Automated Parking Test Using ISAR Images From Automotive Radar

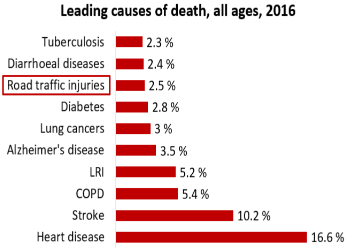
Neeraj Pandey Shobha Sundar Ram

Indraprastha Institute of Information Technology, New Delhi India

IEEE International Conference on Autonomous Systems 2021

Motivation: Improving Road Safety

- Need for improved road safety:
  1. 1.35 million fatalities/ year worldwide [1,2]
  2. 50 million injuries [1,2]
  3. Leading cause of death for young adults [1,2]
- Key strategies for improving road safety
  1. Better technology (sensors and algorithms) - advanced driver assistance systems
  2. **Better drivers**
- Problems with manual driving tests
  1. Tedium / mistakes / corruption of driving test inspectors
  2. Cost and man-hours of conducting tests



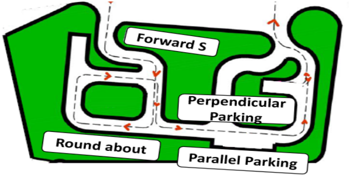
Solution: Automated driver's license test

1. *WHO Global Health Observatory (GHO) data*, `http://www.who.int/gho/road_safety/mortality/en/`
2. *WHO Road traffic injuries*, `http://www.who.int/mediacentre/factsheets/fs358/en/`,2016

State-of-the-Art Automatic Parking Test Solutions

Key Components of a Driver's License Test

- Lane changes
- Turns
- Use of mirrors
- **Parking**



Problems with Camera Based Solutions [1]

- Poor performance in low light and bad weathers condition
- Privacy issues
- Poor depth resolution with low cost sensors

Proposed Solution

Use externally mounted millimeter wave radars for conducting automated parking tests.

1. A. U. Nambi, et al., *Alt: towards automating driver license testing using smartphones* in Proceedings of the 17th Conference on Embedded Networked Sensor Systems, 2019

Millimeter-Wave Radar Based Parking Test

Advantages

- Suitable for low light conditions
- Suitable for all weather conditions
- Proven technology in automotive systems [1] and for parking assistance - to detect parking slot [2], and to aid in backing [3]

Key Features of Proposed System

- Radar is mounted on static platform outside the vehicle
- Inverse synthetic aperture radar (ISAR) images generated from radar data will be used for facilitating parking tests

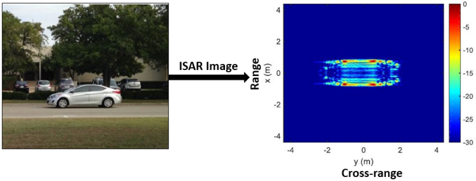
1. J. Hasch, et al., *Millimeter-wave technology for automotive radar sensors in the 77 ghz frequency band*,IEEE Transactions on Microwave Theory and Techniques, 2012
2. V. Paidi, et al., *Smart parking sensors, technologies and applications for open parking lots: a review*, IET Intelligent Transport Systems, 2018
3. D. Fernandez-Llorca, et al., *Parking assistance system for leaving perpendicular parking lots: Experiments in day time/night time conditions*, IEEE Intelligent Transportation Systems Magazine,2014.

Research Objectives

- To demonstrate automatic parking test using ISAR images from single channel externally mounted millimeter-wave automotive radars for two types of parking
  - Angle parking
  - Perpendicular parking
- To experimentally validate proposed parking test with measurement data gathered from TI 1843 millimeter wave radar.

Inverse Synthetic Aperture Radar Imaging

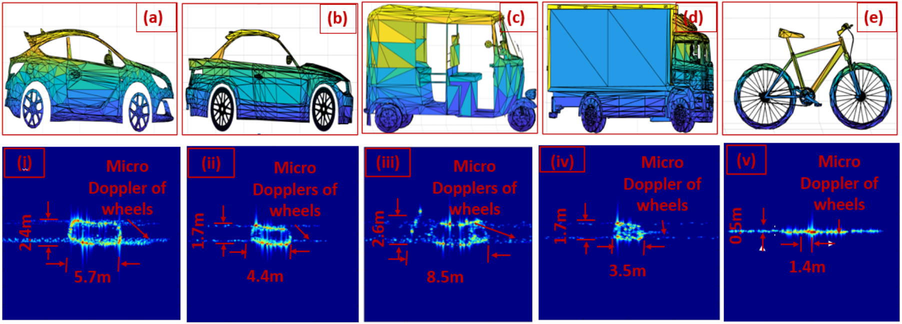
- High-resolution radar imaging of moving objects using single channel sensor data [1]
- Resulting images are two dimensional top-view plots of radar targets along range (depth) and cross-range (azimuth)
- Radar signals are frequency modulated continuous waveforms.
- Broad radar bandwidth provides fine range resolution
- Turning motion of the targets provide broad aspect which facilitate synthetic aperture and hence, fine cross-range resolution.



[2] C. Li, H. Ling, *Wide-angle ISAR imaging of vehicles*, EuCap 2015

1 V. C. Chen, Inverse Synthetic Aperture Radar Imaging; Principles. Institution of Engineering and Technology, 2014.

ISAR Images of Automotive Vehicles



N. Pandey, et. al, Database Of Simulated Inverse Synthetic Aperture Radar Images For Short Range Automotive Radar, IEEE International Radar Conference 2020

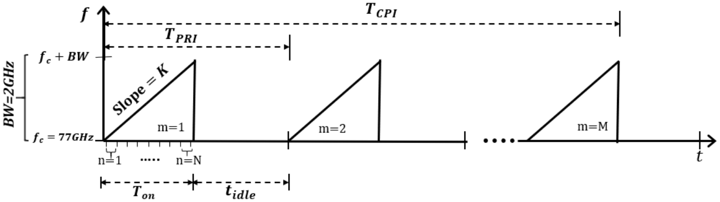
Vehicular information from ISAR images

1. Size, shape, and number of wheels on the vehicle
2. Trajectory followed by the vehicle

Transmitted Radar Signal

- Transmitted signal

$$S_{tx}(\tau) = rect\left(\frac{\tau}{T_{PRI}}\right) e^{j2\pi f_c \tau} e^{j\pi K \tau^2}, \; rect\left(\frac{\tau}{T_{PRI}}\right) = \begin{cases} 1 & 0 \leq \tau \leq T_{PRI} \\ 0 & \text{elsewhere.} \end{cases} \tag{1}$$



- We consider the VUT as an extended target with B point scatterers, a_b the amplitude of each point scatterer
- Time-varying range of the b^{th} point scatterer is

$$r_b(t) = R_b + v_b t \tag{2}$$

where R_b is the starting distance from the radar and v_b is the relative radial velocity with respect to radar

Received Radar Signal

- Due to the motion of the scatterer, the backscattered radar signal is Doppler shifted by $f_{D_b} = \frac{2v_b f_c}{c}$
- Down-converted radar received signal

$$S_{rx}(\tau, t) = \sum_{b}^{B} a_b(t) rect \left(\frac{\tau - \frac{2r_b}{c}}{T_{PRI}} \right) e^{j2\pi f_c \frac{2r_b(t)}{c}} e^{j\pi K(\tau - \frac{2r_b(t)}{c})^2} + \mu, \quad (3)$$

where μ is the additive receiver noise

- Discrete form of (3) is given by

$$S_{rx}[n, m] = \sum_{b}^{B} a_b[m] rect \left[\frac{n - n_b}{N} \right] e^{-j\frac{4\pi f_c}{c} R_b} e^{-j2\pi m f_{D_b} T_{PRI}} e^{j\pi K \frac{1}{{f_s}^2}(n - n_b)^2} + \mu, \quad (4)$$

where $n_b = \frac{2r_b(t)}{cf_s}$, f_s = sampling frequency

- Translational motion compensation is performed within each T_{CPI}

Radar Signal Processing: Generating 2D ISAR Images

- Range-Doppler ambiguity plots are generated,

$$\chi[r, f_d] = 2DFT\{S_{rx}[n, m]\} \quad (5)$$

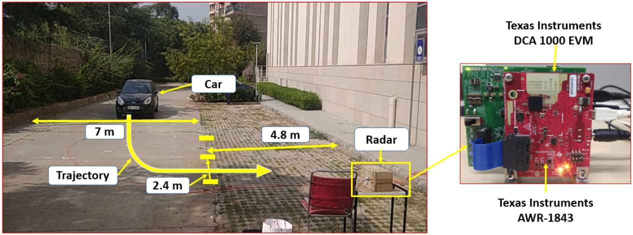
- Angular velocity for each m^{th} CPI is estimated

$$\omega[m] = \frac{\theta[m] - \theta[m-1]}{T_{CPI}} \quad (6)$$

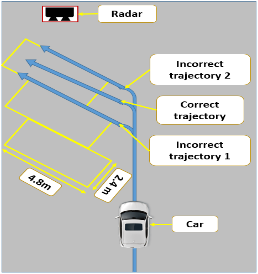
- The Doppler axis for each CPI is converted to the cross range axis by

$$cr = f_D \times \frac{\lambda}{2\omega[m]} \quad (7)$$

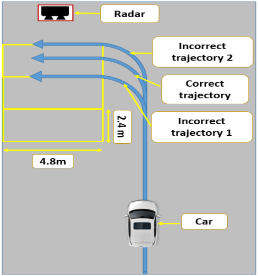
Experimental Setup



(a) The experimental setup for the parking test



(b) 45° angle parking



(c) perpendicular parking

Radar Parameters for Generating ISAR Images

Parameters	Values
Carrier frequency (f_c)	77GHz
Sampling Frequency (f_s)	5MHz
Bandwidth (BW)	2GHz
Chirp rate (K)	7.5×10^{12} Hz^2
Chirp duration (T_{PRI})	400μs
Coherent processing interval (T_{CPI})	0.1s
Ramp time	267 μs
Idle time	133 μs
Transmitted power (P_t)	14dBm

Parking Test Algorithm: Training Algorithm

Step1	Collect L ISAR images of the car following the correct trajectory
Step2	Collect a similar set of ISAR images for several incorrect trajectories
Step3	Covert the images in gray-scale, and select bounding box comparable to the size of the car
Step4	Find the dominant scattering centre position for l^{th} image
Step5	Repeat step4 across all L ISAR images to VUT motion
Step6	Curve fit a 2-D polynomial across the dominant scatter position to estimate the trajectory of VUT across all the L images
Step7	Repeat step6 for all the trajectories
Step8	Store all polynomial functions for testing

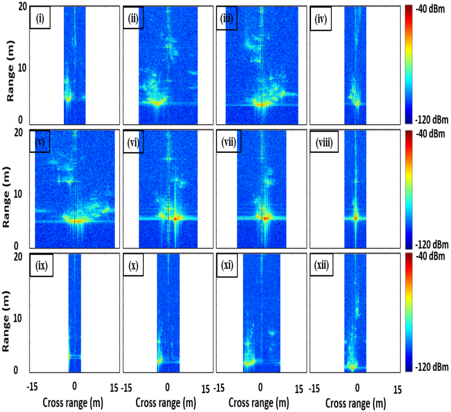
Parking Test Algorithm: Test Algorithm

- **Step1** — Estimate the similar polynomial using steps 1 to 8 of the training algorithm
- **Step2** — Compare with the polynomials stored from training
- **Step3** — Predict the trajectory as either correct or incorrect based on the closest fit of the test polynomial to the training polynomials

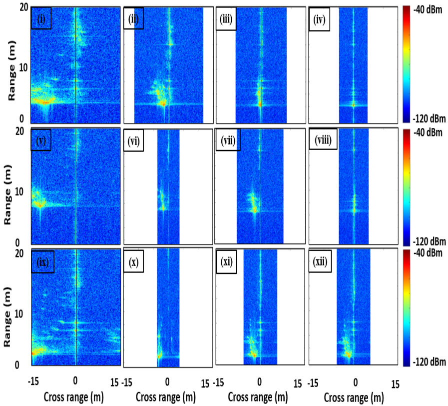
Advantages of the Parking Test

- The speed of VUT need not be identical to that of the car used for training
- Hence, auxiliary sensors are not required for estimating the translational motion characteristics of the test vehicles
- The size of the VUT can differ a little from that used during training by adjusting the size of the bounding box

Results: ISAR Images of Ford Figo



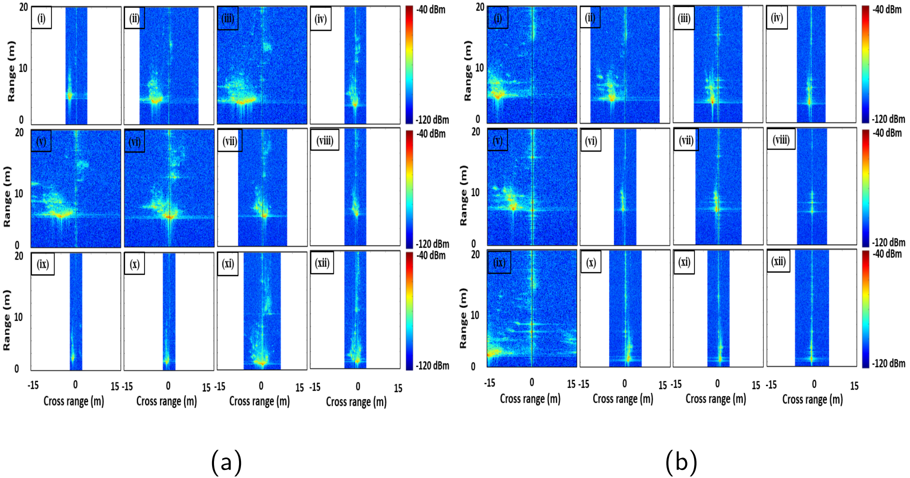
(a)



(b)

ISAR images of Ford Figo carrying out (a) perpendicular parking and (b) angle parking, at 3.5, 4.0, 4.5, 5s. (1-iv) Top, (v-viii) middle, and (ix-xii) bottom rows in both images are generated for car following correct trajectory, incorrect trajectory-1, and incorrect trajectory-2 respectively.

Results: ISAR Images of Honda Brio



Bottom row shows ISAR images of Honda Brio carrying out (a) perpendicular parking and (b) angle parking, at 3.5, 4.0, 4.5, 5s. (i-iv) Top, (v-viii) middle, and (ix-xii) bottom rows in both images are generated for car following correct trajectory, incorrect trajectory-1, and incorrect trajectory-2 respectively.

Results of Parking Test Algorithm

	Predicted Trajectory					
True Trajectory	1	2	3	4	5	6
1	**0.332**	0.387	0.347	-	-	-
2	0.361	**0.347**	0.365	-	-	-
3	0.467	0.481	**0.466**	-	-	-
4	-	-	-	**0.512**	0.534	0.615
5	-	-	-	0.558	**0.512**	0.528
6	-	-	-	0.509	0.540	**0.411**

- The predicted trajectory is based on the minimum NMSE using the parking test algorithm
- The predicted trajectory matched correctly to the ground truth in all cases

Conclusion

- We have demonstrated the use of externally mounted automotive radars for conducting automatic parking tests based on ISAR radar images
- We have developed a simple automated parking test algorithm based on the ISAR images
- We have experimentally validated our proposed algorithm using radar data gathered from the TI-AWR 1843 millimeter-wave sensor