STANDARD OPERATING PROCEDURE

1. PURPOSE

To provide a procedure to define the general workflow to calibrate/tune the IWR1642BOOST EVM for accurate people detection, tracking and counting.

2. SCOPE

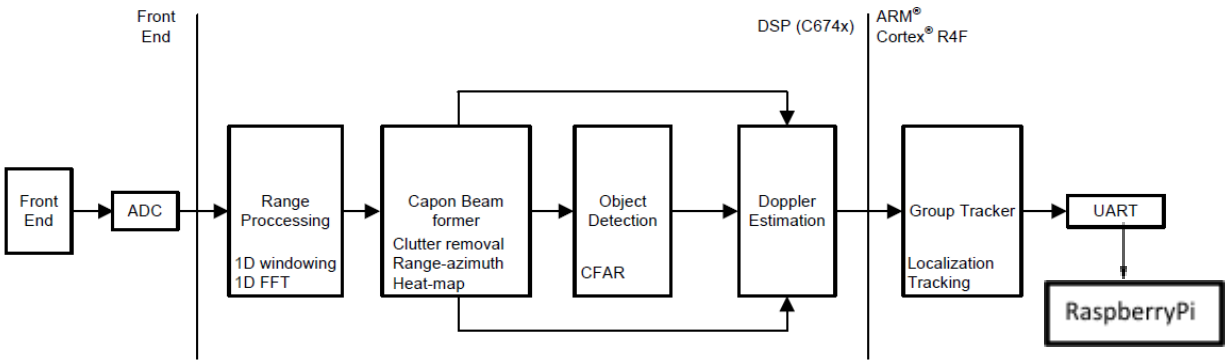
This procedure applies to all individuals who will be assigned to calibrate and tune the radar EVM sensor board.

3. RESPONSIBILITES

It is the responsibility of all supervisors, managers, training coordinators and employees to follow the procedures and guidelines outlined in this SOP.

4. BACKGROUND

The workflow for people detection and counting is described in Figure 1. Raw ADC values are extracted, and a radar data cube is obtained. A radar cube is a 3-dimensional representation along the range, doppler and azimuth dimensions.



The radar cube is then processed firstly along its columns i.e. range using 1D FFT. Next, to steer the beam vector and determine the Direction of arrival (DoA) of the received chirp accurately, the capon Beamforming (Minimum variance distortionless response) algorithm is used. It allows us to remove interference or noise due to external sources in the FOV. Then, the CASO-CFAR (Cell average smallest of – Constant false alarm rate) algorithm is used for object detection based on a range-azimuth heatmap. To determine the velocity vector of objects detected, doppler FFT is computed. Finally, after the point clouds of the objects are grouped and tracked, point cloud information is serially transmitted to the RPi through USB.

4.1 Features of implemented system

Parameter	Value
Operating frequency	77Ghz
Max range	14m
Max velocity	18.9Kmph
Velocity resolution	0.297Kmph
Range resolution	12cm
Horizontal field of view	120^{o}
Vertical field of view	0^{o}
Max number of people detected accurately*	7
Update rate	20Hz

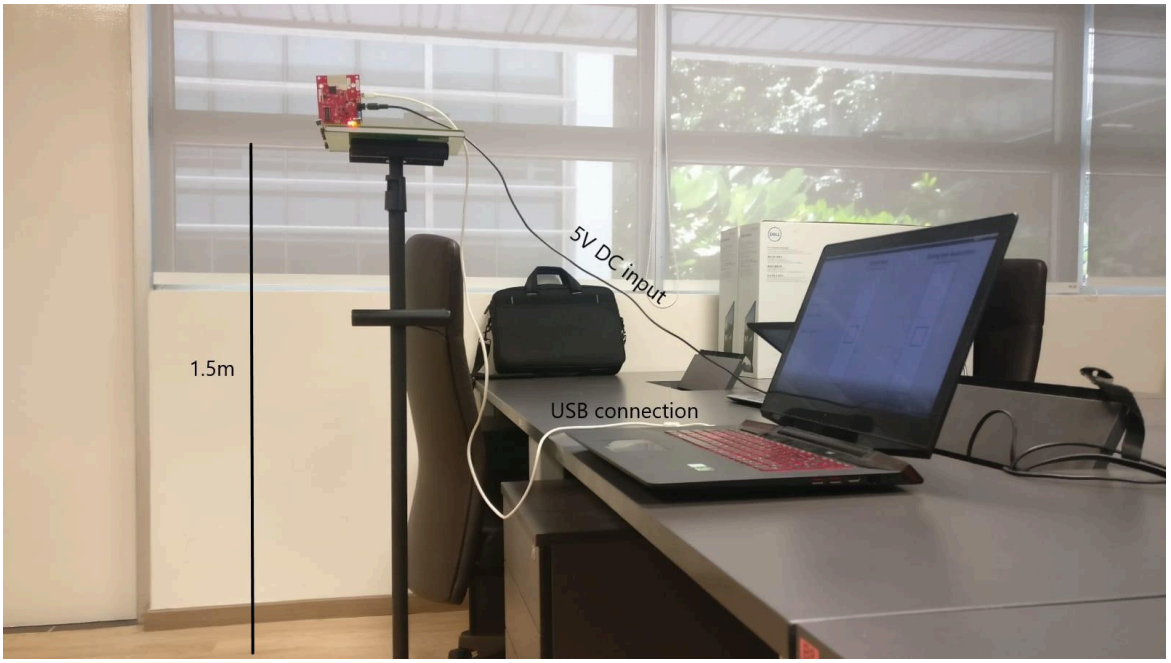
*Soft limit: Can detect up to 20 people but may lead to inaccuracies or out of memory in Buffer space if number of people is greater than 7.

4.2 People counting application

1. To be placed at entrances/exits to count number of people entering or leaving the facility.
2. To aid in counting people who are present in a zone/area.

4.3 Setting up the IWR1642BOOST EVM

- Voltage source: 5v (2.5A)
- **Tilt: 0^{o} (Not required since we're only detecting a person's head/upper body)**
- **Height: 1.5m**
- Power consumption: 2W
- Data transfer: Micro USB for UART communication
- Number of transmitting antennas: 2 (azimuth)
- Number of receiving antennas: 4

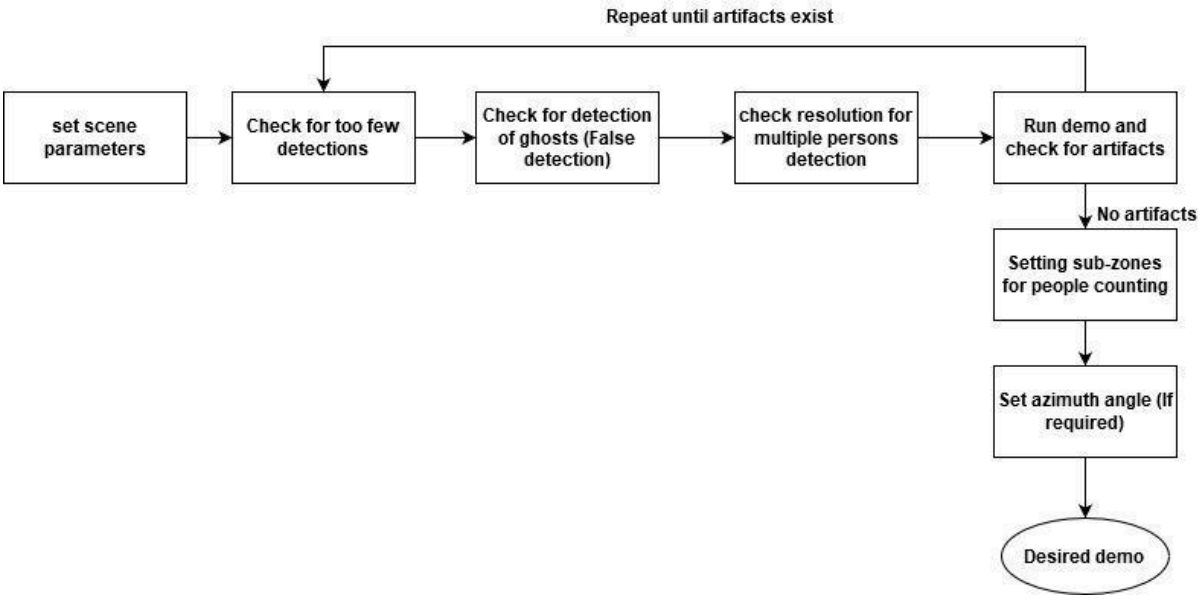


5. CALIBRATION PROCEDURE (FOR PEOPLE DETECTION AT ENTRANCES)

To calibrate the EVM sensor, the .cfg file as shown below should be modified according to the requirements.

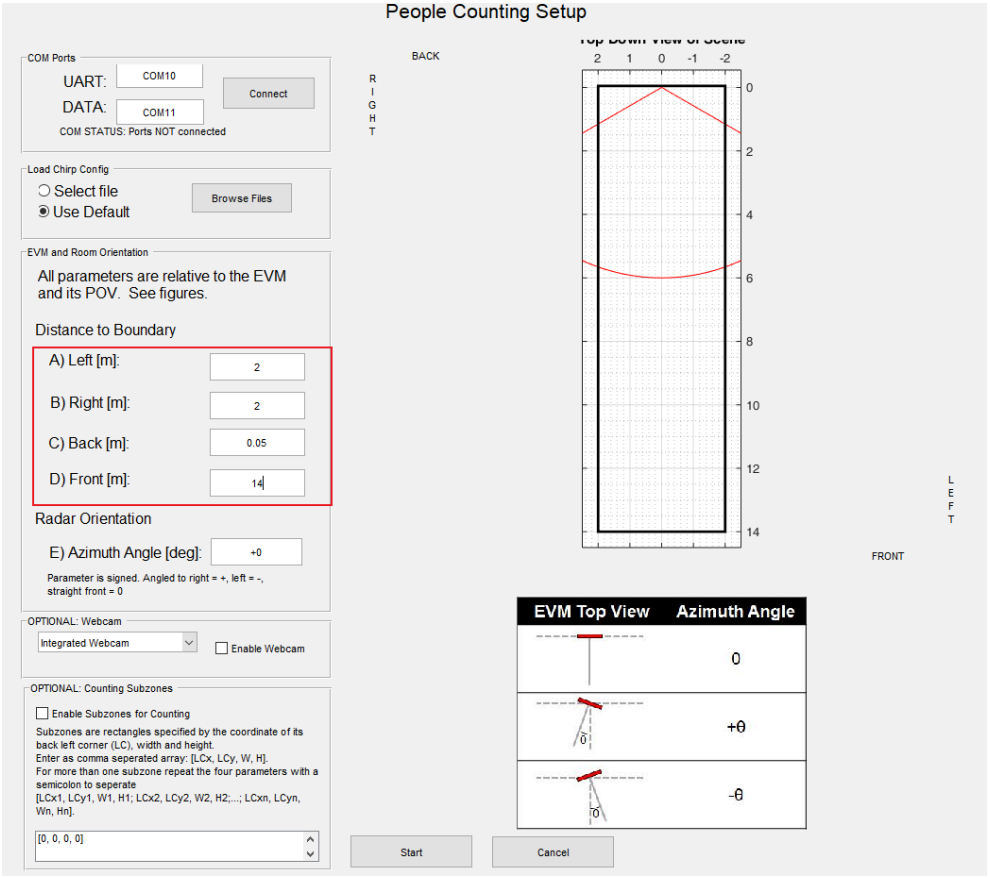
```
dfeDataOutputMode 1
channelCfg 15 3 0
adcCfg 2 1
adcbufCfg 0 1 1 1
profileCfg 0 77 30 7 62 0 0 24 1 128 2500 0 0 30
chirpCfg 0 0 0 0 0 0 0 1
chirpCfg 1 1 0 0 0 0 0 2
frameCfg 0 1 128 0 50 1 0
lowPower 0 1
guiMonitor 1 1 0 0
cfarCfg 6 4 4 0 0 16 16 4 4 50 62 0
doaCfg 600 1875 30 1
SceneryParam -2 2 0.05 14
GatingParam 4 3 2 0
StateParam 5 5 10 100 5
AllocationParam 500 0.01 12 1 2
VariationParam 0.289 0.289 1.0
trackingCfg 1 2 250 20 200 50 90
sensorStart
```

The procedure for tuning the sensor is described in the figure given below.



Step 1: set scene parameters

Modify the .cfg file as: **SceneryParam -2 2 0.05 14 (Left right back front)**. This forms the area of interest in the form of a rectangle. People outside this zone will not be detected. To display the area of interest on the GUI, modify the distance to boundary parameters as shown in figure below.



Step 2: Check for too few detections.

This happens when the radar is not able to pick up objects in its FOV. The allocation parameters are modified in .cfg file: **AllocationParam 400 0.25 15 0.6 1.** The first 3 parameters tuned here decide if the detected object is a person or not.

Allocation parameters (same order): SNR threshold, velocity threshold, points threshold, maxDistanceThreshold, MaxVelocityThreshold

1. **SNR Threshold:** minimum total SNR to detect one person. The SNR threshold should be lowered if very few point clouds are detected i.e the SNR value required is low for an allocated set to be considered a valid tracking object.
2. **Velocity threshold**: Lowering the velocity threshold will allow us to track persons who are moving very slowly. However, chances of false detections (Ghosts) might increase.
3. **Points threshold:** if this threshold is lowered, then less number of points are required to track a person so easier to detect any moving object. Hence, a greater number of people can be detected.

Step 3: Check for detection of ghosts (False detections).

Ghosts or dales detections are observed when there is noise or interference due to external sources like small moving objects (Not person), interference form EM waves generated by other devices etc. Usually, the SNR and number of points allocated for ghosts are very small. For this, the allocation and state parameters are tuned as follows:

a. ***Allocation parameters:***

1. **SNR Threshold:** Increase the SNR threshold if ghosts (false detections) are detected since ghosts usually have very low SNR value.
2. **Points threshold:** Increase this threshold to allocate more points required to represent a point cloud of a person.

b. ***State parameters:***

The allocation parameters are modified in .cfg file: **StateParam 10 4 10 50 3.** The significance of each parameter is described in the table below in the same order:

PARAMETER	DEFAULT	DIM	DESCRIPTION
det2activeThre	10	—	In DETECT state; how many consecutive HIT events needed to transition to ACTIVE state
det2freeThre	5	—	In DETECT state; how many consecutive MISS events needed to transition to FREE state
active2freeThre	10	—	In ACTIVE state and NORMAL condition; how many consecutive MISS events needed to transition to FREE state
static2freeThre	100	—	In ACTIVE state and STATIC condition; how many consecutive MISS events needed to transition to FREE state
exit2freeThre	5	—	In ACTIVE state and EXIT condition; how many consecutive MISS events needed to transition to FREE state

These parameters determine the state of the person detected. The states include:

i. FREE: No detection, radar is in resting stage

ii. DETECT: Radar has detected an object cluster

iii. ACTIVE: The detected object is being tracked.

The order of the states is: **FREE → DETECT → ACTIVE**

There are 3 conditions under ACTIVE stage. They include:

a. NORMAL: When a person is moving around in the detection zone

b. STATIC: When person is completely still but inside the detection zone

c. EXIT: When person exits the detection zone

1. The det2activeThreshold is increased, this will increase the amount of time the ghost has to exist before it can be promoted to ACTIVE state. If ghosts persist only then proceed to tune the remaining parameters. For our config, the det2freeThreshold was lowered so that the ghosts being tracked can quickly go into FREE state.
2. Active2freeThreshold remained the same as default value.

3. Static2freeThre is decreased since for our detection scenario, people are going to be constantly moving and any object other than a person (ghosts, trolleys, chairs etc) will become stationary after some time. Decreasing the threshold help transitioning into FREE state very quickly if an object becomes stationary.
4. Exit2freeThre is also decreased so that the transitioning to FREE state is faster.

Step 4: Check for resolution and accuracy of multiple persons detection

After point clouds have been detected, closest point clouds form clusters using the gating algorithm. After gating, the point clouds are tracked, and their velocity vectors are stored. Sometimes, tracker might allocate one track for multiple people. This happens due to poor velocity or range resolution when two people are very close to each other. The allocation and state parameters are tuned as follows:

a. ***Allocation parameters:***

Now we tune the remaining 2 parameters in the allocation parameters. These parameters decide if the detected points can be added to the cluster. The allocation parameters are modified in .cfg file: **AllocationParam 400 0.25 15 0.6 1.**

1. **maxDistanceThre:** It is the maximum squared distance between a detected point and the centroid of the cluster. Cluster is the object detected. It simply means that number of points required for each cluster. For our implementation, maxDistanceThre is set to be around 0.6m^2 which means only points within this distance will be considered as a cluster.
2. **MaxVelocityThreshold:** it is the maximum velocity difference between point detected and centroid of cluster. This threshold is lowered so that even small movements between two or more people will be easily detected.

b. ***Gating parameters:*** These parameters decide the maximum volume and velocity of a tracked object. The allocation parameters are modified in .cfg as **GatingParam 4 3 2 0**

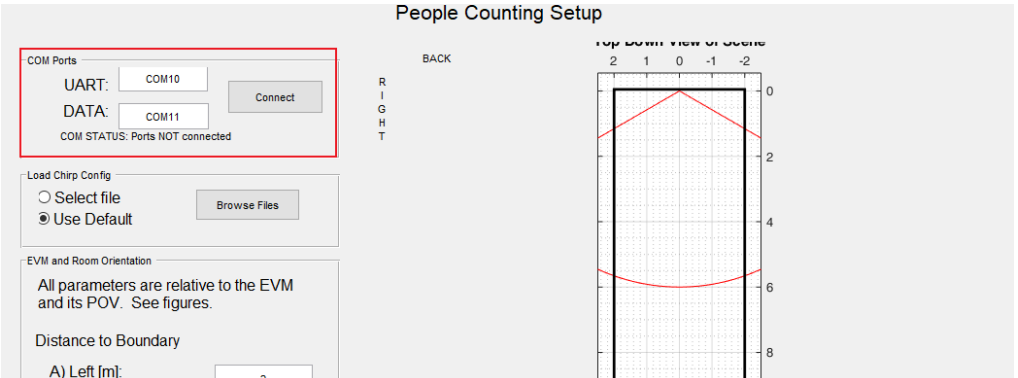
Gating parameters (same order): Gating gain, lengthLimit, WidthLimit, Velocity limit

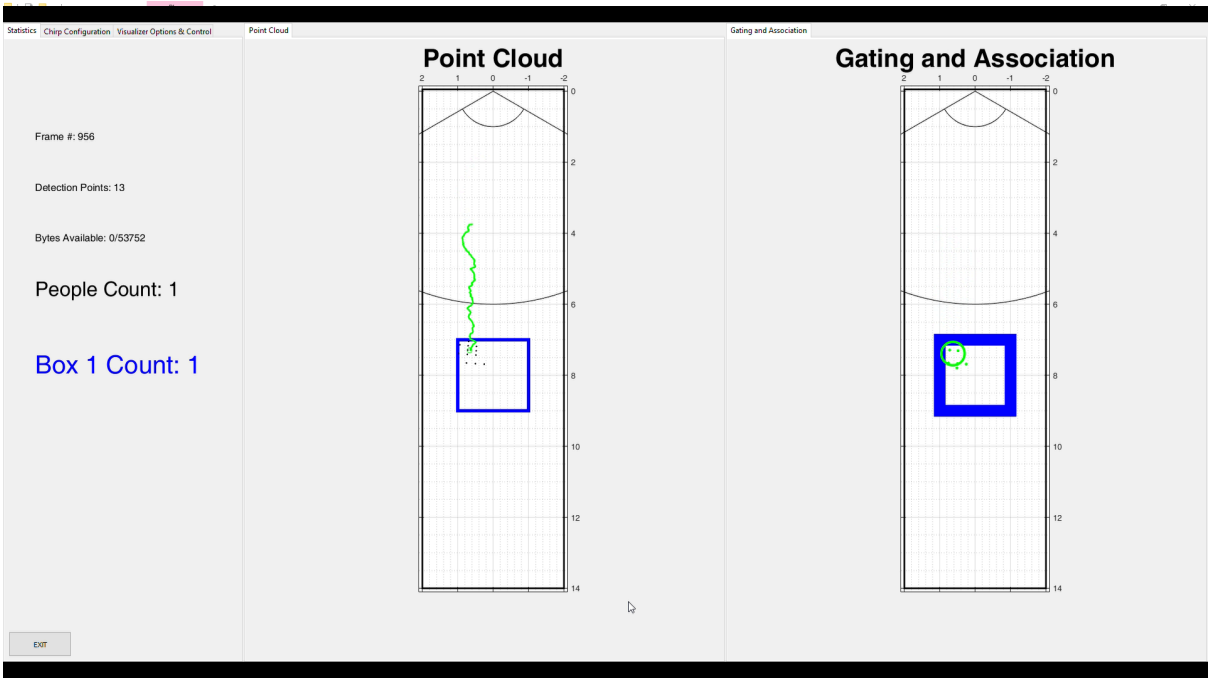
The gating parameters are left unchanged and are set as **default values**. These parameters decide the size of the cluster that is being tracked. For multiple persons, Lowering the above parameters will allow points to move closer to each other within the cluster hence making it easier for the algorithm to separate the individual point clouds.

Gating gain is the volume of an object that is estimated by finding the volume of an ellipsoid. Length and width limit the dimensions of the ellipsoid and velocity threshold limits the velocity of the ellipsoid.

Step 5: Run demo and check for artifacts

Run the demo by keying in the COM ports for UART and DATA ports (Device manager COM ports), then press start to start the GUI. If detection continuous to have artifacts then go back to step 2.

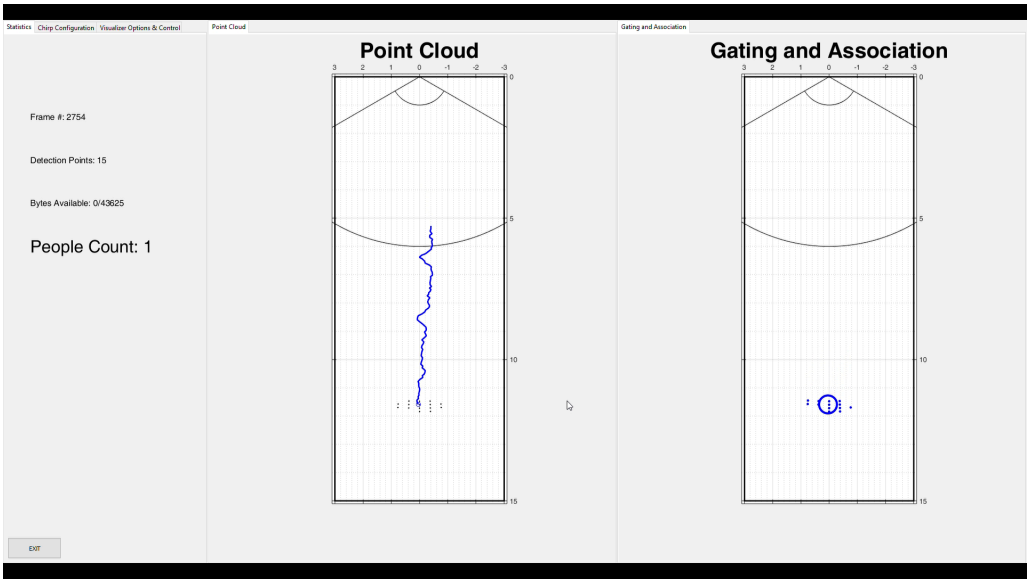


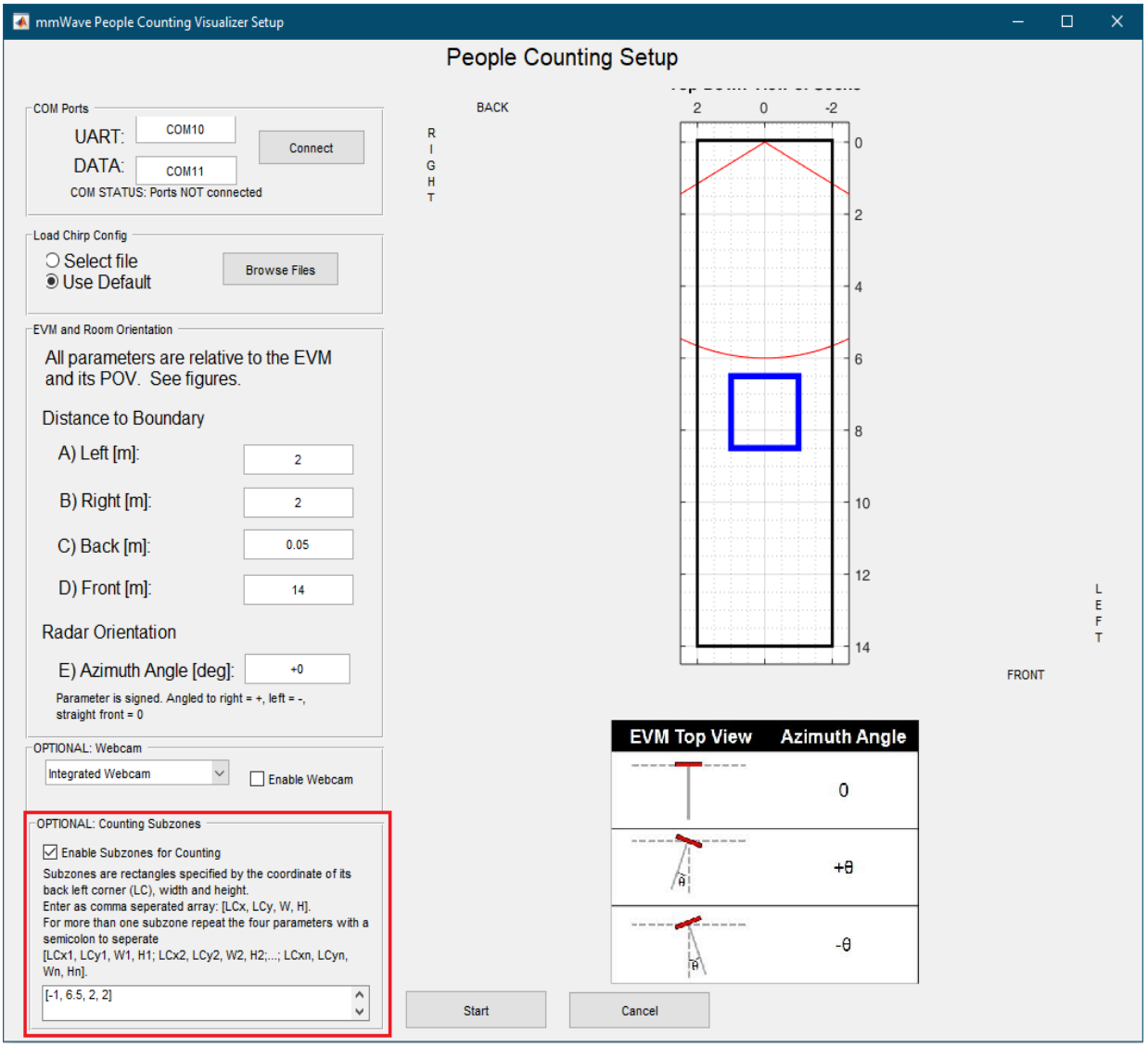


The point cloud tracking and gating is displayed in the figure below, along with the people count and detection points of a single person within range= 14m.

Step 6: Setting sub-zones for people counting

To further reduce false detections and increase accuracy, we can define rectangular sub zones within the FOV as highlighted in figure below, The GUI displays a separate count for people are detected within these subzones. In the GUI it can be set as: [LCx, LCy, W, H]. Multiple zones can be set as: **[LCx1, LCy1, W1, H1; LCx2, LCy2, W2, H2; ……. LCxn, LCyn, Wn, Hn].**





As shown above, a separate count is assigned to the subzone assigned.

Step 7: Set azimuth angle (If required)

Top view Depiction	Azimuth Angle Tilt	.cfg file convention
wall	0	90
EVM, wall	+20	70
wall	-20	110

The azimuth angles are modified in .cfg as: **trackingCfg 1 2 250 20 200 50 90**

Last parameter in the trackingCfg config: Azimuth angle (according to cfg. file convention as shown in figure below) = 90 (or 0 azimuth angle) Setting this will allow us to direct the beam towards a direction for example: away from a wall or any obstacle.