# 3D-Space Mapping System via UAV-based RF Sensing

Technical Report

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# 1. Abstract

# 2. Terminologies

1) Point cloud
   a. CAD model point cloud: Set of points representing the surface of a CAD model.
   b. Radar reflector point cloud: Set of points from (a) that reflects radar signal.
   c. Camera reflector point cloud: Set of points from (a) that are visible by the camera.
2) Antenna spacing: the distance between the consecutive antennas.

# 3. Sensor Configurations

1) **TI IWR6843ISK mmWave radar sensor**
   a. Number of virtual antennas: 24 in azimuth, 64 in elevation
   b. Angular resolution: approx. 4.8 degrees in azimuth, 1.8 degrees in elevation
   c. Start frequency: 60GHz
   d. Frequency slope (sweep slope): 29.982 MHz/us
   e. Idle time: 100 us
   f. ADC start time: 6 us
   g. Number of samples: 256
   h. Sample rate: 2047 ksps
   i. Ramp end time: 133 us
   j. RX gain: 30 dB
   k. Bandwidth: 3987.61 MHz
2) **ZED mini camera**
   a. https://support.stereolabs.com/hc/en-us/articles/360007395634-What-is-the-camera-focal-length-and-field-of-view-
   b. Resolution: HD720
      i. Width: 1280
      ii. Height: 720
      iii. Focal length: 700 pixels, or 2.8 mm
      iv. Pixel size: 0.004 mm
      v. V FOV: 54 degrees
      vi. H FOV: 85 degrees
      vii. fov = 2*arctan(pixelNumber/(2*focalLength))*(180/pi)

# 4. Hawkeye Radar Synthesizer

https://github.com/JaydenG1019/HawkEye-Data-Code

Inputs:

1) CAD model 3D physical point cloud

2) Scene parameters (scene boundary, translation/rotation resolutions)
3) Radar parameters (FOV in range/azimuth/elevation, sample#, sample rate, center/starting frequency, sweep slope, bandwidth, wavelength, number of bins, antenna#, antenna spacing)

Procedure:

1) Translate and rotate the CAD model point cloud within the scene boundary
2) Select the points as radar signal reflectors from the CAD model point cloud
3) Simulate received radar signal in receiver antenna array based on radar configuration
4) Generate the 3D radar intensity heatmap from the radar reflector point cloud

Outputs:

1) Radar 3D intensity heatmap (spherical coordinates)
2) Optional:
   i. translated CAD model point cloud (over 100MB)
   ii. radar reflector point cloud
   iii. simulated radar signal in receiver antenna array

## 5. Depth image generation

Input:

1) CAD model 3D physical point cloud
2) Camera FOVs, resolution, focal length, scene size

Procedure:

1) Select the points as camera reflectors from the CAD model point cloud
2) Further filter out the sparse points at the back but not being blocked (optional)
3) Calculate the distance of each point to the camera (depth)
4) Calculate the coordinates of each point onto the image plane after perspective projection
5) Construct a mesh grid centered at the image plane, grid size matches the pixel size
6) For the grids(cells) that cover multiple points, leave the point with minimum depth

Output:

2D depth image (Perspective projection)

## 6. Convert CAD model in point-cloud format

1) Import or create a CAD model in **FreeCAD**
2) Select workbenches ‘Mesh Design’ in tab ‘View’
3) Select create mesh from a shape in tab ‘meshes’
4) Select workbenches ‘Points’
5) Select convert to points in tab ‘points’

## 7. Select reflector point cloud from CAD model point cloud

1) Define the resolutions of range, elevation, azimuth (rho, theta, phi) for constructing a grid map in spherical coordinates.
2) Convert the point cloud from cartesian to spherical coordinates (cart2sph())
3) Mark the voxels that has points to 1 in the grid map and others to 0
4) Create another empty grid map then go over the voxels, for any pair of theta and phi that defines a direction, mark the first voxel of 1 in this direction
5) Convert the points in marked voxels from spherical coordinates back to cartesian coordinates.

## 8. Figures

1) Spherical coordinate system

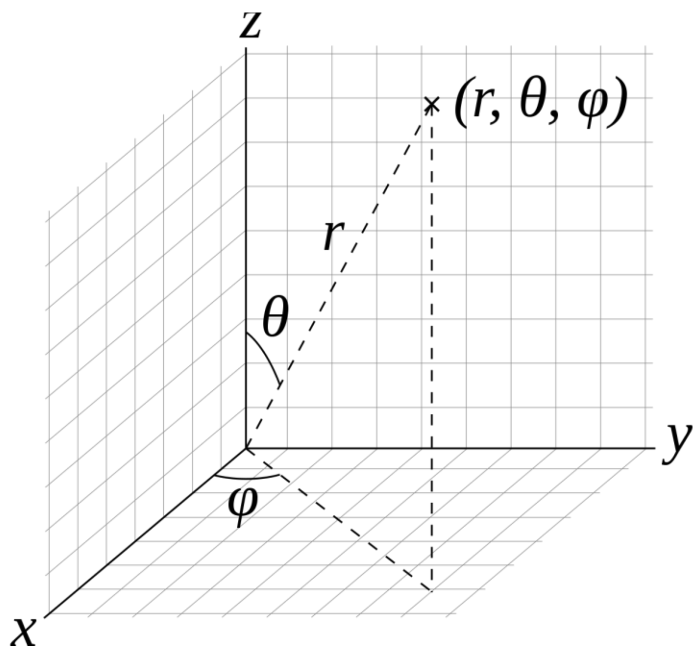



Figure 1. The spherical coordinate system used in Hawkeye and our system, a right-hand rule coordinates with $r$ as range, $\phi$ as azimuth, and $\theta$ as elevation

2) CAD model physical point cloud

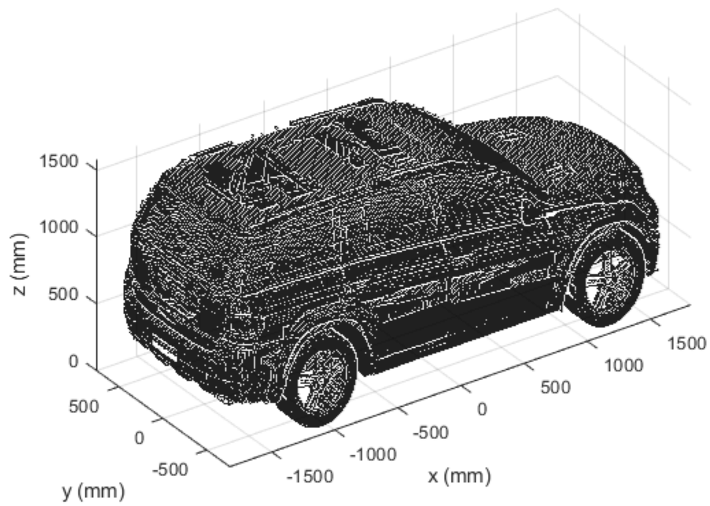



Figure 2. Dense point cloud of a CAD car model

3) Translated and rotated CAD model physical point cloud

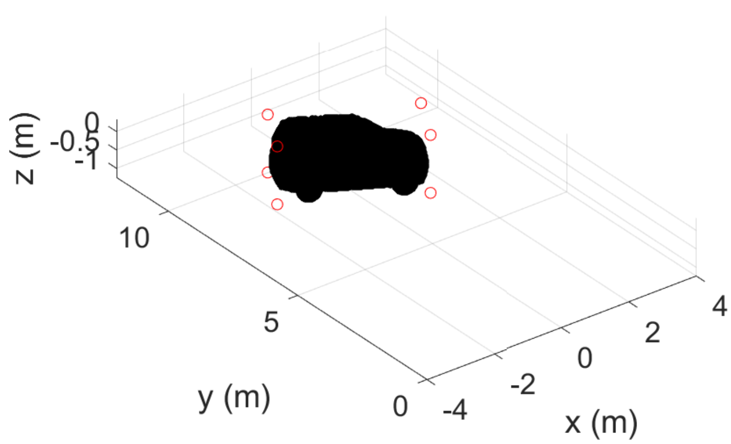



Figure 3. A scene of car (in point cloud) with random placement

4) Camera reflector point cloud

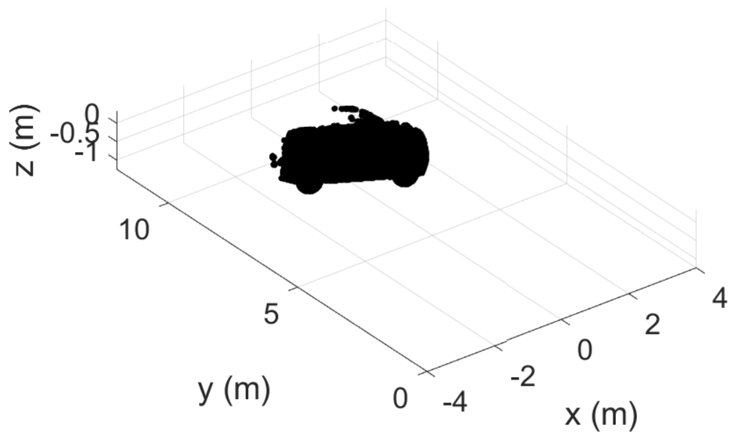



Figure 4. The points that reflects light/signal to the camera at (0,0,0)

5) Radar reflector point cloud

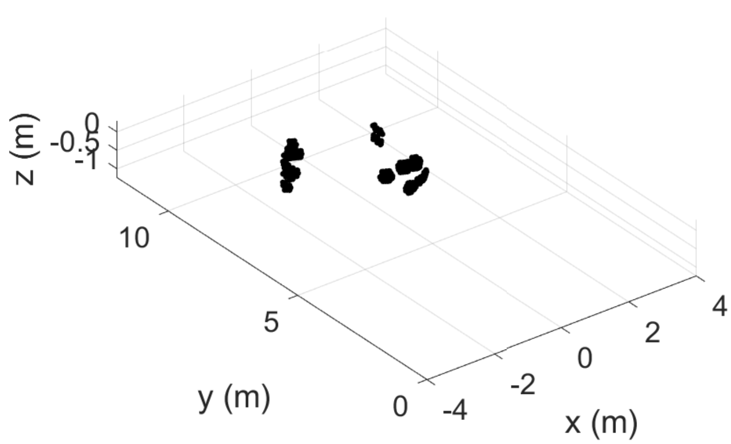
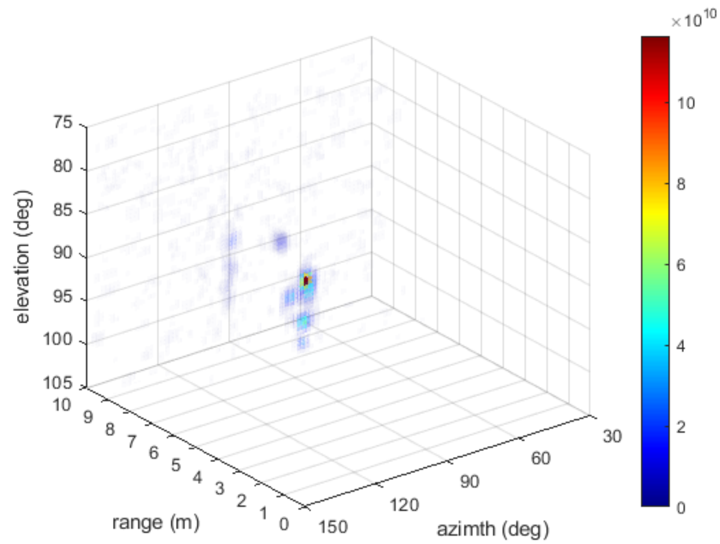


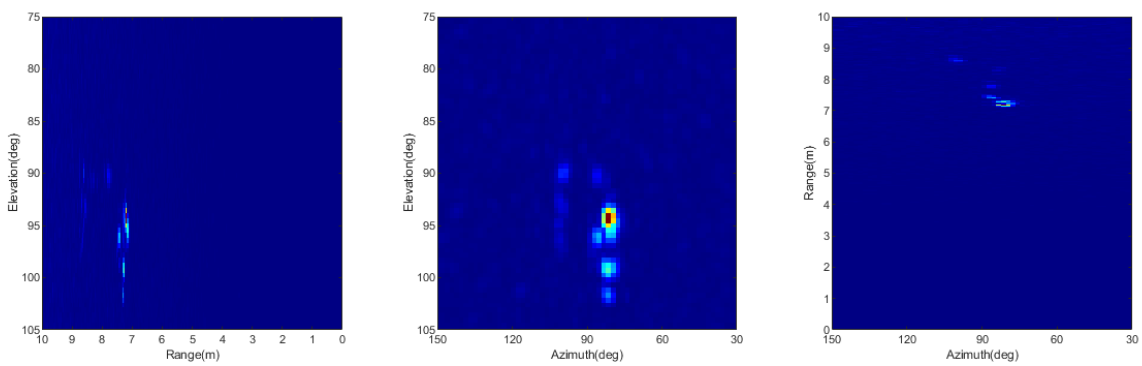

Figure 5. The points that reflects signals to radar sensor at (0,0,0)

6) 3D radar intensity heatmap

a. Spherical coordinate system



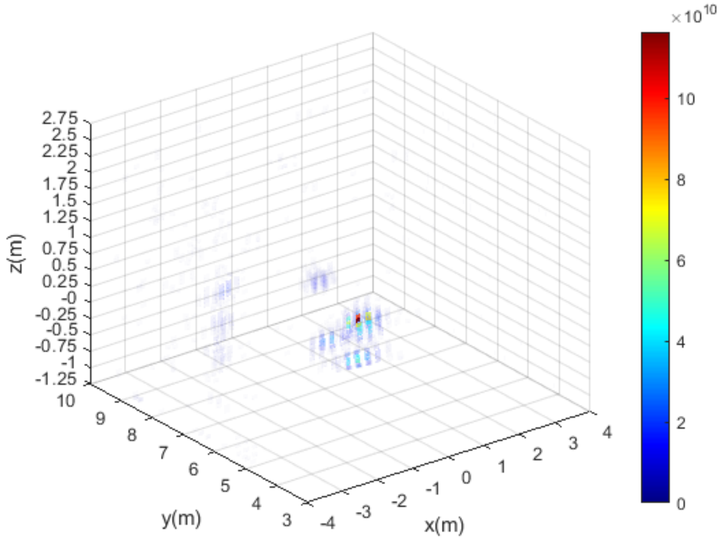

(a)



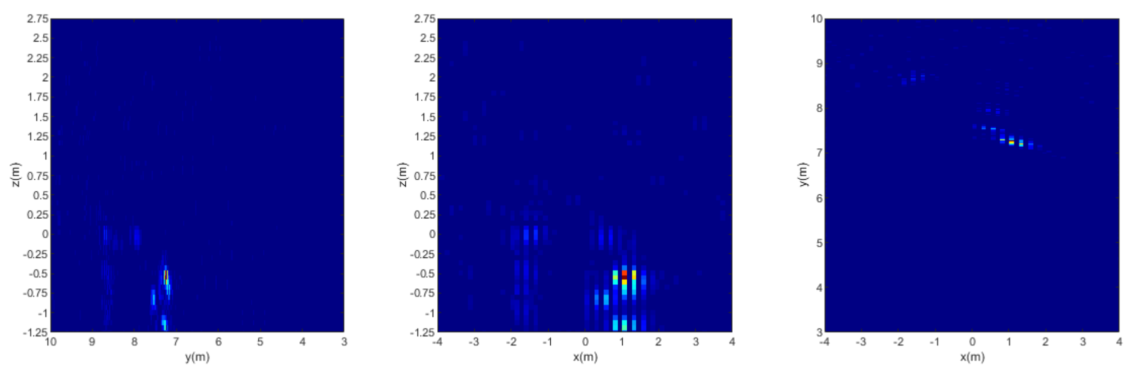

(b)

Figure 6. Intensity heatmaps of the synthesized mmWave signals in spherical coordinates, with (a) 3D representation, (b) three-view drawings for the scene in Figure 3.

b. Cartesian coordinate system




(a)




(b)

Figure 7. Intensity heatmaps of the synthesized mmWave signals in Cartesian coordinates, with (a) 3D representation, (b) three-view drawings for the scene in Figure 3.

7) 2D depth image

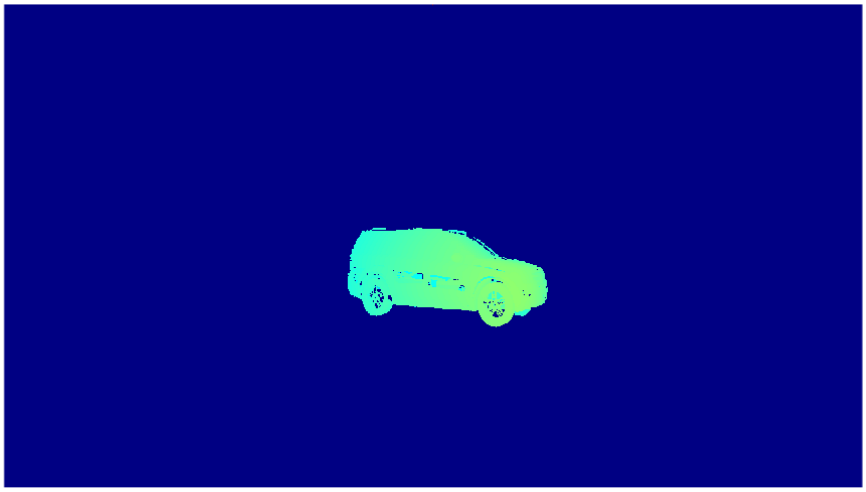


Figure 8. Synthesized 2D depth image by perspective projection for the scene in Figure 3.