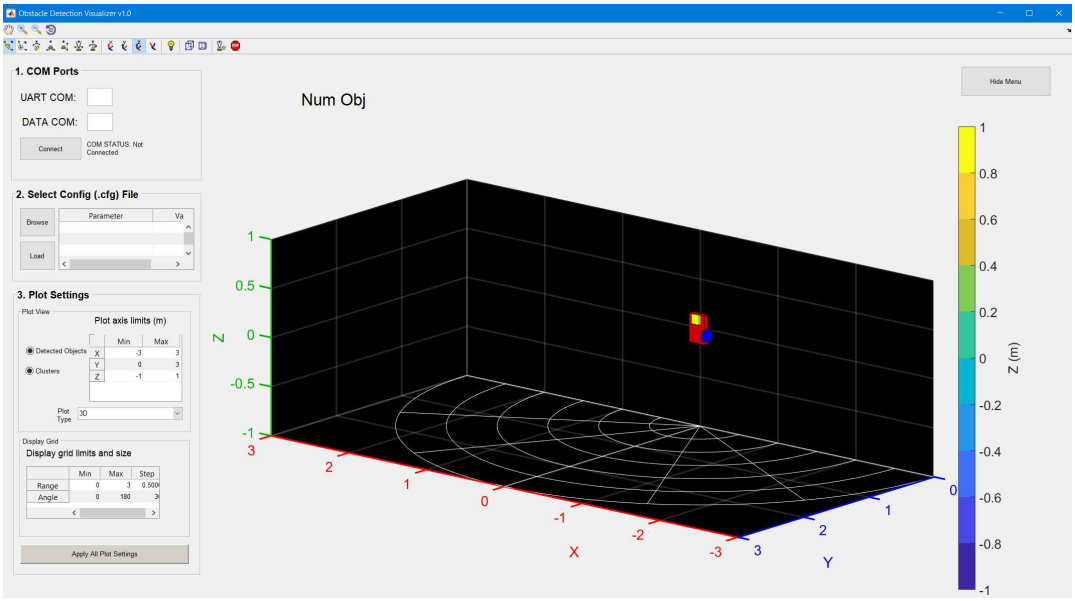
> **SOP2 Removed?**
> Ensure that the jumper has been removed and the EVM power cycled. This puts the board back in functional mode.

4. Run the Lab Visualizer

Before running the demo, you will need to know the COM port numbers for the EVM's User and Data UART ports. This is discussed in the pulldown section above titled "Expand for help using Uniflash". Once found, the COM port numbers will usually not change from run to run or boot to boot. You can run the visualizer either from DOS or within Matlab:

Program File	Purpose
ods_3d_visualizer.m	Running within Matlab
ods_3d_visualizer.exe	Running from a DOS command window

- The following steps assume the AWR1642-ODS EVM is flashed with the Obstacle Detection firmware.
- Mount the EVM as shown above in the Test Setups.
- Attach the micro USB cable from the EVM to the host PC.
- Attach the 5V power adapter cable to the EVM.
- Open a DOS Command Window, and cd to `C:<install_dir>\lab0002_obstacle_detection\gui` .
- At the DOS prompt, enter this command: (there are no command line arguments)
    - ods_3d_visualizer
- After a moment, the visualizer will look like this:



To start the radar chirp processing, perform the following steps:

- Fill in the two COM port numbers, then click the "Connect" button.
- Browse to the provided configuration file: `C:<install_dir>\lab0002_obstacle_detection\chirp_configs\ods_default_config.cfg` .
- Click the "Load" button.
- The visualizer will now begin displaying detected objects and clusters.

To modify the display, the widgets in the "Plot Settings" window can be modified:

- The "Detected Objects" and "Clusters" buttons can be clicked at any time to enable/disable their display.
- To change the display from 3D to a 2D projection, open the "Plot Type" drop-down menu, make a selection, then click the "Apply All" button.
- To change the overall display limits, modify the values in "Plot axis limits" and click the "Apply All" button.
- To change the grid limits, modify the values in "Display grid limits and size" and click the "Apply All" button.

To modify the rendered image orientation and size:

- Select one of the icons shown here, then drag the mouse either up/down or left/right over the image. If you hover over an icon, a message will tell you what the button does. The button shown here in blue allows the size of the image to change. Drag the mouse up over the image (with the left button down) to increase the size, and down to decrease the size.

5. Understanding the Output

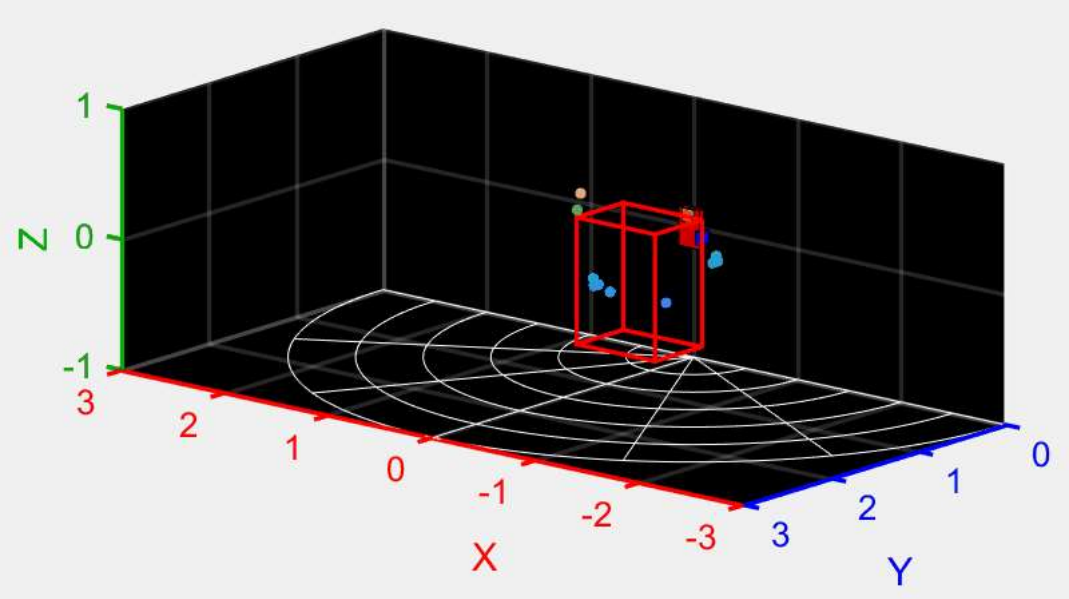
By default, detected objects and clusters are displayed. Detected objects are shown as dots in the 3D space, and clusters are shown as boxes. Cluster box sizes are obtained from the DSP's clustering algorithm. Detected objects are updated at the configured frame rate, and clusters are updated at a slower rate, typically once every four frames. Note that detected objects and clusters can be disabled from being output from the

EVM. This is enabled in the "guiMonitor" command, discussed in the "Visualizer Source Files" section below.

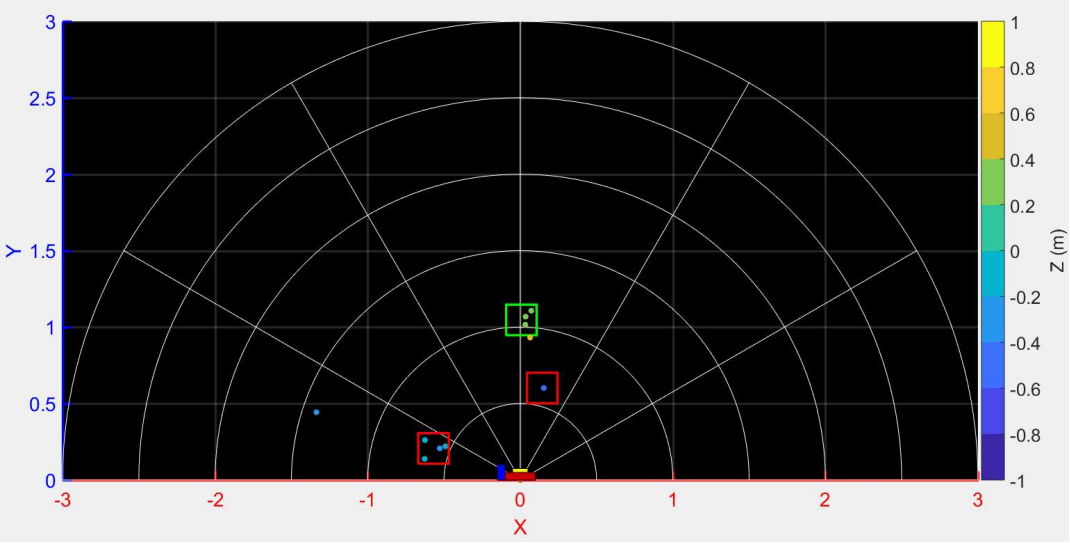
First, there is a banner line over the plot area. This banner displays the current frame number, the number of detected objects for the frame, and the number of clusters for the current frame. The number in parentheses is the number of clusters that are derived from a single point.

Frame: 4325 Objects: 9 Clusters: 2(0)

The detected object (dot) colors are determined by their Z distance (height) from the antenna. Cluster colors are red if the center is within 1 meter of the antenna, and green if outside 1 meter.



Each 2D display shows a flat projection along two of the three planes. Shown here is the "top-down" display that shows objects and clusters in the X-Y plane. Object point colors are still rendered according to Z position:



Developer's Guide

Building the Firmware from Source Code

1. Prerequisites for Firmware

The software prerequisites must be met before continuing!

To verify proper installations, navigate to `C:\ti` and ensure that the following tools have been installed in the *EXACT* directory specified.

Tool	Version	Folder Path	Download link & Details
CCS	7.3 or later	`C:\ti\ccsv7`	Download link (http://processors.wiki.ti.com/index.php/Download_CCS#Code_Composer_Studio_Version Note: CCSv6.x cannot be used
TI SYS/BIOS	6.53.2.00	`C:\ti\bios_6_53_02_00`	Included in mmwave sdk installer
TI ARM compiler	16.9.6.LTS	`C:\ti\ti-cgt-arm_16.9.6.LTS`	Included in mmwave sdk installer
TI DSP compiler	8.1.3	`C:\ti\ti-cgt-c6000_8.1.3`	Version 8.1.3 must be downloaded and installed. Download link (http://software-dl.ti.com/dsps/forms/self_cert_export.html?prod_no=ti_cgt_c6000_8.1.3_windows_installer.exe&ref_url=http://software-dl.ti.com/codegen/esd/cgt_registered_sw/C6000/8.1.3PC)
XDC	3.50.4.43	`C:\ti\xdctools_3_50_04_43_core`	Included in mmwave sdk installer
C64x+ DSPLIB	3.4.0.0	`C:\ti\dsplib_c64Px_3_4_0_0`	Included in mmwave sdk installer
C674x DSPLIB	3.4.0.0	`C:\ti\dsplib_c674x_3_4_0_0`	Included in mmwave sdk installer
C674x MATHLIB	3.1.2.1	`C:\ti\mathlib_c674x_3_1_2_1`	Included in mmwave sdk installer
mmwave device support packages	1.5.3 or later	-	Upgrade to the latest using CCS update process (see SDK user guide for more details)
TI Emulators package	6.0.0576.0 or later	-	Upgrade to the latest using CCS update process (see SDK user guide for more details)

2. Import Lab Project

For the Obstacle Detection lab there are two projects, the DSS for the C674x DSP core and the MSS project for the R4F core. Both need to be imported to CCS and compiled to generate firmware for the xWR1642.

- Start CCS and setup workspace as desired.
- Import the projects below to CCS using either TI Resource Explorer in CCS or CCS Import Projectspecs method:
  - **odsdemo_16xx_dss**
  - **odsdemo_16xx_mss**

Expand for details on importing via TI Resource Explorer in CCS

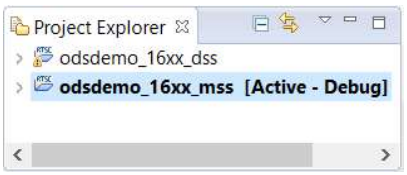
- In the top toolbar, navigate to **View > Resource Explorer**
- In the **Resource Explorer** side panel (not the main panel with "Welcome to.."), navigate to **Software > mmWave Sensors > Industrial Toolbox - > Labs > Obstacle Detection Demo**
- Under the expanded **Obstacle Detection Demo** folder, there should be two CCS projects, **CCS Project - DSS** and **CCS Project - MSS**.
- For each of the two projects: Click on the project, which should open the project in the right main panel, and then click on the Import to IDE button  .

Expand for details on importing via CCS Import Projectspecs

- In the top toolbar, navigate to **Project > Import CCS Projects...**
- With the **Select search-directory** option enabled, click **Browse...**, navigate to the folder `C:\ti\<install_dir>\lab0002_obstacle_detection\src` , and then click **OK**.
- Under **Discovered projects**, select **odsdemo_16xx_dss** and **odsdemo_16xx_mss** (ignore any other projects), then click **Finish**.

Successful Import to IDE

After using either method, both projects should be visible in **CCS Project Explorer**



Project Workspace

When importing projects to a workspace, a copy is created in the workspace. All modifications will only be implemented for the workspace copy. The original project downloaded in mmWave Automotive Toolbox is not touched.

3. Build the Lab

Build DSS Project

The DSS project must be built before the MSS project.

The DSS project must be built using compiler version 8.1.3. To check the build settings, select **odsdemo_16xx_dss** and right click on the project to select **Show build settings...**. Under the **General** tab, the **Advanced Settings** section has a drop down menu for **Compiler Version**. Ensure that it reads **TI v8.1.3**.

With the **odsdemo_16xx_dss** project selected in **Project Explorer**, right click on the project and select **Rebuild Project**. Selecting **Rebuild** instead of **Build** ensures that the project is always re-compiled. This is especially important in case the previous build failed with errors.

Successful DSS Project Build

In the **Project Explorer** panel, navigate to and expand **odsdemo_16xx_dss > Debug** directory. The project has been successfully built if the following files appear in the **Debug** folder:

- odsdemo_16xx_dss.bin
- odsdemo_16xx_dss.xe674

Build MSS Project

After the DSS project is successfully built, select **odsdemo_16xx_mss** in **Project Explorer**, right click on the project and select **Rebuild Project**.

Successful MSS Project Build

In the **Project Explorer** panel, navigate to and expand **odsdemo_16xx_mss > Debug** directory. The project has been successfully built if the following files appear in the **Debug** folder:

- odsdemo_16xx_mss.bin
- odsdemo_16xx_mss.xer4f
- odsdemo_16xx.bin

Build Fails with Errors

If the build fails with errors, please ensure that all the prerequisites are installed as mentioned in the mmWave SDK release notes.

4. Execute the Lab

There are two ways to execute the compiled code on the EVM:

- Deployment mode: the EVM boots autonomously from flash and starts running the bin image
  - Using Uniflash, flash the **odsdemo_16xx.bin** found at `<PROJECT_WORKSPACE_DIR>\odsdemo_16xx_mss\Debug\odsdemo_16xx.bin`
  - The same procedure for flashing can be use as detailed in the Quickstart Flash the Device section.
- Debug mode: enables connection with CCS while lab is running; useful during development and debugging

Expand for help with Debug mode:

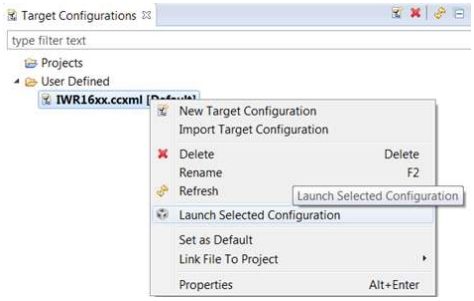
The CCS debug firmware (provided with the mmWave SDK) needs to be flashed once on the EVM.

- CCS Debug method is enabled by flashing the CCS Debug Firmware (provided with the mmWave SDK) using the methods covered in the Quickstart Flash the Device section.
- Use the following image instead

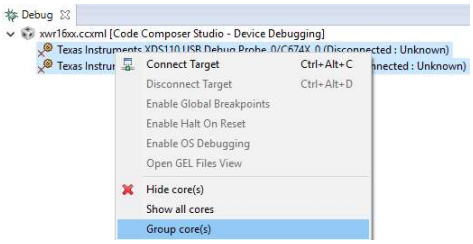
Image	Location	Comment
Meta Image 1/RadarSS	`C:\ti\mmwave_sdk_<ver>\packages\ti\utils\ccsdebug\xwr16xx_ccsdebug.bin`	Provided with the mmWave SDK

After the CCS debug firmware has been flashed, connect the EVM to CCS

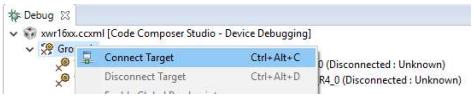
- Create a target configuration (skip to "Open the target..." if config already created previously in another lab for xwr16xx)
  - Go to **File > New > New Target Configuration File**
  - Specify an appropriate file name (ex: AWR16xx.ccxml) and check "**Use shared location**". Click **Finish**.
- In the configuration editor window:
  - Select **Texas Instruments XDS110 USB Debug Probe** for Connection
  - Select **AWR1642** device as appropriate in the Board or Device text box.
  - Press the **Save** button to save the target configuration.
  - [Optional]: Press the **Test Connection** button to check the connection with the board.
- Open the target configuration window by going to **View > Target Configurations**.
  - Under **User Defined** configurations the target configuration previously created should appear.
  - Right click on the target configuration and select **Launch Select Configuration**. The target configuration will launch in the **Debug** **Window**.



- Group cores and connect
  - Select both the **Texas Instruments XDS110 USB Debug probe/C674X_0** and **Texas Instruments XDS110 USB Debug probe/Cortex_R4_0** and then right click and select **Group core(s)**



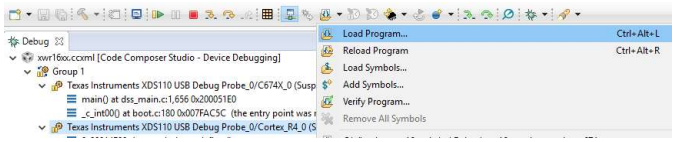
  - Select **Group 1** and then right click and select **Connect Target**



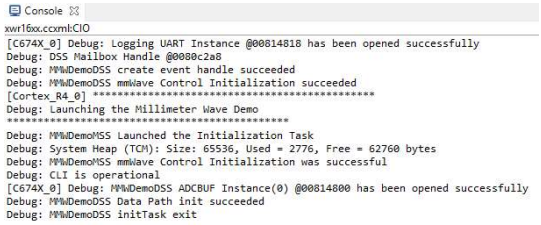
- Load the binary
  - Once both targets are connected, click on the C674X_0 target and then click **Load** button in the toolbar.

  - In the **Load Program** dialog, press the **Browse Project** button .
  - Select **odsdemo_16xx_dss.xe674** found at `<PROJECT_WORKSPACE_DIR>\odsdemo_16xx_dss\Debug\odsdemo_16xx_dss.xe674` and press **Ok**.
  - Press **Ok** again in the **Load Program** dialog.

- Repeat the above Load the Binary process for the Cortex_R4_0 target, selecting instead **odsdemo_16xx_mss.xer4f** found at `<PROJECT_WORKSPACE_DIR>\odsdemo_16xx_mss\Debug\odsdemo_16xx_mss.xer4f`



- Run the binary
  - Select **Group 1**, press the **Run/Resume** button 
  - The program should start executing and generate console output as shown.



> **Successful Run Binary**
>
> If binary is running correctly, the Console will include the "CLI is operational" message which indicates that the program is ready and waiting for the sensor configuration.

After starting the lab on the AWR1642 using either method, the program will wait until a chirp configuration is sent to it via the "User" COM port.

Visualizer Source Files

> Working with and running the Visualizer source files requires a MATLAB License not just the MATLAB Runtime Engine

The detection processing chain is implemented in the C674x DSP core of the AWR1642 device. The visualizer serves to read the UART stream from the device and plots the detected objects and cluster information.

Source files are located at `C:<install dir>\lab0002_obstacle_detection\gui` .

- **ods_3d_visualizer.m**: the Matlab gui program which reads and parses the UART data for visualization.
- **ods_3d_visualizer.exe**: the DOS executable version of the gui program.

Chirp Configuration files are located at `C:<install dir>\lab0002_obstacle_detection\chirp_configs` . In addition to the normal mmWave chirp configuration CLI commands, there are a few commands that are specific to the Obstacle Detection Demo:

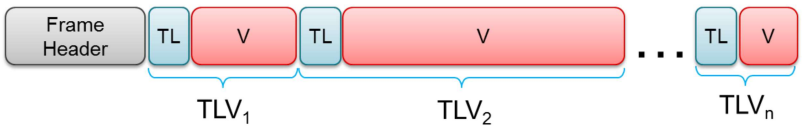
Command	Parameters
guiMonitor	1 1 0 0
	(this command has unique arguments for this demo)
1	1 = send the detected object array.
1	1 = send the cluster array.
0	1 = send the range-azimuth heatmap.
0	1 = send the range-elevation heatmap.
cfarCfg	1 4 12 4 2 8 2 350 30 2 0 5 20
1	Range-azimuth heatmap generation method 1) Covariance BF, 2) MVDR
4	Number of left range bins to skip, default = 4
12	Number of close-In range bins, default = 12. Near field range bins receive special treatment.
4	CFAR noise average window size, default = 4.
2	CFAR detection guard window size, default = 2.
8	FFT spreading effect window size, default = 8. The peak due to the FFT spreading of neighboring peak will be ignored.
2	FFT spreading effect guard window size, default = 2.
350	CFAR detection threshold (in units of 0.1 linear), default = 350.
30	FFT spreading threshold(in the unit of 1e-5 linear), default = 30.
2	Noise calculation type: 0) CFAR-CA: take the average between left-side noise average and right side noise average. 1) take the minimum value of left-side noise average or the total mean. 2) take the minimum of left-side or right-side noise average. Default = 2.
0	Enable local peak requirement: The detection points needs to bigger than its direct left and right neighbor.
5	Peak angle difference threshold (in units of 3 degrees): For the close in target, all the detection has to be a local peak. In addition, if it is less than its second left neighbor, then the peak angle between this two range indexes (current and its second left neighbor) has to be differ by this peak angle difference threshold. Suggested value: 3-5.
20	Max range for detection (in units of 0.1m). Depending on the interested detected range of each application, users can set it differently. There is a hard limitation of up to 256 range bins. Setting a smaller value than the max range that chirp configuration allows can save computation complexity and therefore, can set a higher frame rate in the frame configuration.
dbscanCfg	4 4 13 20 3 256
4	Number of accumulated frames to do clustering. Default = 4.
4	Max distance allowed in clustering (in units of 0.1m), depending on the object size. For door opening, default value is 2 - 4.
13	Weighting factor between the distance and speed in cost function (in units of 0.1). Default value is 1.3. To ignore the speed impact in clustering, this value can be set to 0.
20	Speed clipping threshold (in units of 0.1m/s): if speed is too high, the speed impact in clustering cost function can be too large. Speed is clipped up to this threshold. Default value is 20.
3	Minimum points to claim a cluster: A cluster will be claimed to be cluster if it contains at least this minimum number of detected points. Default value: number of accumulated frames - 1.
256	Fixed point scale: the speed (in m/s) and distance (in m) are scaled up to apply clustering algorithm in fixed-point. Default value: 256.

Please refer to the mmWave SDK's user guide for details on the chirp (RF) related CLI configuration commands.

Data Packet Format

A TLV(type-length-value) encoding scheme is used with little endian byte order. For every frame, a packet is sent consisting of a fixed sized **Frame Header** and then a variable number of TLVs depending on what was selected via the guiMonitor command. There are 4 possible TLV types for the Obstacle Detection demo:

TLV Name	Type	Data Size (bytes)
Detected Objects	1	4 + (12 x numDetObj)
Clusters	2	4 + (12 x numClusters)
Range Azimuth Heatmap	3	60 x Yr x sizeof(float)
Range Elevation Heatmap	4	60 x Yr x sizeof(float)



Frame Header

Size: 40 bytes

```
frameHeaderStructType = struct(...
    'sync',             {'uint16', 8}, ... % syncPattern in hex is: '02 01 04 03 06 05 08 07'
    'version',          {'uint32', 4}, ... % 0xA1642 or 0xA1443
    'totalPacketLen',   {'uint32', 4}, ... % In bytes, including the header
    'platform',         {'uint32', 4}, ... % See description below
    'frameNumber',      {'uint32', 4}, ... % Starting from 1
    'timeCpuCycles',    {'uint32', 4}, ... % Time in DSP cycles when the message was created
    'numDetectedObj',   {'uint32', 4}, ... % number of detected objects
    'numTLVs' ,         {'uint32', 4}, ... % Number of TLVs in this message
    'subFrameIndex',    {'uint32', 4});    % always zero
```

Frame header in MATLAB syntax

TLVs

TLVs in this demo can be of type **DETECTED_OBJECTS**, **CLUSTERS**, **RANGE_AZIMUTH_HEAT_MAP**, or **RANGE_ELEV_HEAT_MAP**. Each TLV consists of a TLV header plus a unique data type.

TLV Header

Size: 8 bytes

```
% TLV Type: 01 = DetectedObjects, 02 = Clusters, 03 = RangeAzimuthHeatmap, 04 = RangeElevHeatmap
tlvHeaderStruct = struct(...
    'type',             {'uint32', 4}, ... % TLV object
    'length',           {'uint32', 4});    % TLV object Length, in bytes, including TLV header
```

TLV header in MATLAB syntax

Following the header are the TLV-type specific payloads

Detected Objects TLV

Type: DETECTED_OBJECTS

Size: 4 + (12 x numDetObj)

The following structure is only present if the TLV header.length is greater than zero.

```
featureVector = struct(...
    'numDetObj',  {'short', 2}, ... % Number of detected objects in the following sub-struct
    'xyzQFormat', {'short', 2}, ... % Q-point shift value to convert to meters
      %per object:
      'speedIdx', {'short', 2}, ... % Doppler index
      'x',        {'short', 2}, ... % x - coordinate in meters, divided by xyzQFormat
      'y',        {'short', 2}, ... % y - coordinate in meters, divided by xyzQFormat
      'z',        {'short', 2}, ... % z - coordinate in meters, divided by xyzQFormat
      'rangeIdx', {'short', 2}, ... % Range index
      'peakVal',  {'short', 2}, ... % Peak value
```

Detected Object Structure in MATLAB syntax

Cluster TLV

Type: CLUSTERS

Size: 4 + (12 x numClusters)

The following structure is only present if the TLV header.length is greater than zero. Note that cluster size can be adjusted by the "max distance" parameter of **dbscanCfg**.

```
featureVector = struct(...
    'numClusters',{'short', 2}, ... % Number of clusters in the following sub-struct
    'xyzQFormat', {'short', 2}, ... % Q-point shift value to convert to meters
      %per cluster:
      'x',        {'short', 2}, ... % x - coordinate in meters, divided by xyzQFormat
      'y',        {'short', 2}, ... % y - coordinate in meters, divided by xyzQFormat
      'z',        {'short', 2}, ... % z - coordinate in meters, divided by xyzQFormat
      'xsize',    {'short', 2}, ... % x size of the cluster, in meters, by xyzQFormat
      'ysize',    {'short', 2}, ... % y size of the cluster, in meters, by xyzQFormat
      'zsize',    {'short', 2}, ... % z size of the cluster, in meters, by xyzQFormat
```

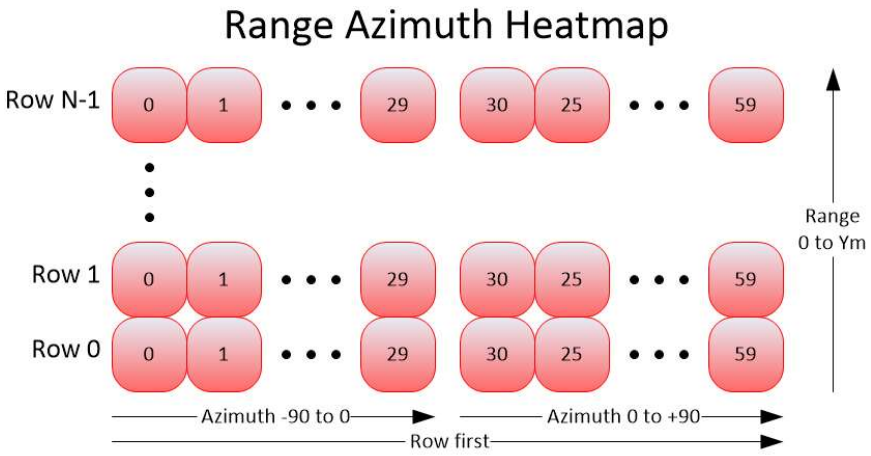
Cluster Structure in MATLAB syntax

The two ODS heatmaps are 2D array of floats, and will be the same size based on the current configuration. The size of the row is currently hardcoded in the target code and visualizer to be 180 degrees divided by the angular or elevation resolution, currently 3 degrees. So each row contains 60 points, and the row corresponds to a range from the antenna. The number of rows, Yr, is calculated by both the target code and visualizer code, based on the **profileCfg** and **cfarCfg** commands in the configuration file. First, the range resolution (in meters) is calculated from **profileCfg**, then the max detection range in **cfarCfg** is divided by the range resolution to obtain the number of range rows.

Range Azimuth Heatmap TLV

Type: RANGE_AZIMUTH_HEAT_MAP

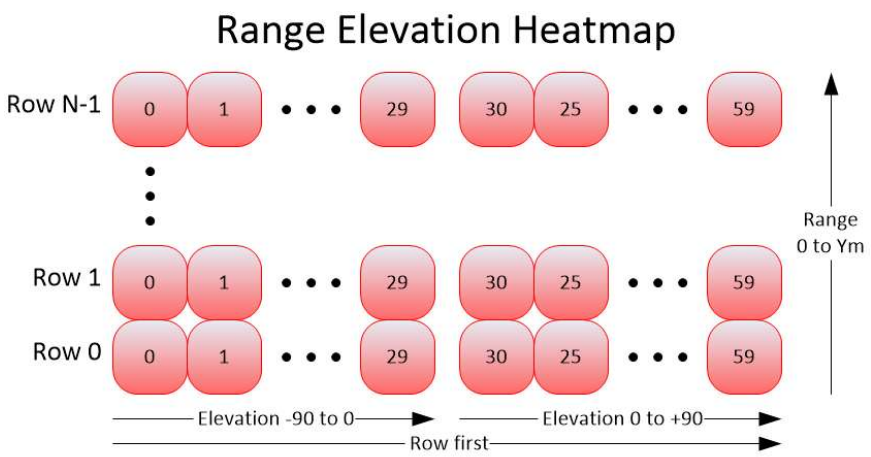
Size: 60 x Yr x sizeof (float)



Range Elevation Heatmap TLV

Type: RANGE_ELEV_HEAT_MAP

Size: 60 x Yr x sizeof (float)



Need More Help?

- Find more details about ODS by referring to the ODS TI Design document (http://www.ti.com/tool/TIDEP-0104)
- Find answers to common questions on mmWave E2E FAQ (https://e2e.ti.com/support/sensor/mmwave_sensors/w/wiki)
- Search for your issue or post a new question on the mmWave E2E forum (https://e2e.ti.com/support/sensor/mmwave_sensors/f/1023)